CONFERENCE BOOK

BALKAN 15. ULUSLARARASI UYGULAMALI BİLİMLER KONGRESİ

ÜSKÜP
20 - 22 MART 2026

BALKAN
15. ULUSLARARASI UYGULAMALI BİLİMLER KONGRESİ

BALKAN 15th INTERNATIONAL CONFERENCE ON APPLIED SCIENCES
MARCH 20-22, 2026
SKOPJE

Published by Academy Global Publishing House

www.balkankongresi.org

BALKAN 15TH INTERNATIONAL CONFERENCE ON APPLIED SCIENCES
MARCH 20 – 22, 2026
SKOPJE

Edited By
PROF. DR. ALİ BİLGİLİ

Issued: 25.04.2026
ISBN: 978-625-5694-92-8

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In the conference 81 papers have been presented by Turkish participants and 123 papers by international participants.
Members of the organizing committees of the conference perform their duties with an "official assignment letter"

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PRESENTATION

Oral presentation

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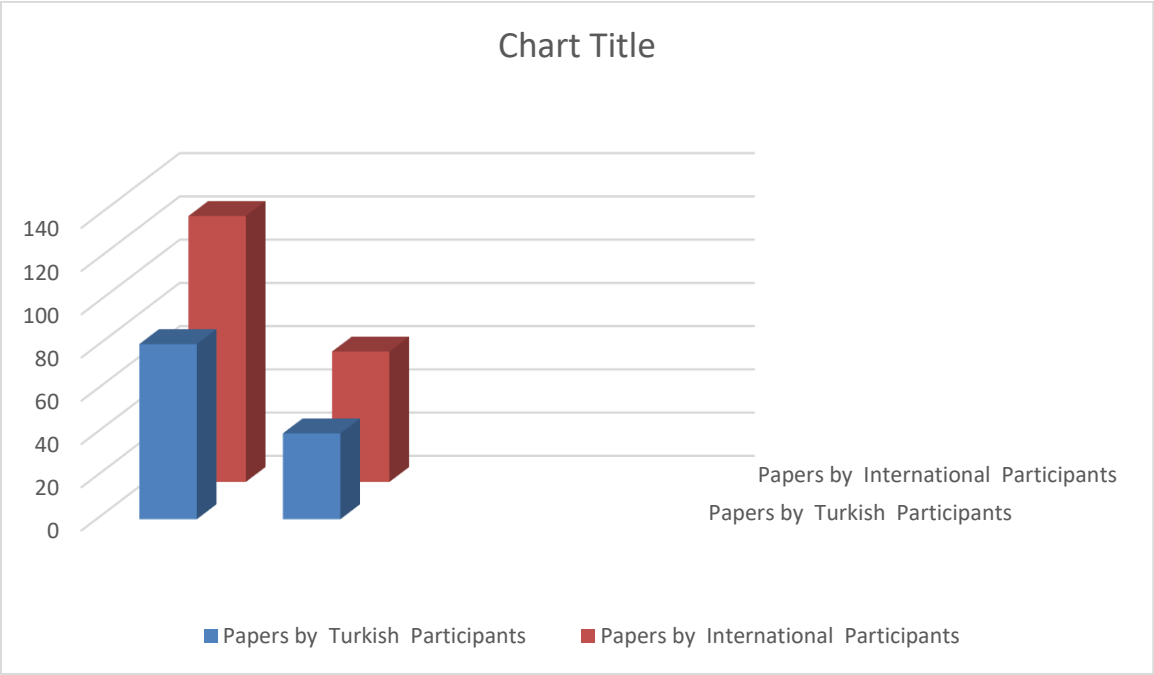
	Number of paper	*%*
Papers by Turkish Participants	81	39,70
Papers by International Participants (28 Countries)	123	60,29



BALKAN 15TH INTERNATIONAL CONFERENCE ON APPLIED SCIENCES
MARCH 20 – 22, 2026
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Academy Global Conferences tarafından düzenlenen **Balkan 15. Uluslararası Uygulamalı Bilimler Kongresi** 20-22 Mart 2026 tarihlerinde Üsküp'te 29 farklı ülkeden akademisyenin katılımıyla gerçekleştirilmiştir. Kongre kapsamında sunulan 204 bildirinin 81'i Türkiye'den, 123'ü ise farklı 28 ülkeden katılan akademisyenler tarafından sunulmuştur. Kongre, 16 Ocak 2020 Akademik Teşvik Ödeneği Yönetmeliğine getirilen "Tebliğlerin sunulduğu yurt içinde veya yurt dışındaki etkinliğin uluslararası olarak nitelendirilebilmesi için Türkiye dışında en az beş farklı ülkeden sözlü tebliğ sunan konuşmacının katılım sağlaması ve tebliğlerin yarıdan fazlasının Türkiye dışından katılımcılar tarafından sunulması esastır." değişikliğine uygun olarak düzenlenmiştir.

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İlgi yazınız uyarınca, Anabilim Dalınız öğretim üyesi Prof.Dr.Ali BİLGİLİ'nin, Yükseköğretim Kurulu'nun 15.06.2023 tarihli oturumunda doçentlik başvuruları şartları ile ilgili değişiklik önerileri kapsamında, "Academy Global Conferences & Publishing (https://www.akademikongre.org/registration)" tarafından önümüzdeki tarihlerde düzenlenecek olan uluslararası kongrelerde; kongre başkanı, kongre düzenleme ve bilim kurulu üyesi olarak görev yapması Dekanlığımızca da uygun görülmüştür.

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- ZOOM bağlantısı için yukarıda verilen bağlantıyı veya yine yukarıda verilen giriş bilgilerini kullanabilirsiniz.
- **Oturum içerisinde en KIDEMLİ olan moderator olarak seçilir. Moderatörün oturum düzenini gözetmesi, akademisyen adaylarını yönlendirmesi beklenmektedir.**
- Oturuma bağlanmadan önce Salon numaranızı adınızın önüne aşağıdaki gibi ekleyiniz. Bu sayede kongre açılışında beklemeden oturumlarınıza gönderilebileceksiniz. Ör. 5 Ahmet Ahmetoglu
- **Sunum süresi 10 dakikadır. Bu sürenin aşılmamasını moderatörler temin edecektir.**
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- Katılımcı, kendi oturumda, oturum bitene kadar bulunmak zorundadır.
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- The Zoom application is free and no need to create an account.
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March 20 – 22, 2026
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YÜZYÜZE

21 Mart / March 21, 2026 / 11:00 – 12:30 Time zone in Skopje

Salon	Moderator		Bildiri No ve Başlığı / Paper ID and Title	Authors
HALL / SALON 1	**Assoc. Prof. Dr., İLKAY ALTINDAĞ**	1	İŞ KAZALARININ ÖNLENMESİNDE KRİTİK FAKTÖR: ÇALIŞANLARIN RİSK ALGISININ VE GÜVENLİK MOTİVASYONUNUN PSİKOSOSYAL BELİRLEYİCİLERİ VE İSG EĞİTİM MODELLERİNİN KARŞILAŞTIRMALI ETKİNLİĞİ ÜZERİNE BİR ARAŞTIRMA	Doktor Öğretim Üyesi, VEDAT CANER
		2	REVERSE MIGRATION AS A POLICY RESPONSE TO MEGACITY SATURATION: THE CASE OF ISTANBUL	Asst. Ömer Cem Ulutaş
		3	DIGITAL INEQUALITY IN URBAN-RURAL CONTEXT: TECHNOLOGY OWNERSHIP AMONG PARENTS AND ADOLESCENTS IN KARABÜK	PhD Candidate, BEGÜM AYDIN AYDOĞAN Associate Professor Dr, ARZU KALAFAT ÇAT
		4	RELIGIOUS CONFIGURATIONS IN KAZUO ISHIGURO'S KLARA AND THE SUN	Arş. Gör. Hatice Şeyma ŞAHİN
		5	IMPACT OF DIGITAL LITERACY AND SOCIAL MEDIA ADDICTION ON ACADEMIC ACHIEVEMENT: A STRUCTURAL EQUATION MODELING ANALYSIS	Assoc. Prof. Dr., İLKAY ALTINDAĞ Assoc. Prof. Dr., ŞERİFE BURCU BOZKURT ALTINDAĞ
		6	MİLLÎ MÜCADELENİN BALKANLARDAKİ İZLERİNİ TAŞIYAN "KAHRAMAN YARADAN" ADLI ESERİN SÖZ VARLIĞI	Doç.Dr.Ergün ACAR

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March 20 – 22, 2026
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YÜZYÜZE

21 Mart / March 21, 2026 / 13:00 – 14:00 Time zone in Skopje

Salon	Moderator		Bildiri No ve Başlığı / Paper ID and Title	Authors
HALL / SALON 1	**Prof. Dr. Faruk Toklu**	1	Evaluation of Some Agronomic Traits of Maize Hybrid Combinations	Prof. Dr. Faruk Toklu Dr. Petek Toklu
		2	EFFECTS OF SALICYLIC ACID AND POTASSIUM SILICATE APPLICATIONS ON TOTAL PROTEIN AND FLAVONOID CONTENT IN GRAPEVINE (Vitis vinifera L.)	Zir. Müh. Mehmet ARI Prof. Dr. Nurhan KESKİN Doç. Dr. İbrahim Selçuk KURU
		3	DESIGN AND DEVELOPMENT OF A WATER-BASED UV-C DISINFECTION SYSTEM	Melisa Ergin Emre Öztürk Prof. Dr. Uğur ÇAVDAR

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21 Mart / March 21, 2026 / 11:00 – 13:00 Time zone in Türkiye (GMT+3)				
Salon	Moderator		Bildiri No ve Başlığı / Paper ID and Title	Authors
HALL / SALON 1	**Doç. Dr. KADİR ADAMAZ**	1	HİCRİ 1242 TARİHLİ MÜŞEAT VE TELHİSAT MECMUASI (1746-1761)	Doç. Dr. KADİR ADAMAZ
		2	TÜRKLEŞME, YERLEŞME, ULAŞIM, GÜVENLİK, EKONOMİ, SAĞLIK VE EĞİTİME KATKI BAĞLAMINDA OSMANLI DEVLETİNDE TEKKE VE ZAVİYELER	Doç. Dr. KADİR ADAMAZ
		3	THE EDUCATION OF THE TURKISH MINORITY IN MACEDONIA DURING THE YUGOSLAV PERIOD: LITERACY, SCHOOLING, AND TEACHER TRAINING AND MOBILISATION	Assoc. Prof. Dr. Sinan BAŞARAN
		4	BOSNA HERSEK'TE AVUSTURYA-MACARİSTAN İMPARATORLUĞU'NUN ASIL AMACI VE İŞGALİN İLK YILLARI	Yüksek Lisans Öğrencisi, NELDİN DURMİŞİ
		5	1840/1841 NÜFUS SAYIMINA GÖRE BALÇIK KAZASINDA YERLEŞİM VE MÜSLÜMAN NÜFUS	YL. Öğrencisi Dilek Yeşil
		6	YOZGAT MÜZESİNDEKİ II.GIYASEDDİN KEYHÜSREV DÖNEMİ SİKKELERİ	Doktora Öğrencisi Yağmur DOĞAN

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Salon	Moderator		Bildiri No ve Başlığı / Paper ID and Title	Authors
HALL / SALON 2	**Doç. Dr. Melike Somuncu**	1	A TIMELESS IDENTITY: Virginia Woolf's Famous Orlando Character	Doç. Dr. SEVRA FIRINCIOĞULLARI
		2	THE SEMANTIC CO-OCCURRENCE OF THE WORDS "LION" IN IDIOMS	Doç. Dr. Melike Somuncu
		3	THE CONCEPT OF CO-OCCUPATION AND A MEANING-BASED APPROACH TO THE SEMANTIC PROPERTIES OF SOME IDIOMS FORMED WITH THE WORD	Doç. Dr. Melike Somuncu
		4	ŞAİR VECHÎ VE FİRÂKNÂMESİ	Dr.,SEYFULLAH KOŞMAZ
		5	ʿABÎRÎ'NİN RAVZÂ ADLI MESNEVİSİ	Dr.,SEYFULLAH KOŞMAZ
		6	A POETRY JOURNAL İN THE İZMİR PRESS DURİNG THE SECOND CONSTİTUTİONAL PERİOD: GENCİNE-İ EDEB	MÜNEVVERE KAVAK Dr. Öğr. Üyesi, TANER TUNÇ

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HALL / SALON 3	**Doç. Dr., DOĞAN AYDOĞAN**	1	TÜRKİYE'DE SEMBOLİK TÜKETİM KONUSUNDA YAZILAN LİSANSÜSTÜ TEZLERİN İNCELENMESİ	Prof. Dr. Sezen BOZYİĞİT
		2	ELEKTRONİK AĞIZDAN AĞIZA İLETİŞİM İLE GÖSTERİŞÇİ TÜKETİM ARASINDAKİ İLİŞKİNİN İNCELENMESİ: BİR META-ANALİZ ÇALIŞMASI	Prof. Dr. Sezen BOZYİĞİT
		3	INSTAGRAM REELS İÇERİKLERİNİN SPOR ÜRÜNLERİNDE POTANSİYEL MÜŞTERİ DAVRANIŞINA ETKİSİ	HİLAL CANLI Merve TÜRKMEN BARUTÇU
		4	EVALUATİONS ON THE IMPORTANCE OF SEO İN BRANDİNG PROCESSES İN DİGİTAL TOURİSM	Dr. Gözde Engin GÜNAY
		5	THE IMPACT OF PERCEIVED ORGANIZATIONAL JUSTICE ON JOB PERFORMANCE: EVIDENCE FROM WHITE-COLLAR EMPLOYEES IN THE MANUFACTURING INDUSTRY	Erkan ORAK Prof. Dr. Ebru AYKAN
		6	MATERYALİST KİŞİLİK TİPİNİN, SOSYAL MEDYA BAĞIMLILIĞI, YABANCILAŞMA, GÖRELİ YOKSUNLUK VE AİDİYET DÜZEYİ DEĞİŞKENLERİ İLE İLİŞKİSİNİN ANALİZİ	Doç. Dr., DOĞAN AYDOĞAN
		7	MUHAFAZAKÂR MODA VE TÜKETİM TOPLUMU, MUHAFAZAKÂR MODA TEMALI WEB SİTELERİ ÜZERİNE GÖSTERGEBİLİMSEL BİR ANALİZ	ZAHİDE ŞAHİN Doç. Dr., DOĞAN AYDOĞAN
		8	KURUMSAL SOSYAL SORUMLULUK ÇERÇEVESİNDE SÜRDÜRÜLEBİLİR HAVALİMANI ÖNERİSİ	Yüksek Lisans Öğrencisi, Nisanur ALBAYRAK Arş. Gör., Ozan Emre UDUM

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HALL / SALON 4	**Prof. Dr. MERAL BALCI**	1	PARİS ANLAŞMASI SONRASI KÜRESEL İKLİM POLİTİKALARININ ULUSLARARASI TİCARET ÜZERİNDEKİ ETKİLERİ: AB YEŞİL MUTABAKATI VE CBAM ÇERÇEVESİNDE TÜRKİYE'NİN KONUMU	Yüksek Lisans Öğrencisi Fatma Doğankaya
		2	BÖLGESEL GÜVENLİK VE ULUSÖTESİ İŞ BİRLİĞİ BAĞLAMINDA KOLLUK DİPLOMASİSİ: TÜRK GÜMRÜK MUHAFAZA TEŞKİLATI VE SELEC ANALİZİ	Yüksek Lisans Öğrencisi, EMRE AKSAY
		3	SOFT POWER: JAPONYA ÖRNEĞİ	Prof. Dr. MERAL BALCI Yüksek Lisans Öğrencisi FATMA NUR KÖŞKER
		4	TÜRKİYE'NİN BRICS SÜRECİ: OLASILIKLAR VE YAPISAL SINIRLAR	Prof. Dr. MERAL BALCI MELİH EKREM ADIYAMAN
		5	DİJİTAL DİPLOMASİ ve BÖLGESEL KRİZ YÖNETİMİ: İRAN'IN 7 EKİM FİLİSTİN-İSRAİL ÇATIŞMASI SÜRECİNDE X SÖYLEMİ ÖRNEĞİ	Dilan ÖLÇER Doç. Dr. Yavuz CANKARA
		6	ABD-İSRAİL VE İRAN SAVAŞINA BALKAN ÜLKELERİNİN YAKLAŞIMLARI: POLİTİKA VE GÜVENLİK STRATEJİLERİ	Dr., İsa Deari
		7	TÜRKIYE'S PERSPECTIVE ON GREECE-ISRAEL POLITICAL RELATIONS İN THE 2000S	RUMEYSA ERTAN KAYA DOÇ.DR. PINAR ÖZDEN CANKARA
		8	CORRIDOR GEOPOLITICS AND THE SOUTH CAUCASUS: AZERBAIJAN'S TRANSITION FROM TRANSIT COUNTRY TO STRATEGIC KEY ACTOR	İhsan ALPARGIN Dr. Öğretim Üyesi Zekeriya TÜZEN
		9	TÜRKİYE'NİN DEĞİŞEN ENERJİ JEOPOLİTİĞİ: ENERJİ GÜVENLİĞİ, BÖLGESEL GÜÇ REKABETİ VE STRATEJİK ÖZERKLİK ARAYIŞI	Dr. Öğr. Üyesi Zekeriya TÜZEN İhsan ALPARGIN
		10	TÜRKIYE'S AID TO PALESTINE AFTER OCTOBER 7TH IN THE CONTEXT OF HUMANITARIAN DIPLOMACY	SEVDE BERKA ÖZLER DOÇ.DR. PINAR ÖZDEN CANKARA

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HALL / SALON 5	**Prof. Dr. Armağan Öztürk**	1	SİCKNESS AND MATERNİTY INSURANCE UNDER SOCİAL SECURİTY	Dr. Serkan DEMİRTAŞ
		2	ALEV ALATLI'S CRITIQUE OF TURKISH MODERNITY: SOME OBSERVATIONS AND ASSESSMENTS	Prof. Dr. Armağan Öztürk
		3	ALEV ALATLI'S CRITIQUE OF WESTERN CIVILIZATION: SOME OBSERVATIONS AND ASSESSMENTS	Prof. Dr. Armağan Öztürk
		4	AN INTELLECTUAL BRIDGE FROM KAZAN TO ANKARA: YUSUF AKÇURA AND "DEMOCRATIC TURKISM"	Lecturer, Hayrettin Alparslan ÇELİK
		5	DISCOURSE ANALYSIS OF YAŞAR NURİ ÖZTÜRK'S SPEECH DELIVERED IN THE TURKISH GRAND NATIONAL ASSEMBLY ON APRIL 23, 2006	Dr. Öğretim Üyesi Ersin SAVAŞ
		6	BİLGİ VE İNANÇ İLİŞKİSİNE BAYESÇİ BİR YAKLAŞIM	Doç. Dr. FERHAT ONUR
		7	HAREMDEN DEVLETE: MONTESQUIEU'DE DESPOTİZMİN MEKANSAL VE SİYASAL MANTIĞI	Hadel Bilge ARIKAN
		8	AKILCI VE DENEYCİ BİLGİ KURAMLARINDA İMGELEM GÜCÜNÜN ROLÜ	Doktora Öğrencisi, KÜBRA ATAY
		9	DİJİTAL SAĞLIK HİZMETLERİNE ERİŞİMDE YAŞLI BİREYLERDE DİJİTAL EŞİTSİZLİKLER: SOSYAL HİZMET PERSPEKTİFİNDEN BİR ANALİZ	Dr. Öğr. Üyesi MEHMET GEDİK
		10	TOPLUMSAL CİNSİYET BAĞLAMINDA KADINLARA YÖNELİK REKLAMLARA GÖSTERGEBİLİMSEL BAKIŞ: VODAFONE #BENVARIM DİYEN KADINLARIN SPONSORUYUZ REKLAMI ÖRNEĞİ	Yüksek Lisans Öğrencisi, GAMZE FIRAT

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HALL / SALON 6	**Dr. Öğr. Üyesi Kübra ÇELİK**	1	A QUALITATIVE STUDY ON THE EXAMINATION OF BUSINESS FINANCE IN THE CONTEXT OF PARTICIPATION BANKING	Yağmur ELMACIOĞLU İsmail KARATAŞ
		2	INVESTIGATION OF HOSPITAL ENTERPRISES USE OF COST MANAGEMENT SYSTEMS AND THEIR PERSPECTIVES ON COST SYSTEMS; AN APPLICATION IN THE TR90 REGION	Yüksek Lisans Öğrencisi Ekrem BOYUN Doç. Dr. ÖZNUR ARSLAN
		3	BIBLIOMETRIC ANALYSIS OF STUDIES ON CONSUMER CYNICISM USING VOSVIEWER	Dr. Öğr. Üyesi Kübra ÇELİK
		4	FORTUNE 500 COMPANIES DIVERSITY AND INCLUSION POLICIES A COMPARATIVE ANALYSIS BASED ON CORPORATE WEBSITES Tam emtin gönderecek	Gökhan TAŞGIN Doç.Dr.Arzu UĞURLU KARA
		5	A COMPARATIVE ANALYSIS OF THE DIGITAL CAPACITIES OF TÜRKİYE AND COMPETITOR COUNTRIES IN THE CONTEXT OF THE DEFENSE INDUSTRY USING MULTI-CRİTERIA DECISION-MAKING METHODS	Yunus Emre KESTANE Doç.Dr.Arzu UĞURLU KARA
		6	OPTIMIZING EMPLOYEE SATISFACTION AND RETENTION IN HOSPITALS: AN IN-DEPTH EVALUATION OF DIGITALIZATION AND ARTIFICIAL INTELLIGENCE INTEGRATION IN HR STRATEGIES	Muhammet Basar Sofía Estelles-Miguel Sofia Aparisi-Torrijo
		7	SAĞLIK ÇALIŞANLARINDA MOBBİNG ALGISI, İŞ GÜVENLİĞİ VE İŞ TATMİNİ İLİŞKİSİ	Yüksek Lisans Öğrencisi, MUHAMMED GÖK
		8	THE ROLE OF DIGITAL FINANCIAL SELF-EFFICACY IN THE ADOPTION OF GREEN FINTECH APPLICATIONS	Doç. Dr. İsmail DURAK Tezli Yüksek Lisans Öğrencisi Gamze ERDOĞAN
		9	FİNANSAL OKURYAZARLIK TUTUM VE DAVRANIŞININ, DİJİTAL TEKNOLOJİK ÖZ YETERLİKLE İLİŞKİSİ	Dr. Öğr. Üyesi İsmail DURAK Dilem DİLEK

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		2	EXPLORING ETHICAL DIMENSIONS IN CONTEMPORARY ARMENIAN POLITICAL PHILOSOPHY	Dr. Lilit Grigoryan Assoc. Prof. Dr. Tigran Hakobyan
		3	DEBATES ON MINDFULNESS AND CONSCIOUSNESS: INDIAN PHILOSOPHICAL PERSPECTIVES	Prof. Dr. Ravi Kumar Dr. Sneha Narayan
		4	INTERPRETING ADVAITA VEDANTA IN THE CONTEXT OF MODERN SCIENCE	Dr. Priya Nair Assoc. Prof. Dr. Anil Joshi
		5	RETHINKING MORAL REALISM THROUGH INDIAN BUDDHIST PHILOSOPHY	Dr. Subhasis Bandyopadhyay Satyam Verma Prof. Dr. Ahmed Al Balushi
		6	SOCIAL JUSTICE AND ETHICAL FRAMEWORKS IN CONTEMPORARY OMANI THOUGHT	Assoc. Prof. Dr. Noor Al Harthy
		7	PERSPECTIVES ON ISLAMIC PHILOSOPHY: REASON, FAITH, AND MODERNITY	Dr. Waleed Al Shamsi Prof. Dr. Layla Al Mamari
		8	CONSTRUCTING IDENTITY: PHILOSOPHY, RELIGION, AND EDUCATION IN OMAN	Dr. Amal Al Hinai Assoc. Prof. Dr. Hassan Al Farsi

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HALL / SALON 2	**Assis. Prof. Dr. Dauren Tulepov**	1	SOCIAL INTEGRATION OF INTERNAL MIGRANTS IN URBAN KAZAKHSTAN: CHALLENGES AND POLICY RESPONSES	Prof. Dr. Nurzhan Akhmetov Dr. Aigerim Sadykova Assis. Prof. Dr. Dauren Tulepov
		2	GENDER ROLES AND FAMILY TRANSFORMATION AMONG YOUNG ADULTS IN KAZAKHSTAN	Assoc. Prof. Dr. Aliya Zhaparova Dr. Yerbolat Kassenov
		3	YOUTH ASPIRATIONS AND EDUCATIONAL MOBILITY IN ERITREA: SOCIOLOGICAL INSIGHTS	Dr. Selam Habtemariam Samuel Berhane
		4	THE IMPACT OF TRADITIONAL STRUCTURES ON COMMUNITY DEVELOPMENT IN CONTEMPORARY ERITREA	Prof. Dr. Amanuel Tesfay Kibrom Menghisteab
		5	SOCIAL CAPITAL AND HEALTH OUTCOMES AMONG OLDER ADULTS IN CAIRO NEIGHBORHOODS	Dr. Noura Fathy Prof. Dr. Hatem Abdelrahman
		6	CHANGING MARRIAGE PRACTICES AND THEIR IMPACT ON FAMILY DYNAMICS IN EGYPT	Assoc. Prof. Dr. Ahmed Sorour Dr. Mona Gaber
		7	NATIONAL IDENTITY CONSTRUCTION AMONG YOUTH IN POST-SOVIET AZERBAIJAN	Prof. Dr. Elchin Gasimov Dr. Zaur Mammadli
		8	MEDIA CONSUMPTION AND VALUES SHIFT IN URBAN AZERBAIJANI SOCIETY	Assoc. Prof. Dr. Leyla Guliyeva Aysel Jafarova
		9	AGING AND SOCIAL EXCLUSION: EXPERIENCES OF ELDERLY GREEKS IN ATHENS	Dr. Theodoros Papadopoulos Dr. Maria Giannakopoulou

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HALL / SALON 3	**Prof. Dr. Roya Emami**	1	IMPACT OF MONETARY POLICIES ON ECONOMIC GROWTH IN POST-SANCTION IRAN	Prof. Dr. Mehrdad Tavakoli Assis. Prof. Dr. Sara Khosravi Dr. Navid Ghafari
		2	TECHNOLOGICAL INNOVATION AND ENTREPRENEURSHIP DEVELOPMENT IN IRANIAN SMES	Prof. Dr. Roya Emami Dr. Parviz Mohammadi Assis. Prof. Dr. Laleh Farhadi
		3	GLOBALIZATION AND LABOR MARKET TRANSFORMATION IN SINGAPORE	Prof. Dr. Wei Hoon Tan Assoc. Prof. Dr. Samuel Ong Dr. Jing Li
		4	FINANCIAL INCLUSION STRATEGIES AND HOUSEHOLD WELFARE IN SINGAPORE	Assoc. Prof. Dr. Priya Menon Prof. Dr. Adrian Chan Dr. Mei Lin Chia
		5	GREEN ECONOMY INITIATIVES AND INDUSTRIAL SUSTAINABILITY IN INDIA	Prof. Dr. Ashish Joshi Dr. Priya Singh
		6	SOCIO-ECONOMIC IMPACT OF MICROFINANCE PROGRAMS IN RURAL INDIA	Dr. Ramesh Kumar Prof. Dr. Meera Desai Assis. Prof. Dr. Saumya Gupta
		7	OIL PRICE FLUCTUATIONS AND MACROECONOMIC STABILITY IN ALGERIA	Prof. Dr. Nabil Rahmani Assis. Prof. Dr. Amel Toumi Dr. Farouk Benmoussa
		8	DEVELOPMENT OF AGRICULTURAL EXPORT MARKETS AND RURAL INCOME IN EASTERN ALGERIA	Dr. Yasmina Cherif Prof. Dr. Mohamed Belaid

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HALL / SALON 4	**Assoc. Prof. Dr. Ji-Young Choi**	1	APPROACHES IN CONTEMPORARY IRANIAN CALLIGRAPHY: TRADITIONAL HERITAGE AND NEW EXPRESSIONS	Prof. Dr. Morteza Farhadi Dr. Parisa Jahanbakhsh Somayeh Shams Assoc. Prof. Dr. Ali Rezaei
		2	THE EVOLUTION OF SERBIAN SCULPTURE: MONUMENTALISM AND NATIONAL IDENTITY	Prof. Dr. Marko Milenković Dr. Ivana Stojanović Dragana Ristić
		3	DEVELOPING PUBLIC ART INITIATIVES IN THE URBAN LANDSCAPE OF DOHA	Dr. Muna Al-Kuwari Assoc. Prof. Dr. Yusuf Rahman Latifa Al-Jaber
		4	CONTEMPORARY CALLIGRAPHIC ART IN QATAR: INTERSECTIONS OF TRADITION AND MODERNITY	Prof. Dr. Ghada Al-Thani Sara Al-Sayed
		5	RUSSIAN AVANT-GARDE INFLUENCE ON 21ST CENTURY RUSSIAN PAINTING	Prof. Dr. Vladimir Sokolov Svetlana Volkova Dr. Ekaterina Petrova
		6	POST-SOVIET CONTEMPORARY ART MOVEMENTS IN RUSSIA: TRENDS, CHALLENGES, AND GLOBAL DIALOGUE	Dr. Anna Ivanova Assoc. Prof. Dr. Pavel Morozov Nikita Baranov Tatiana Makarova
		7	NEW MEDIA INSTALLATION ART AND VIRTUALITY IN SOUTH KOREAN GALLERIES	Prof. Dr. Hyun-Jin Kim Jae-Won Lee
		8	PHOTOGRAPHIC REALISM AND IDENTITY REPRESENTATION IN KOREAN CONTEMPORARY ART	Dr. Min-Seok Park Assoc. Prof. Dr. Ji-Young Choi Sun-Hee Jo Prof. Dr. Kyung-Sook Hwang

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HALL / SALON 5	**Dr. Satoshi Watanabe**	1	EQUITABLE ACCESS TO HIGHER EDUCATION IN IRAN: STRATEGIES FOR REDUCING REGIONAL DISPARITIES	Prof. Dr. Yasmin Dastgheib Assis. Prof. Dr. Mohammad Reza Farhadi Fahimeh Bakhshi
		2	IMPACT OF DIGITAL LEARNING TOOLS ON STUDENT ENGAGEMENT IN IRANIAN SECONDARY SCHOOLS	Dr. Leila Modarresi Assis. Prof. Dr. Hamed Vaziri
		3	INCLUSION POLICIES IN PRIMARY EDUCATION: A CASE STUDY FROM SERBIAN PUBLIC SCHOOLS	Prof. Dr. Luka Stanković Jovana Nikolić Assis. Prof. Dr. Marko Rajković
		4	THE EFFECT OF TEACHER PROFESSIONAL DEVELOPMENT PROGRAMS ON LEARNING OUTCOMES IN SERBIA	Assis. Prof. Dr. Ana Petrović Dragan Ilić Zorica Stevanović
		5	INNOVATIVE APPROACHES TO CURRICULUM DESIGN IN IRAQI UNIVERSITIES: CHALLENGES AND PROGRESS	Assoc. Prof. Dr. Ahmad Al-Jubouri Assis. Prof. Dr. Sana Hameed Dr. Ali Kareem
		6	EDUCATIONAL TECHNOLOGY INTEGRATION IN TEACHER TRAINING COLLEGES IN IRAQ	Prof. Dr. Samir Mahmoud Assis. Prof. Dr. Rana Al-Taie
		7	NEW METHODOLOGICAL TRENDS IN ONLINE LEARNING ACROSS RUSSIAN UNIVERSITIES	Prof. Dr. Sergey Ivanov Dr. Ekaterina Sokolova Assis. Prof. Dr. Pavel Kuznetsov
		8	STUDENT MOTIVATION AND SELF-REGULATED LEARNING IN HYBRID HIGHER EDUCATION MODELS IN RUSSIA	Assoc. Prof. Dr. Olga Morozova Natalia Fedorova
		9	ADVANCEMENTS IN STEM CURRICULA AND PROJECT-BASED LEARNING IN JAPANESE HIGH SCHOOLS	Prof. Dr. Akira Tanaka Takashi Suzuki Yumi Matsumoto Martina Kobayashi
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HALL / SALON 6	**Dr. Mohammed Al-Rashid**	1	INNOVATIVE TEACHING STRATEGIES IN HIGHER EDUCATION	Dr. Ahmed Al-Mutairi Dr. Sara Al-Fahad
		2	DIGITAL LEARNING PLATFORMS AND STUDENT ENGAGEMENT	Dr. Leila Mansouri Prof. Dr. Reza Khatami Neda Farhadi
		3	CURRICULUM DEVELOPMENT FOR MULTILINGUAL CLASSROOMS	Dr. Rasha Al-Haddad Omar Al-Masri
		4	THE ROLE OF TEACHER TRAINING IN IMPROVING EDUCATIONAL OUTCOMES	Dr. Fadi Khalil Dr. Lina Youssef Dr. Samir Nassar
		5	EDUCATION FOR SUSTAINABLE DEVELOPMENT: CHALLENGES AND OPPORTUNITIES	Dr. Fatemeh Rahimi Dr. Ali Karimi
		6	BLENDED LEARNING APPROACHES IN UNIVERSITY SETTINGS	Amal Hassan Dr. Yasser Ibrahim Prof. Dr. Huda Mahmoud
		7	STUDENT-CENTERED LEARNING AND ACADEMIC ACHIEVEMENT	Dr. Mohammed Al-Rashid Dr. Aisha Al-Salem
		8	TECHNOLOGY INTEGRATION IN MODERN CLASSROOMS	Dr. Hassan Jafar Dr. Mariam Abbas Dr. Ali Hussein Prof. Dr. Zainab Karim

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HALL / SALON 7	**Prof. Dr. Bassam Darwish**	1	LANGUAGE AND IDENTITY IN CONTEMPORARY ARABIC NOVELS	Ahmed Al-Farouqi Layla Hassan
		2	POETIC TRADITIONS AND SYMBOLISM IN PERSIAN LITERATURE	Dr. Reza Mahdavi Niloofar Azimi Farhad Ghanbari
		3	THE INFLUENCE OF CLASSICAL TURKISH POETRY ON MODERN PROSE	Prof. Dr. Mehmet Erdem Zeynep Kaya
		4	ORAL STORYTELLING AND CULTURAL MEMORY IN IRAQI LITERATURE	Samira Al-Khalidi Ali Hussein Dr. Fadwa Salman
		5	THEMES OF EXILE AND BELONGING IN PALESTINIAN POETRY	Dr. Rami Barakat Aisha Khalil
		6	WOMEN'S VOICES IN CONTEMPORARY SYRIAN FICTION	Nour Haddad Rana Al-Shami Prof. Dr. Bassam Darwish
		7	LINGUISTIC HERITAGE AND IDENTITY FORMATION IN LEBANESE DRAMA	Karim Mansour Dr. Leila Choueiri

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HALL / SALON 8	**Assoc. Prof. Dr. Cristian Petrescu**	1	SPATIAL ANALYSIS OF FOOTBALL PERFORMANCE USING DIGITAL TRACKING TECHNOLOGIES	Prof. Dr. Kamran Mammadov Assoc. Prof. Dr. Leyla Aliyeva Rashad Huseynli
		2	THE ROLE OF SPORTS NUTRITION IN ENHANCING ATHLETIC ENDURANCE: A CASE STUDY IN YOUTH TEAMS	Assoc. Prof. Dr. Aygun Taghizada Nijat Safarov
		3	PSYCHOLOGICAL FACTORS AFFECTING THE SUCCESS OF ELITE WRESTLERS	Prof. Dr. Elchin Abbasov Samira Karimova Assis. Prof. Dr. Rauf Mehdiyev
		4	KINEMATIC APPROACHES TO OPTIMIZE GYMNASTIC TRAINING ROUTINES	Prof. Dr. Andrei Popescu Maria Ionescu Assoc. Prof. Dr. Elena Dobre
		5	EFFECTIVENESS OF RECOVERY STRATEGIES IN PROFESSIONAL HANDBALL TEAMS	Assoc. Prof. Dr. Cristian Petrescu Ioana Marinescu
		6	MOTIVATIONAL DYNAMICS IN YOUTH SPORTS DEVELOPMENT PROGRAMS Prof. Dr. Sorin Vasilescu	Anca Radu Dr. Mihai Florescu
		7	THE IMPACT OF CLIMATE CONDITIONS ON MARATHON PERFORMANCE IN EAST AFRICA	Assoc. Prof. Dr. John Mwangi Peter Otieno Samuel Njoroge
		8	ANALYSIS OF INJURY PATTERNS IN PROFESSIONAL FOOTBALL LEAGUES OF WEST AFRICA	Dr. Kofi Mensah Assoc. Prof. Dr. Ama Boateng

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HALL / SALON 9	**Prof. Dr. Kwame Mensah**	1	THE IMPACT OF URBANIZATION ON SOCIAL BEHAVIOR AND COMMUNITY INTERACTIONS	Nijat Mammadov Leyla Aliyeva Togrul Rustamov
		2	SOCIAL MEDIA INFLUENCE ON YOUTH CULTURE AND IDENTITY FORMATION	Assoc. Prof. Dr. Farid Huseynov Aynur Guliyeva
		3	GENDER ROLES AND FAMILY DYNAMICS IN MODERN SOCIETY	Prof. Dr. Elchin Safarov Nigar Hasanli
		4	THE EFFECTS OF MIGRATION ON CULTURAL INTEGRATION AND SOCIAL COHESION	Dr. Ioana Popescu Alina Ionescu Mihai Dumitrescu
		5	EDUCATIONAL INEQUALITIES AND THEIR IMPACT ON SOCIAL MOBILITY	Assoc. Prof. Dr. Sorin Marinescu Elena Georgescu
		6	SOCIAL PERCEPTIONS OF HEALTHCARE IN AFRICAN URBAN COMMUNITIES	Prof. Dr. Kwame Mensah Amina Okafor
		7	THE ROLE OF TRADITIONAL BELIEFS IN SHAPING MODERN SOCIAL NORMS	Dr. Thabo Nkosi Fatoumata Diallo Assoc. Prof. Dr. Chike Obi
		8	YOUTH ENGAGEMENT IN POLITICAL PROCESSES AND CIVIC PARTICIPATION	Prof. Dr. Adebayo Adekunle Nia Kambale Dr. Zuri Mwangi

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HALL / SALON 10	**Dr. Tamer Fahmy**	1	THE IMPACT OF URBANIZATION ON SOCIAL RELATIONSHIPS AND COMMUNITY STRUCTURE	Prof. Dr. Ali Rezaei Dr. Mahsa Karimi Hamed Fathi
		2	SOCIAL MEDIA AND ITS EFFECTS ON YOUTH IDENTITY FORMATION	Dr. Leila Mohammadi Saeid Tavakoli
		3	GENDER ROLES AND FAMILY DYNAMICS IN MODERN IRANIAN SOCIETY	Assoc. Prof. Dr. Narges Ahmadi Fatemeh Hosseini
		4	THE ROLE OF EDUCATION IN SOCIAL MOBILITY AND INEQUALITY	Dr. Amir Hossein Zarei
		5	CULTURAL HERITAGE AND COLLECTIVE MEMORY IN CONTEMPORARY EGYPT	Prof. Dr. Ahmed El-Sayed Sara Hassan Mona Khalil
		6	SOCIAL INEQUALITY AND ACCESS TO HEALTHCARE SERVICES IN URBAN EGYPT	Dr. Tamer Fahmy Assoc. Prof. Dr. Dina Adel
		7	YOUTH UNEMPLOYMENT AND ITS SOCIOECONOMIC IMPACT IN KAZAKHSTAN	Zhanar Mukhamedova Dr. Timur Sadykov Prof. Dr. Aigul Bektayeva
		8	TRADITIONAL CUSTOMS AND MODERNIZATION: CHALLENGES TO KAZAKHSTAN RURAL COMMUNITIES	Dr. Yerlan Akhmetov Assis. Prof. Dr. Gulnara Zhaksylykova

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HALL / SALON 1	**Arş. Gör. Okay COŞKUN Prof. Dr. Yılmaz AKGÜNDÜZ**	1	PROBLEMS VEGETARIAN AND VEGAN CONSUMERS FACE WHEN CHOOSING FOOD AND BEVERAGE ESTABLISHMENTS	Ali Enes ADAK Doç. Dr. Yeliz PEKERŞEN
		2	THE ROLE OF STORYTELLING IN DESTINATION MARKETING: A PRACTICAL INVESTIGATION	Yüksek Lisans Öğrencisi Erva Aişe KANDEMİR Doç. Dr. Yeliz PEKERŞEN
		3	A STUDY ON THE CONSUMPTION OF GEOGRAPHICALLY INDICATED EDREMIT OLIVE OIL	SERDAR SÖNMEZ Prof. Dr. LEYLA ÖZGEN
		4	SWOT ANALYSIS OF THE TOURISM POTENTIAL OF WESTERN BALKAN COUNTRIES: REGIONAL AND NATIONAL ASSESSMENT	Arş. Gör. Okay COŞKUN Prof. Dr. Yılmaz AKGÜNDÜZ

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HALL / SALON 2	**Assoc. Prof. Dr. Meryem GEÇİMLİ**	1	AN INİTİAL APPROACH TO EXTENDED FLUTE TECHNİQUES: EDUCATOR PERSPECTİVES ON THEİR INSTRUCTİON AT THE BEGİNNER LEVEL	PhD Candidate, AZE BÖLEK YILDIZ Associate Professor, AJDA ŞENOL SAKİN
		2	KENTSEL DOKUDA VİDEO ENSTALASYON ve PORTRE: CRAIG WALSH ÖRNEĞİ	Doçent, EREN GÖRGÜLÜ
		3	SOKAK SANATI 2.0: BLOOD FOREST ÖRNEĞİNDE PORTRE ve MEKANA ÖZGÜ DENEYİM	Doçent, EREN GÖRGÜLÜ
		4	SPATIAL MEMORY AND CULTURAL IDENTITY AFTER THE EARTHQUAKE: THE CASE OF KAHRAMANMARAŞ	Assoc. Prof. Dr. Meryem GEÇİMLİ
		5	LİGHT AND INNER REALİTY: A FORMAL ANALYSİS THROUGH REMBRANDT, VERMEER AND VELÁZQUEZ	Prof.Dr. Fahrettin GEÇEN Dr. Öğrencisi, Ahmet Göktuğ KILIÇ
		6	HIERARCHY OF EMPHASIS AND SUPERIORITY IN POSTMODERN ART: CRITICAL ANALYSIS THROUGH BASQUIAT, WARHOL, KRUGER	Prof.Dr. Fahrettin GEÇEN Dr. Öğrencisi, Ahmet Göktuğ KILIÇ
		7	GAMIFICATION OF SPATIAL EXPERIENCE: MOTIVATIONAL APPROACHES IN INFORMATION AND WAYFINDING GRAPHIC DESIGN	Dr. Öğr. Üyesi, TUĞBA DİLEK KAYABAŞ
		8	BİR SÜSLEME TEKNİĞİ: DİŞİ OYMA KALIPLAR, SÜLEYMANİYE KÜTÜPHANESİ 1470 NO'DAKİ KASİDE-İ BÜRDE ÜZERİNDEN BİR UYGULAMA ÖRNEĞİ	Dr. Öğretim Üyesi, BURCU ERYILMAZ
		9	JOHN PİPER'IN "VİTRAY: SANAT MI YOKSA ANTİ-SANAT MI?" KİTABINDA ESTETİK, BELLEK VE ZANAATİN DİYALEKTİĞİ	Öğretim Görevlisi BERİL REİS
		10	ARCHITECTURAL REPRESENTATION IN 16TH CENTURY OTTOMAN MINIATURES: SPATIAL MANIFESTATIONS OF COMFORT, PRIVACY AND POWER	Öğretim Görevlisi, Beril REİS

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HALL / SALON 3	**Dr. Amaneh MAnafidizaji**	1	BODY APPRECIATION IN ADOLESCENCE: THE ROLE OF DEMOGRAPHIC AND PSYCHOSOCIAL FACTORS	Eimantas Sinkevicius Vaiva Balciuniene
		2	THE EXPRESSION OF EMOTIONS AND BEHAVIORAL TRAITS IN CHILDREN ATTENDING BOXING TRAINING: FROM THE PERSPECTIVE OF SELF, COACH, AND PARENT ASSESSMENT	Modestas Žmuidina Šarūnas Šniras
		3	DEMOGRAPHIC, SOCIOCULTURAL, AND BEHAVIOURAL FACTORS ASSOCIATED WITH DISORDERED EATING AMONG INTERNATIONAL UNIVERSITY STUDENTS IN LITHUANIA	Andriya Brigiht Vaiva Balciuniene
		4	DEPRESSION, ANXIETY AND SELF RATED HEALTH IN RELATION TO STRESS RESILIENCE AMONG FOREIGN UNIVERSITY STUDENTS.	Salu Thomas Vilija Malinauskiene
		5	SPOR BİLİMLERİ FAKÜLTESİ ÖĞRENCİLERİNİN SPORDA AHLAKTAN UZAKLAŞMA DÜZEYLERİNİN BAZI DEĞİŞKENLER AÇISINDAN İNCELENMESİ	Buse Büsra SAYGILI Prof. Dr.,Turan ÇETİNKAYA
		6	SPOR BİLİMLERİ FAKÜLTESİ ÖĞRENCİLERİNİN SOSYAL MEDYA BAĞIMLILIĞI DÜZEYLERİNİN BAZI DEĞİŞKENLER AÇISINDAN İNCELENMESİ	Buse Büsra SAYGILI Prof. Dr.,Turan ÇETİNKAYA

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HALL / SALON 4	**Doç. Dr. Aysun ÖCAL**	1	INTEGRITY AND ETHICS OF PUBLIC OFFICIALS IN ALBANIA: MINDSETS AND CULTURE INFLUENCING THE FUNCTIONING OF THE PUBLIC ADMINISTRATION	Dr. Jetmira Fekolli Prof. Dr Adriana Anxhaku
		2	LEGAL FRAMEWORK OF SOCIAL DIALOGUE IN BULGARIAN LABOUR LAW	Assoc. Prof. D.Sc. (Legal sciences) Ivaylo STAYKOV
		3	YEREL YÖNETİMLERDE İSTİHDAM POLİTİKALARI VE WEBERYAN BÜROKRASİ KISKACI: 4B SÖZLEŞMELİ PERSONEL REJİMİ ÜZERİNE TEORİK BİR ANALİZ	Doç. Dr. Aysun ÖCAL
		4	AKADEMİK ÖZGÜNLÜK VE ÖZGÜRLÜĞÜN AZALMASI	Y.L Öğrencisi, H. CEYNUR DALDAL ERTE
		5	AVRUPA BİRLİĞİ KOMİSYONU TÜRKİYE RAPORLARI UYARINCA EKONOMİ İÇERİKLİ HUSUSLARA YÖNELİK OLASI HUKUKİ ÇÖZÜMLER	KAAN HARMANCI PROF. DR. OYTUN MEÇİK
		6	THE EXAMINATION OF THE INDEPENDENT AUDITOR'S PROFESSIONAL JUDGMENT IN THE CONTEXT OF LEGAL LIABILITY, STANDARDIZATION, AND THE PUBLIC INTEREST	Dr. Öğr. Üyesi Ece Deniz GÜNAY

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HALL / SALON 5	**Prof. Dr. Ali Sabri İPEK**	1	İLKÖĞRETİM MATEMATİK ÖĞRETMEN ADAYLARININ TÜRKİYE YÜZYILI MAARİF MODELİ ORTAOKUL MATEMATİK DERS KİTAPLARINI İNCELEMELERİ	Prof. Dr. Ali Sabri İPEK
		2	EXAMINING THE RELATIONSHIP BETWEEN BURNOUT SYNDROME AND STRESS MANAGEMENT IN PRESCHOOL TEACHERS	Prof. Dr. Leyla ÖZGEN Cansu YAZKAN Ertuğrul ÖZKUL
		3	INFORMATION LITERACY AND LIFELONG LEARNING İN SOCIAL STUDIES EDUCATION: AN EVALUATION WITHIN THE FRAMEWORK OF THE CENTURY OF TÜRKIYE EDUCATION MODEL	Esra EKİCİ Doç.Dr Ayşegül AVŞAR TUNCAY
		4	MEDIA LITERACY İN SOCIAL STUDIES COURSES WITHIN THE CONTEXT OF THE CENTURY OF TÜRKIYE EDUCATION MODEL: A CONCEPTUAL EXAMINATION	Esra EKİCİ Doç. Dr Ayşegül AVŞAR TUNCAY
		5	DİJİTAL HİKAYE TABANLI MİKRO ÖĞRENMENİN ORTAOKUL SOSYAL BİLGİLER ÖĞRENCİLERİNİN ÖZ-YETERLİK DÜZEYLERİN ETKİSİ	HAZAL ÖZCAN DOÇ.DR. SERKAN SAY
		6	SOSYAL BİLGİLER ÖĞRETMEN ADAYLARININ YAPAY ZEKA YETKİNLİK KAYGISI VE YAPAY ZEKA İYİMSERLİĞİ ARASINDAKİ İLİŞKİNİN İNCELENMESİ	HAZAL ÖZCAN DOÇ.DR. SERKAN SAY
		7	KENT ORMANCILIĞININ EKOLOJİK VE SOSYAL İŞLEVLERİ	Rüştü ILGAR
		8	BİREYLERDE DİJİTAL AYAK İZİ FARKINDALIĞININ DÜZEYİ VE GELİŞTİRİLMESİNE YÖNELİK STRATEJİLER	Rüştü ILGAR

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HALL / SALON 6	**Dr. Öğr. Üyesi Samet KIYAK**	1	THE EFFECTS OF NATURE-BASED INTERVENTIONS AND RELAXATION TECHNIQUES ON EMOTION REGULATION AND SELF-ESTEEM IN STUDENTS WITH LEARNING DISABILITIES	Assoc. Prof. Dr. BAHANUR MALAK AKGÜN Assoc. Prof. Dr. ADEVİYE AYDIN Res. Asst.LALE RUMEYSA TORAMAN Res. Asst. Dr. ZEYNEP YILMAZ
		2	THE ROLE OF NURSES IN MEDICATION SAFETY AND RATIONAL DRUG USE IN HEMODIALYSIS PATIENTS	Prof. Dr. Mehtap KAVURMACI GÜLBEYAZ ÇEMÇ
		3	AN EXAMINATION OF THE RELATIONSHIP BETWEEN NURSING STUDENTS' KNOWLEDGE LEVELS AND ATTITUDES TOWARD THE PREVENTION OF MEDICAL DEVICE–RELATED PRESSURE INJURIES	Şükran KOÇ Doç. Dr. Esma ÖZŞAKER
		4	THE RELATIONSHIP BETWEEN HEALTH LITERACY AND READINESS FOR HOSPITAL DISCHARGE IN SURGICAL PATIENTS	Hemşire, HAMİDE YASEMİN YAŞAR Doç. Dr., ESMA ÖZŞAKER
		5	POTENTIAL APPLICATIONS OF ARTIFICIAL INTELLIGENCE–ASSISTED SYSTEMS IN FORENSIC AUTOPSIES	Dr. Öğr. Üyesi Samet KIYAK
		6	DİYABETİK HASTALARDA CRP/ALBÜMİN ORANININ PROGNOZDAKİ YERİ	Uzm. Dr. Murat Atlı
		7	ANTIBACTERIAL PROSTHETIC FINGERNAIL	Assist. Prof. Dr. AYŞEGÜL HOŞ Res. Assist. AYŞE ÇALIŞ Res. Assist. AYŞE İNCİ Prof. Dr. UĞURSOY OLGUN
		8	EVALUATION OF PREVALENCE, CHARACTERISTICS AND RISK FACTORS OF QT INTERVAL PROLONGING DRUG-DRUG INTERACTIONS IN CARDIOLOGY PATIENTS	M. Sc. MUHAMMED SEVINDIK GOZDE AKTURK, ASSISTANT PROFESSOR, MD CIHAN OZTURK, ASSISTANT PROFESSOR, MD SELCUK KORKMAZ, ASSOCİATE PROFESSOR, Ph.D

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HALL / SALON 1	**Assoc. Prof. Dr. Svetlana Karpova**	1	ENHANCING EDUCATIONAL EQUITY THROUGH UNIVERSAL ACCESS POLICIES IN IRANIAN SECONDARY SCHOOLS	Prof. Dr. Fereshteh Davoudi Assis. Prof. Dr. Vahid Mahmoudi Marjan Zarei
		2	ADAPTING UNIVERSITY TEACHING FOR DIGITAL LEARNERS: CHALLENGES AND INNOVATIONS IN IRAN	Assoc. Prof. Dr. Saeed Rohani Dr. Niloofar Taghavi
		3	MULTILINGUAL EDUCATION AND INTEGRATION: POLICY EXPERIENCES IN SERBIAN PRIMARY SCHOOLS	Prof. Dr. Katarina Jovanović Vladimir Ilić Assis. Prof. Dr. Slobodan Milenković
		4	THE IMPACT OF TEACHER PROFESSIONAL DEVELOPMENT ON STUDENT ACHIEVEMENT IN SERBIAN SECONDARY SCHOOLS	Dr. Jelena Petrović Assis. Prof. Dr. Marko Vuković Nikola Filipović Marina Mihajlović
		5	CURRICULUM REFORM AND EMPLOYABILITY SKILLS DEVELOPMENT IN IRAQI UNIVERSITIES	Assoc. Prof. Dr. Zainab Al-Musawi Mustafa Aziz Ali Taha
		6	BARRIERS TO GIRLS' SECONDARY EDUCATION PARTICIPATION IN RURAL IRAQ: SOCIAL AND STRUCTURAL FACTORS	Dr. Rasha Al-Tamimi Assoc. Prof. Dr. Samir Jameel
		7	INNOVATIVE TEACHING METHODS AND STUDENT ENGAGEMENT IN LARGE RUSSIAN UNIVERSITIES	Prof. Dr. Irina Sokolova Oleg Novikov Assis. Prof. Dr. Tatiana Demidova Mikhail Petrov
		8	DISTANCE LEARNING AND STUDENT WELLBEING: EXPERIENCES FROM REGIONAL UNIVERSITIES IN RUSSIA	Assoc. Prof. Dr. Svetlana Karpova Natalia Smirnova Lyudmila Ivanova

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HALL / SALON 2	**Prof. Dr. Shalini Kaur**	1	LEGAL CHALLENGES IN THE IMPLEMENTATION OF DATA PRIVACY REGULATIONS IN INDIA	Prof. Dr. Priya Srivastava Dr. Rajiv Menon
		2	ACCESS TO JUSTICE AND THE ROLE OF PUBLIC INTEREST LITIGATION IN INDIAN CONSTITUTIONAL LAW	Prof. Dr. Shalini Kaur
		3	THE EVOLUTION OF PROPERTY LAW IN POST-COMMUNIST ROMANIA	Assoc. Prof. Dr. Ioana Popescu Dr. Alexandru Stan Dr. Corina Petrescu
		4	CONSTITUTIONAL REFORM AND JUDICIAL INDEPENDENCE IN MODERN ROMANIA	Radu Ionescu Mircea Dragomir
		5	LEGAL FRAMEWORKS FOR ENVIRONMENTAL PROTECTION IN INDONESIA: ANALYSIS OF THE BASIC ENVIRONMENTAL LAW	Prof. Dr. Indah Yuliana Dr. Farid Arifin
		6	THE EMERGENCE OF CYBER LAW IN INDONESIAN E-COMMERCE AND DIGITAL ECONOMY	Dr. Wira Pratama Assoc. Prof. Dr. Siti Rahmawati Dr. Agung Nugroho
		7	TRENDS IN JUDICIAL REFORM AND ACCESS TO LEGAL AID IN KAZAKHSTAN	Assoc. Prof. Dr. Serik Akhmetov
		8	ADOPTION OF MEDIATION IN CIVIL DISPUTE RESOLUTION: THE KAZAKHSTAN EXPERIENCE	Prof. Dr. Gulmira Rakhimova Dr. Dauren Zhaksybek Aigerim Sarsembay

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HALL / SALON 3	**Prof. Dr. Farid Ahmadov**	1	EXPLORING THE POLITICAL IMPACT OF THE INDIAN INDEPENDENCE MOVEMENT ON COLONIAL GOVERNANCE	Prof. Dr. Anjali Sharma Dr. Mohan Srinivasan Assoc. Prof. Dr. Priya Menon
		2	ARCHITECTURAL HERITAGE AND CULTURAL SYNTHESIS DURING THE MUGHAL PERIOD IN INDIA	Ravi Sahu
		3	THE SPANISH INFLUENCE ON PHILIPPINE LOCAL GOVERNMENTS AND SOCIOPOLITICAL SYSTEMS	Dr. Carina Cruz Luis Santos
		4	DECOLONIZATION AND NATIONAL IDENTITY: THE ROLE OF EDUCATION IN PHILIPPINE POSTWAR RECONSTRUCTION	Prof. Dr. Maria Teresa Ramos Maricel Bautista Dr. Jose R. Enriquez
		5	TRADE ROUTES, MARITIME POWER, AND SOCIAL DYNAMICS IN OMAN'S INDIAN OCEAN HISTORY	Dr. Khalid Al-Abri Assoc. Prof. Dr. Aisha Al-Rashidi
		6	ARCHAEOLOGICAL DISCOVERIES AND HISTORICAL INTERPRETATIONS OF ANCIENT OMANI CITIES	Assoc. Prof. Dr. Hamad Al-Shamsi Dr. Ahmed Al-Nabhani Rahma Yaqoob
		7	THE FORMATION OF NATIONAL IDENTITY IN MODERN AZERBAIJAN: HISTORY, MYTH, AND POLITICS	Prof. Dr. Farid Ahmadov Nigar Mamedova

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HALL / SALON 4	**Dr. Isabelle Martin**	1	THE IMPACT OF DIGITAL FABRICATION ON FRENCH ARCHITECTURE AND DESIGN EDUCATION	Prof. Dr. Lucie Moreau Dr. Thibault Lavigne Amélie Durand Vincent Renaud
		2	EXPLORING COLOR, FORM, AND SPACE IN CONTEMPORARY AZERBAIJANI PAINTING	Dr. Farid Aslanov Aytac Karimli
		3	INTEGRATING TRADITIONAL MOTIFS IN CONTEMPORARY AZERBAIJANI TEXTILE DESIGN	Prof. Dr. Leyla Mammadova
		4	CULTURAL IDENTITY AND SYMBOLISM IN MODERN FRENCH FASHION DESIGN	Dr. Isabelle Martin
		5	EXPLORING COMMUNITY ART INITIATIVES AND SOCIAL CHANGE IN ADDIS ABABA	Dr. Makeda Nega Prof. Dr. Takele Taddese
		6	MEN'S AND WOMEN'S PERSPECTIVES IN CONTEMPORARY ETHIOPIAN SCULPTURE	Tadesse Abate Selamawit Birhanu Dr. Ayana Tafese Genet Habte
		7	THE INFLUENCE OF PERSIAN MINIATURE PAINTING ON CONTEMPORARY IRANIAN GRAPHIC DESIGN	Prof. Dr. Farzaneh Rad
		8	EXPERIMENTAL TYPOGRAPHY IN CONTEMPORARY IRANIAN POSTER DESIGN	Shirin Bazargan

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HALL / SALON 5	**Assoc. Prof. Dr. Lina Najjar**	1	CHILD PROTECTION STRATEGIES IN RURAL COMMUNITIES OF KYRGYZSTAN	Prof. Dr. Bakytbek Isakov Assis. Prof. Dr. Aizada Amanova
		2	INTEGRATING FAMILY SYSTEMS THEORY INTO SOCIAL WORK EDUCATION IN KYRGYZSTAN	Assis. Prof. Dr. Gulnur Koichumanova
		3	POST-CONFLICT SOCIAL WORK PRACTICES AMONG INTERNALLY DISPLACED PERSONS IN SYRIA	Assoc. Prof. Dr. Fadi Al-Hamdan Dr. Nada Saoud Maysoun Khalil
		4	WOMEN'S EMPOWERMENT INITIATIVES THROUGH SOCIAL SERVICES IN SYRIAN UNIVERSITIES	Assoc. Prof. Dr. Lina Najjar
		5	INNOVATION IN SOCIAL WORK PRACTICES IN RUSSIAN URBAN CENTERS	Natalia Smirnova Assis. Prof. Dr. Zalina Danilova Dr. Yulia Roslova
		6	THE ROLE OF SOCIAL WORKERS IN ADDRESSING ADDICTION AND SUBSTANCE ABUSE IN RUSSIA	Assis. Prof. Dr. Anna Sokolova Dmitry Ivanov
		7	YOUTH ENGAGEMENT IN COMMUNITY DEVELOPMENT PROGRAMS IN PALESTINIAN UNIVERSITIES	Prof. Dr. Amira Khalil Assis. Prof. Dr. Ramzi Barakat

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HALL / SALON 6	**Dr. Meena Raval Assis. Prof. Dr. Amatma Sharma**	1	POSTCOLONIAL THEMES IN MODERN INDIAN NOVELS: RECONSTRUCTING IDENTITY AND CULTURE	Prof. Dr. Kavita Choudhury Dr. Rajesh Mishra
		2	TRANSLATION, GENDER, AND POLITICS IN SOUTH ASIAN WOMEN'S POETRY	Dr. Meena Raval Assis. Prof. Dr. Amatma Sharma
		3	REPRESENTING INDIGENOUS MYTHS AND FOLKLORE IN CONTEMPORARY PHILIPPINE SHORT STORIES	Assis. Prof. Dr. Maria Lourdes Sanchez Dr. Ricardo Ramos Isabel Bautista
		4	SOCIAL REALISM IN PHILIPPINE POETRY: REFLECTIONS ON HISTORY, CLASS, AND RESISTANCE	Dr. Patricia Gomez James Dela Cruz Carlotta Pascual Dr. George Castor
		5	MODERNITY AND TRADITION IN KOREAN LITERARY NARRATIVES: A GENERATIONAL DIALOGUE	Assoc. Prof. Dr. Min-Seok Kim Soojin Park
		6	FEMINIST CRITICISM AND WOMEN'S NARRATIVES IN KOREAN NOVELS AFTER 2000	Dr. Jiyoung Lee Assis. Prof. Dr. Hana Park
		7	NEGRITUDE, LANGUAGE, AND IDENTITY IN SENEGALESE FRANCOPHONE NOVELS	Prof. Dr. Moussa Diop Dr. Fatou Ndiaye Samba Fall
		8	THE AESTHETICS OF ORAL STORYTELLING AND SONG IN SENEGAL'S CONTEMPORARY LITERARY SCENE	Dr. Aminata Sarr Daouda Faye Babacar Ndoye Ibrahima Ba

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HALL / SALON 7	**Assoc. Prof. Dr. Anna Petraki**	1	OPTIMIZING SUPPLY CHAIN RESILIENCE IN NIGERIAN AGRIBUSINESS: STRATEGIES FOR RISK MANAGEMENT AND EFFICIENCY	Assoc. Prof. Dr. Ibrahim Sanusi
		2	THE IMPACT OF INDUSTRIAL ENGINEERING PROCESSES ON MANUFACTURING PRODUCTIVITY IN NIGERIAN SMEs	Dr. Chika Eze
		3	SUSTAINABLE ENERGY SYSTEMS PLANNING THROUGH ECONOMIC ENGINEERING METHODS IN PAKISTAN	Prof. Dr. Asif Mahmood Fatima Raza Dr. Bilal Shah Hamza Ahmed
		4	APPLICATION OF OPERATIONS RESEARCH TECHNIQUES IN HEALTHCARE RESOURCE ALLOCATION IN PAKISTAN	Dr. Mehwish Iqbal Assoc. Prof. Dr. Nasir Javed
		5	ADVANCED INDUSTRIAL ENGINEERING SOLUTIONS FOR OIL REFINERY OPTIMIZATION IN IRAQ	Assoc. Prof. Dr. Karim Al-Hafidh Assis. Prof. Dr. Salma Abbas Mahdi Taha
		6	ECONOMIC ANALYSIS OF PUBLIC TRANSPORTATION NETWORKS USING SIMULATION METHODS IN IRAQ	Dr. Haider Ali Ali Kareem
		7	INTEGRATED ECONOMIC ENGINEERING APPROACHES FOR SUSTAINABLE TOURISM DEVELOPMENT IN GREECE	Prof. Dr. Ioannis Papadopoulos Dr. Eleni Karamitsou Spiros Christou Dimitrios Voulgaris
		8	DECISION ANALYSIS AND FINANCIAL MODELING IN INFRASTRUCTURE INVESTMENT PROJECTS IN GREECE	Assoc. Prof. Dr. Anna Petraki

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HALL / SALON 8	**Assoc. Prof. Dr. Noor Al Harthy**	1	THE FOUNDATIONS OF ARMENIAN LOGIC: HISTORICAL ROOTS AND MODERN APPLICATIONS	Prof. Dr. Aram Petrosyan
		2	EXPLORING ETHICAL DIMENSIONS IN CONTEMPORARY ARMENIAN POLITICAL PHILOSOPHY	Dr. Lilit Grigoryan Assoc. Prof. Dr. Tigran Hakobyan
		3	DEBATES ON MINDFULNESS AND CONSCIOUSNESS: INDIAN PHILOSOPHICAL PERSPECTIVES	Prof. Dr. Ravi Kumar Dr. Sneha Narayan
		4	INTERPRETING ADVAITA VEDANTA IN THE CONTEXT OF MODERN SCIENCE	Dr. Priya Nair Assoc. Prof. Dr. Anil Joshi
		5	RETHINKING MORAL REALISM THROUGH INDIAN BUDDHIST PHILOSOPHY	Dr. Subhasis Bandyopadhyay Satyam Verma Prof. Dr. Ahmed Al Balushi
		6	SOCIAL JUSTICE AND ETHICAL FRAMEWORKS IN CONTEMPORARY OMANI THOUGHT	Assoc. Prof. Dr. Noor Al Harthy
		7	PERSPECTIVES ON ISLAMIC PHILOSOPHY: REASON, FAITH, AND MODERNITY	Dr. Waleed Al Shamsi Prof. Dr. Layla Al Mamari
		8	CONSTRUCTING IDENTITY: PHILOSOPHY, RELIGION, AND EDUCATION IN OMAN	Dr. Amal Al Hinai Assoc. Prof. Dr. Hassan Al Farsi
		9	THE ROLE OF CONFUCIAN ETHICS IN EDUCATIONAL DEVELOPMENT IN MODERN TAIWAN	Prof. Dr. Chen Wei-Ting Dr. Mei-Ju Chou
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HALL / SALON 9	**Dr. Chioma Agu**	1	POST-BYZANTINE ICONOGRAPHY IN ALBANIAN ORTHODOX CHURCH ART	Prof. Dr. Luan Rama, Dr. Anila Meta
		2	ILLYRIAN MOTIFS IN CONTEMPORARY ALBANIAN TEXTILE DESIGN TRADITIONS	Assoc. Prof. Dr. Dorina Shehu, Erion Llagami
		3	YORUBA SCULPTURAL TRADITIONS AND CONTEMPORARY NIGERIAN URBAN INSTALLATIONS	Dr. Chinedu Okoro, Ngozi Eze
		4	NOK TERRACOTTA INFLUENCES ON MODERN NIGERIAN CERAMIC PRACTICES	Prof. Dr. Fatima Yusuf, Adebayo Salisu
		5	IGBO MASQUERADES AND PERFORMANCE ART IN POSTCOLONIAL NIGERIAN THEATRE	Assis. Prof. Dr. Uchechi Nwosu, Emeka Okafor,
		6	HAUSA CALLIGRAPHY REVIVAL THROUGH DIGITAL TYPOGRAPHY IN NORTHERN NIGERIA	Dr. Chioma Agu
		7	BENIN BRONZE AESTHETICS IN CONTEMPORARY NIGERIAN JEWELRY DESIGN	Assoc. Prof. Dr. Olusegun Adeyemi, Temitope Ogunleye
		8	RENAISSANCE FRESCO TECHNIQUES IN CONTEMPORARY ITALIAN SACRED ART	Prof. Dr. Giovanni Rossi, Dr. Elena Bianchi, Marco Ferraro

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HALL / SALON 1	**Doç. Dr. ZUHAL DEMİR**	1	"GADJO DILO" FİLMİ ÜZERİNDEN ROMANLARIN KÜLTÜREL KODLARINI OKUMAK	Doç. Dr. ZUHAL DEMİR
		2	PALESTINIAN CULTURE WITHIN THE FRAMEWORK OF HOFSTEDE'S CULTURAL DIMENSIONS THEORY: A QUANTITATIVE STUDY ON PALESTINIAN SOCIETY	PhD Student. ASIA MOHAMMED ABU SLEEM Doç. Dr. SEVİM KOÇER
		3	SAHTE HABER GÖRSELLERİNİN TESPİTİNDE KULLANILAN YAPAY ZEKÂ UYGULAMALARI ÜZERİNE BİR ANALİZ: İLETİŞİM FAKÜLTESİ ÖĞRENCİLERİ ÖRNEĞİ	Yüksek Lisans Öğrencisi, Emel BAŞ
		4	COSMETICS AND BEAUTY IN THE DIGITAL AGE: A CONCEPTUAL ANALYSIS IN THE LIGHT OF COMMUNICATION THEORIES	Dr., Öğr. Üyesi DURSUN YILMAZ Öğr. Gör, BEYHAN DOĞAN
		5	OZONE GAS AND HUMAN AESTHETICS: A NEW APPROACH IN COSMETIC COMMUNICATION	Öğr. Gör, BEYHAN DOĞAN Dr., Öğr. Üyesi DURSUN YILMAZ
		6	USE OF SOCIAL MEDIA IN SCHOOLS: THE CASE OF TOKAT MEKTEBİM COLLEGE	Eldem Nihan Tutmaz Prof. Dr., Murat Seyfi
		7	THE POLITICAL TRANSFORMATION OF CULTURAL PERFORMANCE IN THE DIGITAL AGE	Dr. Öğr. Üyesi Fatih CEYLAN Dr. Öğr. Üyesi DURSUN YILMAZ
		8	THE PUNCH PHENOMENON AND REAL-TIME MARKETING: A CASE STUDY OF IKEA	Dr. Öğr. Üyesi DURSUN YILMAZ Dr. Öğr. Üyesi Fatih CEYLAN
		9	A QUALITATIVE STUDY ON DAUGHTER-IN-LAW–MOTHER-IN-LAW COMMUNICATION	Öğr. Gör. OLGUN KÜÇÜK Doç. Dr. MEVLÜT CAN KOÇAK
		10	SOCIAL MEDIA PHENOMENA AND SUICIDE: THE CASE OF KÜBRA AYKUT	Öğr. Gör. OLGUN KÜÇÜK Doç. Dr. MEVLÜT CAN KOÇAK
		11	ADVERTISING, MODERNITY, AND IDENTITY: A BARTHESIAN SEMIOTIC ANALYSIS OF MODANISA'S "KENDIN OLMAK" CAMPAIGN	Asmaa Abushalhoub Prof. ŞAHİNDE YAVUZ

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HALL / SALON 2	**Doç Dr. Özer ÖZBOZDAĞLI**	1	KASTAMONU TARİHİ KENT DOKUSU İÇİNDE BİR SİVİL MİMARLIK ÖRNEĞİ ŞEYHOĞLU KONAĞI	GÜLSEN KIRBAŞ, M.A.
		2	A STUDY ON OCCUPATIONAL HEALTH AND SAFETY PERCEPTIONS OF INDIVIDUALS WORKING IN ARCHAEOLOGICAL EXCAVATIONS: THE CASE OF MUĞLA PROVINCE	Nurhilal ALİREİSOĞLU Prof. Dr. Hulusi DOĞAN Öğr. Gör. Meliha Yaren BERKTAŞ
		3	THE 1958 LEBANON EVENTS ACCORDING TO THE L'ORIENT NEWSPAPER	Dr., Öğr. Gör., Ece YÜKSEL
		4	KÜLTÜREL MİRASIN GELECEK KUŞAKLARA AKTARIMINDA DOLİCHE MİTHRAS TAPINAĞININ ROLÜ	Arkeolog, Sosyal Bilgiler Öğretmeni, Pelin ERKALE TANCAN Arkeolog, Gövher KULGEREL
		5	TRADE IN SALONICA ACCORDING TO THE BRITISH CONSULAR REPORT OF 1902	Doç Dr. Özer ÖZBOZDAĞLI
		6	1968 IN TÜRKIYE IN THE SHADOW OF THE COLD WAR: THE GLOBAL WAVE AND NATIONAL DYNAMICS	Öğr. Gör. Feryat BULUT
		7	THE POLITICAL TRAJECTORY OF THE BURSA SPEECH: AUTHENTICITY DEBATES, THE DEMOCRAT PARTY ERA, AND THE REINTERPRETATION OF ATATÜRK'S LEGACY BY YOUTH	Öğr. Gör. Feryat BULUT
		8	TUNA BULGAR DEVLETİ'NDE SİYASİ İSTİKRARSIZLIK VE DEĞİŞEN AİLE İKTİDARLARI: DURAKLAMA DÖNEMİ ÜZERİNE BİR İNCELEME	Araştırma Görevlisi Dr. Esra ÇAVDAR ÇAVUŞOĞLU

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HALL / SALON 3	**Bilim Uzmanı, İFFET AKSOY**	1	EĞİTİM VE YOZLAŞMA: AHLAKİ VE KÜLTÜREL BOYUT	Prof. Dr. İSMAİL AYDOĞAN Yüksek Lisans Öğrencisi MURAT AKINCI
		2	BİR FİZİKİ MEKÂN OLARAK OKULUN ÖĞRETMEN VE ÖĞRENCİ ÜZERİNDEKİ ETKİSİ	Prof. Dr. İSMAİL AYDOĞAN Yüksek Lisans Öğrencisi AYDAN AKINCI
		3	ÖĞRETMENLERİN ROL ÇEŞİTLİLİĞİ VE ETKİLERİ	Prof. Dr. İSMAİL AYDOĞAN Yüksek Lisans Öğrencisi Funda YAREN
		4	İSPANYA SOSYAL BİLGİLER DERS KİTAPLARINDA İSLAMİYET VE ENDÜLÜS DÖNEMİ ANLATISI	Öğr. Gör. Dr. MURAT YÜKSEL
		5	İSPANYA SOSYAL BİLGİLER DERS KİTAPLARINDA DEĞER EĞİTİMİNİN İÇERİK VE ETKİNLİKLER ÜZERİNDEN İNCELENMESİ	Öğr. Gör. Dr. MURAT YÜKSEL
		6	VELİ-ÖĞRETMEN İLETİŞİMİNDE ORTAYA ÇIKAN ENGELLER	Prof. Dr. Neslin İHTİYAROĞLU Yüksek Lisans Öğrencisi Pelin ACUN
		7	İŞİTME KAYIPLI ÇOCUKLARIN ERKEN MATEMATİK VE FEN BECERİLERİ	Doktora Öğrencisi, SEYİT IŞIKLI Doç. Dr., ELİF AKAY
		8	TÜRKİYE'DE İŞİTME KAYIPLI ÖĞRENCİLERE SUNULAN DESTEK EĞİTİM HİZMETLERİ: NİCELİKTEN NİTELİĞE GEÇİŞ ARAYIŞLARI	Doktora Öğrencisi, SEYİT IŞIKLI Doç. Dr., ELİF AKAY
		9	SINIF YÖNETİMİNDE DİJİTAL ARAÇLARIN PEDAGOJİK ANALİZİ PEDAGOJİK BİR DEĞERLENDİRME ÇERÇEVESİ	Bilim Uzmanı, İFFET AKSOY Uzman Öğretmen ONUR ÖMER DÜZGÜN
		10	EĞİTİMDE ANİMASYONLARIN ÖĞRENME ÜZERİNDEKİ ETKİSİ: YAPILMIŞ ÇALIŞMALAR ÜZERİNE BİR ANALİZ	Bilim Uzmanı, İFFET AKSOY Uzman Öğretmen ÖZGÜR CAM
		11	FEN ÖĞRETİMİNDE WEB 2.0 ve WEB 3.0 ARAÇLARI	Bilim Uzmanı, İFFET AKSOY Başöğretmen Özge PEKER TASASIZ
		12	ÖĞRETMENLİKTE ROL ÇATIŞMASI: ÖNCELİKLENDİRME SORUNU	Prof. Dr. İSMAİL AYDOĞAN Yüksek Lisans Öğrencisi NAZİFE DURSUN

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HALL / SALON 4	**Doç. Dr. Muhammet İbrahim AKYÜREK**	1	THE IMPACT OF PATERNALISTIC LEADERSHIP ON TEACHER COMMITMENT	Doç. Dr. Muhammet İbrahim AKYÜREK Bilgenur TAŞTAN
		2	THE IMPACT OF SHARED INSTRUCTIONAL LEADERSHIP ON TEACHER WELL-BEING	Doç. Dr. Muhammet İbrahim AKYÜREK Simge YAŞAR
		3	ACADEMIC CAREER OPPORTUNITIES FOR INTERNATIONAL STUDENTS IN TÜRKİYE: A DOCUMENT ANALYSIS WITHIN THE FRAMEWORK OF POLICY AND LEGISLATION	Assoc. Prof. Dr. MUHAMMET İBRAHİM AKYÜREK
		4	THE IMPACT OF INNOVATIVE SCHOOL LEADERSHIP ON TEACHER COMMITMENT	Doç. Dr. Muhammet İbrahim AKYÜREK Öğretmen Adayı, Elife DELİKTAŞ
		5	PUBLIC NATURE-BASED EDUCATION PRACTICES IN TÜRKIYE: THEORETICAL FOUNDATIONS AND CONTEMPORARY PERSPECTIVES	Assoc. Prof. Dr. Muhammet İbrahim Akyürek Emine Yıldız, Master's Student
		6	EDUCATION SYSTEMS AND MIGRATION DYNAMICS: A LONG-RUN COMPARATIVE ANALYSIS OF EDUCATIONAL EXPANSION AND INTERNATIONAL MOBILITY WITH A FOCUS ON TÜRKİYE	RESEARCH ASSISTANT HUSNIYE MERVE BINGOL TURKAN
		7	TÜRKİYE YÜZYILI MAARİF MODELİ BAĞLAMINDA SANAT VE ESTETİK EĞİTİMİNİN OKUL YÖNETİMİNE YANSIMALARI	Dr. YASİN DEMİRCİ Öğr. Gör. HAMİDE SOYSAL DEMİRCİ
		8	GELENEKSEL TÜRK EL SANATLARININ EĞİTİM KURUMLARINDA YAŞATILMASI: OKUL YÖNETİCİLERİNİN ROLÜ	Dr. YASİN DEMİRCİ Öğr. Gör. HAMİDE SOYSAL DEMİRCİ
		9	İŞİTME KAYIPLI ÖĞRENCİLERİN DİNLEDİĞİNİ ANLAMA BECERİLERİNİN İNCELENMESİ: SİSTEMATİK LİTERATÜR TARAMASI	Araş. Gör. GAMZE AK Prof. Dr. H. PELİN KARASU
		10	AN EXAMINATION OF SAMED BEHRENGİ'S WORK TITLED 'THE LITTLE BLACK FISH' IN TERMS OF STUDENT PROFILES IN THE TÜRKIYE CENTURY EDUCATION MODEL	Research Assistant Abdusselam KÖSE

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HALL / SALON 5	**Dr.Öğr.Üyesi Shanay Guliyeva Kabaoghlu**	1	EBEVEYNLERİ BOŞANMIŞ ORTAOKUL ÖĞRENCİLERİNİN SOSYAL BECERİLERİNİN VE DUYGUSAL REGÜLASYONLARININ İNCELENMESİ: BİR DURUM ÇALIŞMASI	Yüksek Lisans Öğrencisi BAŞAK TOYRAN GENÇ Prof. Dr. SEVDA ASLAN MUCUR
		2	EVALUATING WORKPLACE TRAUMA INTERVENTIONS IN AN ERA OF GLOBAL CRISES: FROM CRISIS RESPONSE TO TRAUMA GOVERNANCE	Asiye Yüksel AĞARGÜN
		3	AN ANALYSIS OF GENDER PERCEPTION IN THE REWRITING OF FAIRY TALES	Dr.Öğr.Üyesi Shanay Guliyeva Kabaoghlu YL. ÖğrencisiEzgi Ormanlı
		4	AN EXAMINATION OF THE LEVELS OF INTOLERANCE OF UNCERTAINTY IN SENIOR UNIVERSITY STUDENTS ACCORDING TO CERTAIN DEMOGRAPHIC VARIABLES	Psychological Counselor Sümeyye Hilal ÖCALAN Asst. Prof. Zehni KOÇ
		5	ÜNİVERSİTE ÖĞRENCİLERİNDE SOSYAL MEDYA BAĞIMLILIĞININ BEDEN ALGISI, ÖZGÜVEN, ERTELEME DAVRANIŞI VE DEPRESYON İLE İLİŞKİSİNİN İNCELENMESİ	Öğrenci: Melike Nur BULUT Öğrenci: Esra BARAN Öğrenci: Rümeysa Nur SOYLU Dr. Öğr. Üyesi: Süleyman AKÇIL
		6	GENDER ROLE ATTITUDES, RELATIONAL SELF-CONSTRUAL, AND RELATIONSHIP SATISFACTION IN YOUNG ADULTS: A REVIEW	Master's Student Ece Özgül Yamak Dr. Öğr. Üyesi Muhammet Fatih Yılmaz

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HALL / SALON 6	**Prof. Dr. RAMAZAN BİÇER**	1	MECELLE'NİN ORTADOĞU ÜLKELERİNDE UYGULANMASI	Yüksek Lisans Öğrencisi, MEDİNE ÇAKMAK
		2	RELIGIOUS AND INTELLECTUAL LIFE IN KASHGAR IN THE 19TH CENTURY	Prof. Dr. RAMAZAN BİÇER
		3	THE ROOT AND UNIQUE NATION OF THE BALKANS: THE BOSNIANS /BOSNIAK	Prof. Dr. Ramazan BİÇER
		4	HANEFÎ-MÂTÜRÎDÎ TEOLOJİSİNDE EHL-İ FETRET MESELESİNE ÖZGÜN BİR YAKLAŞIM -İBNÜ'L-HÜMÂM ÖRNEĞİ-	Prof. Dr., RECEP ÖNAL YL Öğrencisi, YUNUS ÇALIŞKAN
		5	KELAM EKOLLERİNİN İLAHÎ SIFAT VE FİİLLER BAĞLAMINDA KÖTÜLÜK PROBLEMİNE YAKLAŞIMLARI ÜZERİNE BİR ANALİZ	Prof. Dr., RECEP ÖNAL YL Öğrencisi, MİKAİL KARA
		6	RELIGION IN THE DIGITAL AGE: EXPERTISE, AUTHORITY, RISK	Dr. Ömer ACAR Dr. Murat GENCER
		7	IBN MĀLIK'S EVIDENCE THROUGH POETRY: THE EXAMPLE OF MECRÛRĀT	Dr. Yusuf ÇAKIR
		8	RELIGIOUS PLURALISM AND INTERRELIGIOUS DIALOGUE FROM THE PERSPECTIVE OF THE PHILOSOPHY OF RELIGION	Ülkü Koçak

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HALL / SALON 7	**Prof. Dr. Ali Osman ÖZTÜRK**	1	A EAR-CENTERED PEDAGOGİCAL MODEL IN CLASSICAL HARMONY EDUCATION: PROBLEM-BASED LEARNING FOR THE AURAL INTERNALIZATION OF I–IV–V DEGREE FUNCTIONS	Kutup Ata TUNCER Prof. Dr. Turan SAĞER
		2	THE EFFECTIVENESS OF SCHOOL PRINCIPALS' MANAGEMENT PROCESSES: AN EVALUATION BASED ON TEACHERS' DEMOGRAPHIC CHARACTERISTCS	Yüksek Lisans Öğrencisi, ADEM AZRAK Doç. Dr., GÖKÇE ÖZDEMİR
		3	ON THE PEDAGOGICAL AND LITERARY APPROACH OF WILFRIED BUCH	Prof. Dr. Ali Osman Öztürk (MA) İsmail Yusuf Kızılkaya
		4	PROF. DR. VURAL ÜLKÜ: A LIFE DEDICATED TO SERVING GERMAN STUDIES	Prof. Dr. Ali Osman ÖZTÜRK
		5	SINIF ÖĞRETMENLERİNİN MATEMATİK DERSLERİNDE SOMUT ÖĞRETİM MATERYALİ KULLANIMI ÜZERİNE GÖRÜŞLERİ VE UYGULAMALARI	AYSU YALÇIN DOÇ. DR. KEMAL ALTIPARMAK
		6	THE CURRICULAR DESIGN OF RENEWAL AND ENLIGHTENMENT-BASED LEARNING CITY: A NEEDS ANALYSIS	ECEM YÖRÜK Prof. Dr. OSMAN YILMAZ KARTAL

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HALL / SALON 8	**Prof. Dr. Yusuf Bayraktutan**	1	LABOR FORCE PARTICIPATION AND THE NEET PHENOMENON FROM A GENDER PERSPECTIVE: AN EVALUATION ON WOMEN	DR. SİNEM SOYHAN DOÇ. DR. SELÇUK GEMİCİOĞLU
		2	TÜRKİYE'DE PETROL FİYATLARININ OYNAKLIĞININ ANALİZİ	Öğrenci,SİDAR AYDIN Prof. Dr,MEHMET HALİS ÖZER
		3	INTERNATIONAL TRADE EFFECTS OF CARBON BORDER ADJUSTMENT MECHANISM: AN ANALYSIS FOR TURKIYE	Prof. Dr. Yusuf Bayraktutan Arş. Gör. Merve Acar
		4	İHRACATTA DÖVİZ KURUNUN ASİMETRİK ETKİSİ: SEÇİLMİŞ ÜLKELER VE TÜRKİYE İÇİN BİR ANALİZ	Doç. Dr. Naciye Tuba YILMAZ Prof. Dr. Yusuf BAYRAKTUTAN
		5	THE ROLE OF BLOCKCHAIN TECHNOLOGY IN THE GREEN DEAL PROCESS ON INTERNATIONAL TRADE AND FINANCIAL TRANSPARENCY	Master's Student ŞEYMANUR YILMAZ
		6	THE TRANSFORMATION OF THE STATE'S ROLE IN THE ECONOMY IN THE NEOLIBERAL ERA: A NEW REGULATORY STATE MODEL BASED ON BLOCKCHAIN TECHNOLOGY	Master's Student ŞEYMANUR YILMAZ
		7	SILK ROAD: HISTORICAL ORIGINS OF TRADE BETWEEN CENTRAL ASIAN COUNTRIES	Dr. Öğr. Üyesi YAHYA AYYILDIZ Doç. Dr. Murat ARISAL

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HALL / SALON 9	**Prof. Dr. Mehtap KAVURMACI**	1	SYPHILIS COINFECTION AMONG PEOPLE LIVING WITH HIV	Uzm. Dr. Muhammed Furkan KÜRKÇÜ
		2	CİLT KANSERİNDEN KORUNMA	Prof. Dr. Mehtap KAVURMACI
		3	THE EFFECT OF TOGETHER SUPPLEMENTATION OF BORON AND VITAMIN D ON SERUM INSULIN AND THYROID HORMONES IN RATS	Azra Mila Eryavuz Mehmet BAŞEĞMEZ Fahriye KAN İsmail KÜÇÜKKURT Abdullah ERYAVUZ
		4	FORMATION KINETICS OF CATIONIC LIPOSOMES: COARSE-GRAINED MOLECULAR DYNAMICS MODELING OF CHOLESTEROL AND STIGMASTEROL GRADIENT	Asst. Prof. Dr. OZAN KILIÇKAYA Asst. Prof. Dr. CENK YILDIZ
		5	BREAST CANCER BIOMARKER DISCOVERY VIA HYBRID MACHINE LEARNING AND A META-HEURISTIC ALGORITHM	MSc (c.) CEMRE ŞİMŞEK Assoc. Prof. MEHMET VAROL
		6	BENCHMARKING k-NN AND MICE FOR MISSING DATA IMPUTATION IN CLINICAL PREDICTIVE MODELS: A STRESS-TEST ANALYSIS UNDER MAR MECHANISM	Uzm. Dr. Furkan ŞAKİROĞLU Prof. Dr. Cemil ÇOLAK
		7	SURVIVAL ANALYSIS IN THE SHADOW OF OVERFITTING: DISCRIMINATION PERFORMANCES OF COX REGRESSION AND RANDOM SURVIVAL FORESTS	Uzm. Dr. Furkan ŞAKİROĞLU Prof. Dr. Cemil ÇOLAK

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HALL / SALON 10	**Assoc. Prof. Dr. Volkan KILIÇ**	1	SYSTEMATIC EVALUATION OF DEEP LEARNING AND HYBRID PIPELINES FOR DOPAMINE SIGNAL DECONVOLUTION IN ELECTROCHEMICAL MIXTURE ANALYSIS	BSc Student, Emir Ersel BİLGİÇ BSc Student, Ece AYFER Assoc. Prof. Dr. Volkan KILIÇ
		2	MACHINE-LEARNING-BASED PEAK DECONVOLUTION FOR DOPAMINE AND HYDROQUINONE QUANTIFICATION IN DIFFERENTIAL PULSE VOLTAMMETRY	BSc Student, Emir Ersel BİLGİÇ Assoc. Prof. Dr. Volkan KILIÇ
		3	MULTI-TASK 3D CT REPORT GENERATION WITH ORGAN-DISEASE AWARE FUSION AND STATE SPACE ENCODERS	BSc Student, Batu ARIBAKIR BSc Student, Emir ÇİL Res. Asst. Bengü FETİLER
		4	A BENCHMARK STUDY OF DEEP LEARNING ARCHITECTURES FOR MULTI-ORGAN SEGMENTATION IN CHEST CT VOLUMES	BSc Student, Batu ARIBAKIR BSc Student, Emir ÇİL Res. Asst. Bengü FETİLER
		5	MULTI-LABEL THORACIC DISEASE CLASSIFICATION IN CHEST CT VOLUMES: A COMPARATIVE STUDY OF MAMBA-BASED STATE SPACE MODELS	BSc Student, Emir ÇİL BSc Student, Batu ARIBAKIR Res. Asst. Bengü FETİLER
		6	PLEURA EFFUSION CLASSIFICATION IN CHEST CT VOLUMES: A COMPARATIVE STUDY OF CNN AND VISION TRANSFORMER	BSc Student, Emir ÇİL BSc Student, Batu ARIBAKIR Res. Asst. Bengü FETİLER
		7	PERSONALIZED AND SEASON-AWARE GLUCOSE PREDICTION USING WEARABLE SENSOR DATA WITH HYBRID KALMAN FILTER AND Q-LEARNING	BSc Student, Gözde Havin FİDAN Assoc. Prof. Dr. Volkan KILIÇ

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HALL / SALON 1	**Assoc. Prof. Dr. Soraya Mahmoudi**	1	THE EVOLUTION OF SILK ROAD TRADE ROUTES AND THEIR IMPACT ON AZERBAIJANI CULTURAL EXCHANGE	Prof. Dr. Elnur Mammadov, Dr. Aysel Karimova, Farid Huseynov
		2	MEDIEVAL ISLAMIC SCHOLARSHIP AND INTELLECTUAL DEVELOPMENTS IN AZERBAIJAN	Assoc. Prof. Dr. Nigar Aliyeva, Elvin Rahimov
		3	PERSIAN HISTORIOGRAPHY AND THE QAJAR DYNASTY'S RELATIONS WITH CENTRAL ASIA	Dr. Reza Ahmadi, Assoc. Prof. Dr. Soraya Mahmoudi
		4	SAFAVID ARCHITECTURAL INFLUENCES ON URBAN PLANNING IN 16TH-CENTURY IRAN	Fatemeh Karimi, Dr. Mohammad Jafari
		5	COLONIAL LEGACIES AND NATIONALIST HISTORIOGRAPHY IN POST-INDEPENDENCE ALGERIA	Prof. Dr. Karim Belkacem, Yacine Hadji
		6	BERBER CULTURAL RESISTANCE AND IDENTITY FORMATION UNDER OTTOMAN RULE IN ALGERIA	Dr. Nadia Zerhouni, Assoc. Prof. Dr. Samir Lounis, Amina Boualem
		7	BYZANTINE-GEORGIAN DIPLOMATIC RELATIONS AND THEIR IMPACT ON CAUCASUS GEOPOLITICS	Prof. Dr. Nino Tsiskarishvili, Dr. Levan Beridze
		8	SOVIET MODERNIZATION POLICIES AND THEIR EFFECTS ON GEORGIAN RURAL ECONOMIES	Assis. Prof. Dr. Tamar Kapanadze, Giorgi Gelashvili, Dr. Maka Chikvaidze

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HALL / SALON 2	**Prof. Dr. Chinedu Okonkwo,**	1	POSTCOLONIAL THEMES IN CHINUA ACHEBE'S NOVELS AND NIGERIAN IDENTITY FORMATION	Prof. Dr. Chinedu Okonkwo,
		2	ORAL TRADITION TRANSFORMATION IN CONTEMPORARY NIGERIAN POETRY	Assoc. Prof. Dr. Emeka Nwosu, Fatima Yusuf, Chukwudi Obi
		3	EPIC MOTIFS IN MAHMUD KASHGARI'S DIVANÜ LÜGAT-İT TÜRK AND KAZAKH LITERARY TRADITION	Dr. Aidana Kairatova, Assoc. Prof. Dr. Erlan Tursunov
		4	FEMINIST DISCOURSE IN MODERN KAZAKH PROSE POST-INDEPENDENCE	Gulnaz Abilkair, Dr. Zhanna Satybaldiyeva
		5	FRENCH COLONIAL INFLUENCE ON MODERN ALGERIAN ARABIC POETRY	Prof. Dr. Ahmed Zerhouni, Samia Belkacem
		6	BERBER ORAL EPICS AND IDENTITY POLITICS IN POSTCOLONIAL ALGERIAN LITERATURE	Dr. Lounis Hadji, Assoc. Prof. Dr. Fatima Mansouri, Karim Djemai
		7	SYMBOLISM IN VASHA-GIRASI GEORGIAN ROMANTIC POETRY AND NATIONAL AWAKENING	Prof. Dr. Nino Chikhradze, Dr. Levan Tsiklauri

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HALL / SALON 3	**Assis. Prof. Dr. Sergei Kuznetsov**	1	THE AFRICAN UBUNTU ETHICS AND CONTEMPORARY GLOBAL HUMAN RIGHTS DISCOURSE	Prof. Dr. Chukwuemeka Okoro, Tunde Adebayo
		2	EXISTENTIALISM IN POST-COLONIAL AFRICAN IDENTITY FORMATION: SARTRE VERSUS SENEGALESE THINKERS	Assoc. Prof. Dr. Fatima Yusuf, Emeka Nwosu
		3	NOMADIC EPISTEMOLOGY AND KNOWLEDGE PRODUCTION IN CENTRAL ASIAN PHILOSOPHY	Dr. Almaz Kairatov, Aidana Tursunova, Bekzat Omirbek
		4	ECOLOGICAL COSMOLOGY IN KAZAKH TRADITIONAL WORLDVIEWS AND MODERN ENVIRONMENTAL ETHICS	Zhanar Sarsenova, Prof. Dr. Erlan Baiserke
		5	ISLAMIC RATIONALISM VERSUS SUFISM IN ALGERIAN PHILOSOPHICAL TRADITIONS	Assoc. Prof. Dr. Larbi Hadji, Dr. Souad Belkacem
		6	DECOLONIAL EPISTEMOLOGY AND KNOWLEDGE DECOLONIZATION IN POST-INDEPENDENCE ALGERIA	Amine Zerhouni, Fatima Lounis
		7	HEIDEGGERIAN BEING-IN-THE-WORLD AND ORTHODOX THEOLOGY IN RUSSIAN PHILOSOPHY	Prof. Dr. Dmitry Ivanov, Dr. Elena Petrova
		8	DOSTOEVSKY'S POLYPHONIC NOVELS AND BAKHTINIAN DIALOGISM IN CONTEMPORARY ETHICS	Assis. Prof. Dr. Sergei Kuznetsov, Anna Volkova, Mikhail Orlov
		9	NIETZSCHEAN WILL-TO-POWER IN RUSSIAN SLAVOPHILISM AND EURASIANISM	Dr. Olga Smirnova, Viktor Kuzmin

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HALL / SALON 4	**Prof. Dr. Almaz Kulanov**	1	IMPACT OF OIL PRICE VOLATILITY ON ALGERIAN FISCAL SUSTAINABILITY AND ECONOMIC DIVERSIFICATION	Prof. Dr. Ahmed Belhadj, Dr. Fatima Zahraoui, Karim Lounis
		2	MICROFINANCE IMPACT ON RURAL WOMEN ENTREPRENEURSHIP IN ALGERIAN AGRICULTURAL SECTORS	Assoc. Prof. Dr. Nadia Bouabida, Samir Khelifa
		3	SUKUK ISLAMIC BOND MARKET DEVELOPMENT AND EGYPTIAN FISCAL FINANCING STRATEGIES	Dr. Mohamed El-Sayed, Yasser Ramadan
		4	EXCHANGE RATE PASS-THROUGH EFFECTS ON EGYPTIAN IMPORT INFLATION DYNAMICS	Assoc. Prof. Dr. Hala Abdel Aziz, Dr. Omar Khalil, Nour El-Din
		5	KAZAKHSTAN'S GREEN ENERGY TRANSITION AND ITS MACROECONOMIC IMPLICATIONS	Prof. Dr. Almaz Kulanov
		6	DIGITAL FINANCIAL INCLUSION STRATEGIES IN KAZAKHSTAN'S RURAL ECONOMIES	Dr. Aizhan Tulegenova, Bekzat Nurgaliyev, Assis. Prof. Dr. Madina Sarsenbayeva
		7	RUSSIA'S SANCTIONS EVASION STRATEGIES AND THEIR TRADE DIVERSIFICATION EFFECTS	Prof. Dr. Irina Petrova, Dr. Sergei Volkov
		8	CRYPTOCURRENCY ADOPTION DYNAMICS IN RUSSIA'S SHADOW ECONOMY SECTORS	Assoc. Prof. Dr. Dmitry Kuznetsov, Elena Morozova, Nikita Ivanov
		9	NATURAL GAS PRICING REFORMS AND RUSSIA'S LONG-TERM ENERGY EXPORT COMPETITIVENESS	Dr. Olga Smirnova, Prof. Dr. Alexei Fedorov, Maria Volkova
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HALL / SALON 5	**Dr. Leila Ahmadi**	1	DIGITAL TRANSFORMATION STRATEGIES FOR SUSTAINABLE GROWTH IN OMANI SMEs	Prof. Dr. Ahmed Al-Maskari, Dr. Fatima Al-Harthi
		2	BLOCKCHAIN APPLICATIONS IN SUPPLY CHAIN MANAGEMENT FOR OMANI LOGISTICS FIRMS	Assoc. Prof. Dr. Khalid Al-Belushi, Sara Al-Mahrooqi
		3	IMPACT OF ESG INVESTING ON FIRM PERFORMANCE IN TEHRAN STOCK EXCHANGE	Dr. Reza Hosseini, Assoc. Prof. Dr. Mina Sharifi
		4	SERVANT LEADERSHIP EFFECTS ON EMPLOYEE INNOVATION IN IRANIAN TECH STARTUPS	Mohammad Karimi, Dr. Leila Ahmadi
		5	CIRCULAR ECONOMY MODELS FOR PLASTIC WASTE MANAGEMENT IN IRANIAN MANUFACTURING	Prof. Dr. Ali Rezaei, Fatemeh Bahrami
		6	FINTECH DISRUPTION AND TRADITIONAL BANKING COMPETITIVENESS IN IRAN	Assis. Prof. Dr. Saeed Jafari, Neda Tavakoli
		7	AGILE PROJECT MANAGEMENT ADOPTION IN IRANIAN CONSTRUCTION INDUSTRY	Hassan Nourbakhsh, Dr. Parisa Ghasemi
		8	STRATEGIC ALLIANCES AND MARKET EXPANSION FOR RUSSIAN ENERGY FIRMS	Prof. Dr. Irina Petrova, Dr. Dmitry Volkov, Elena Kuznetsova

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HALL / SALON 6	**Assis. Prof. Dr. Jelena Milenkovic**	1	ASSESSING THE IMPACT OF TELEMEDICINE ON RURAL HEALTHCARE ACCESS IN GERMANY	Prof. Dr. Stefan Becker
		2	INVESTIGATING THE RELATIONSHIP BETWEEN AIR POLLUTION AND RESPIRATORY DISEASE PREVALENCE IN BERLIN	Prof. Dr. Stefan Becker Dr. Thomas Schneider Assis. Prof. Dr. Katharina Lehmann
		3	PREVALENCE AND SOCIOECONOMIC FACTORS IN MALARIA CONTROL EFFORTS AMONG ERITREAN SCHOOLCHILDREN	Dr. Selam Tesfay Mebrahtu Berhane
		4	MATERNAL AND NEONATAL HEALTH OUTCOMES AFTER COMMUNITY-BASED INTERVENTIONS IN ASMARA	Assoc. Prof. Dr. Abeba Tsehaye Dr. Semhar Fissehatsion
		5	CARDIOVASCULAR DISEASE PREVENTION STRATEGIES IN SERBIAN PRIMARY CARE: AN EPIDEMIOLOGICAL STUDY	Prof. Dr. Nikola Jovanovic Dr. Milena Petrovic Assis. Prof. Dr. Stefan Cvetkovic Dr. Danijela Markovic
		6	EVALUATING MENTAL HEALTH SERVICES CAPACITY AND ACCESSIBILITY IN SOUTHERN SERBIA	Assis. Prof. Dr. Jelena Milenkovic
		7	VACCINATION COVERAGE AND INFECTION RATES AMONG CHILDREN IN CAIRO SCHOOLS	Dr. Amal El-Gohary Prof. Dr. Mahmoud Hassan Assis. Prof. Dr. Salma Bakr
		8	BARRIERS TO WOMEN'S CANCER SCREENING PARTICIPATION IN EGYPT: A MULTICENTER STUDY	Assoc. Prof. Dr. Maha Fathy Dr. Nour El-Din Hassan
		9	HEALTH PROMOTION STRATEGIES FOR DIABETES PREVENTION AMONG EGYPTIAN ADOLESCENTS	Yasmine Elbia Dr. Mohamed Khalil Assis. Prof. Dr. Salma Bakr
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HALL / SALON 7	**Assoc. Prof. Dr. Mahsa Rahmani**	1	MOLECULAR CHARACTERIZATION AND ANTIBIOTIC RESISTANCE PATTERNS IN ESCHERICHIA COLI ISOLATED FROM DAIRY HERDS	Fariba Shafiei Prof. Dr. Amir Hosseini
		2	PREVALENCE OF TOXOPLASMOSIS IN SMALL RUMINANTS: EPIDEMIOLOGICAL STUDY IN KHORASAN REGION	Assoc. Prof. Dr. Mahsa Rahmani
		3	VETERINARY SURGICAL MANAGEMENT OF BONE FRACTURES IN WORKING DOGS: A CLINICAL STUDY	Dr. Marko Milosevic Prof. Dr. Jelena Stojanovic
		4	ZOONOTIC TRANSMISSION OF BRUCELLOSIS FROM LIVESTOCK TO HUMAN POPULATIONS IN NORTHERN SERBIA	Assis. Prof. Dr. Nikola Ilic Dr. Ana Petrovic
		5	EPIDEMIOLOGICAL ASSESSMENT OF CANINE PARVOVIRUS OUTBREAKS IN SOUTHWESTERN NIGERIA	Dr. Chinedu Okafor Amina Musa
		6	ASSESSMENT OF TICK-BORNE HEMOPARASITES IN DAIRY CATTLE AND THEIR IMPACT ON MILK PRODUCTIVITY	Dr. Fatima Lawal
		7	MOLECULAR TYPING AND ANTIBIOGRAM PROFILES OF METHICILLIN-RESISTANT STAPHYLOCOCCUS AUREUS IN POULTRY FARMS	Dr. Patrick O. Nwosu Dr. Chuka Eze Dr. Musa Ibrahim
		8	CLINICAL AND PATHOLOGICAL FINDINGS IN FELINE LOWER URINARY TRACT DISEASE: A HOSPITAL-BASED INVESTIGATION	Dr. Ifeoma Udoh

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HALL / SALON 8	**Dr. Giorgi Lomsadze**	1	ADVANCES IN THE SYNTHESIS OF FUNCTIONALIZED ORGANIC MOLECULES FOR PHARMACEUTICAL APPLICATIONS	Prof. Dr. Elchin Sultanov Assoc. Prof. Dr. Rzayev Ramil Afaq Rzayeva
		2	CATALYTIC PERFORMANCE IN INDUSTRIAL PROCESSES	Dr. Sevinj Aliyeva Sabina Jafarova Assoc. Prof. Imanov Elmar
		3	DEVELOPMENT AND APPLICATION OF METAL-ORGANIC FRAMEWORKS IN ENVIRONMENTAL REMEDIATION	Prof. Dr. Adriana Popescu Dr. Bogdan Iliescu
		4	KINETIC AND THERMODYNAMIC STUDY OF COPPER-CATALYZED ORGANIC TRANSFORMATION REACTIONS	Assoc. Prof. Dr. Dragos Marinescu Cristina Ghenea Dr. Nana Ezugbaia
		5	NOVEL APPROACHES TO BIOPOLYMER SYNTHESIS FOR MEDICAL DEVICE ENGINEERING	Dr. Giorgi Lomsadze
		6	ELECTROCHEMICAL METHODS FOR DETECTION OF HEAVY METAL IONS IN DRINKING WATER	Assoc. Prof. Dr. Tinatin Mchedlishvili Mariam Kapanadze
		7	CATALYTIC CONVERSION OF BIOMASS-DERIVED SUBSTRATES TO BIOFUELS USING TRANSITION METAL COMPLEXES	Dr. Alemu Getachew Solomon Tadesse

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HALL / SALON 9	**Prof. Dr. Vladimir Orlov**	1	DEVELOPMENT OF ADVANCED METAL MATRIX COMPOSITES FOR HIGH-TEMPERATURE APPLICATIONS	Prof. Dr. Nasim Kholov Dr. Shirin Sharipova
		2	INVESTIGATION OF NANOSTRUCTURED CERAMICS FOR PHOTOCATALYTIC WATER PURIFICATION	Dr. Mehrangez Davlatova Assoc. Prof. Dr. Rustam Kurbonov
		3	MULTISCALE MODELING OF MECHANICAL BEHAVIOR IN NANOCRYSTALLINE TITANIUM ALLOYS	Prof. Dr. Aarav Patel Dr. Kavita Sharma Assis. Prof. Dr. Rajesh Mehta
		4	EFFECT OF ULTRASONIC CONSOLIDATION ON THE JOINING OF DISSIMILAR METAL SHEETS	Assoc. Prof. Dr. Pranav Reddy Dr. Sunita Iyengar Dr. Maria Sokolova
		5	SYNTHESIS AND ELECTRICAL CHARACTERIZATION OF GRAPHENE-BASED FLEXIBLE ELECTRONICS	Prof. Dr. Vladimir Orlov
		6	ADVANCED COATING STRATEGIES FOR CORROSION RESISTANCE IN POWER PLANT STEELS	Assis. Prof. Dr. Ekaterina Miroshnichenko Dr. Alexey Kuznetsov Assoc. Prof. Dr. Igor Kolosov
		7	BIOCOMPATIBLE POLYMER NANOCOMPOSITES FOR TISSUE ENGINEERING APPLICATIONS	Prof. Dr. Shirin Hosseini Assoc. Prof. Dr. Farzad Abedini Dr. Mehdi Javadi
		8	INVESTIGATION OF FUNCTIONALIZED SILICA NANOPARTICLES FOR DRUG DELIVERY SYSTEMS	Dr. Leyla Kamali Assis. Prof. Dr. Sahar Farhadi Assoc. Prof. Dr. Milad Ghasemi

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HALL / SALON 10	**Prof. Dr. Noura Bouzid**	1	ENHANCED PROTEIN EXTRACTION FROM KAZAKHSTAN LEGUMES USING NOVEL ENZYMATIC METHODS	Prof. Dr. Ayanbek Akhmetov Dr. Nuraiya Tuleuova Kuralay Zhaksybek
		2	DEVELOPMENT AND CHARACTERIZATION OF SMART BIODEGRADABLE FOOD PACKAGING FILMS BASED ON KAZAKHSTANI STARCH SOURCES	Dr. Dauren Sarsembayev Assis. Prof. Dr. Zhanar Azhimetova
		3	INTEGRATED MICROALGAE CULTIVATION SYSTEMS FOR NUTRIENT-RICH FOOD PRODUCTION IN BANGLADESH	Assoc. Prof. Dr. Imran Hossain Dr. Nusrat Jahan Dr. Tanvir Rahman
		4	POST-HARVEST TECHNOLOGIES FOR REDUCING FRUIT AND VEGETABLE LOSS IN BANGLADESHI MARKETS	Dr. Rehana Parvin Assoc. Prof. Dr. Mahbub Alam Dr. Shamsul Haque
		5	APPLICATION OF 3D PRINTING IN DESIGNING FUNCTIONAL FOODS WITH TAILORED TEXTURE IN SINGAPORE	Prof. Dr. Wei Chun Ng Dr. Fiona Low Assoc. Prof. Dr. Marcus Tan
		6	DATA-DRIVEN OPTIMIZATION IN INDUSTRIAL FERMENTATION FOR SUSTAINABLE FOOD INGREDIENTS	Dr. Adeline Lee Assis. Prof. Dr. Samuel Chua Assoc. Prof. Dr. Joseph Goh
		7	DEVELOPMENT OF NATURAL ANTIOXIDANT SYSTEMS TO PRESERVE QUALITY IN ALGERIAN OLIVE OIL	Prof. Dr. Noura Bouzid Assis. Prof. Dr. Hakim Benali
		8	MODEL-BASED DESIGN OF NOVEL EMULSION SYSTEMS FOR DAIRY ALTERNATIVES IN ALGERIAN FOOD INDUSTRY	Dr. Yacine Khellaf Assoc. Prof. Dr. Houria Touati Dr. Samir Fekhara

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HALL / SALON 1	**Assoc. Prof. Dr. Volkan KILIÇ**	1	Q-FORMER BRIDGED VIT–GPT-2: A UNIFIED TRANSFORMER FRAMEWORK FOR VIDEO CAPTIONING VIA VISION-LANGUAGE ALIGNMENT	MSc Student Murat KILCI Res. Asst. Bengü FETİLER Assoc. Prof. Volkan KILIÇ
		2	LEVERAGİNG Q-FORMER ALIGNMENT IN VIT–GPT-2: A STREAMLINED APPROACH FOR IMAGE CAPTIONING	MSc Student Murat KILCI Res. Asst. Bengü FETİLER Assoc. Prof. Volkan KILIÇ
		3	UROSCAN: A LIGHTWEIGHT DEEP LEARNING FRAMEWORK FOR REAL-TIME COLORIMETRIC URINALYSIS ON SMARTPHONES	BSc Student, Emir ÇİL Assoc. Prof. Dr. Volkan KILIÇ
		4	CELL MORPHOLOGY STUDIO: A DESKTOP PLATFORM FOR AUTOMATED NEUROTOXICITY ASSESSMENT AND MORPHOLOGICAL REPORTING	BSc. Student, Eren Bilal YILDIZ BSc. Student, Atalay ŞAHAN Assoc. Prof. Dr. Volkan KILIÇ
		5	ViT-UNet-CBAM: A HYBRID TRANSFORMER - CONVOLUYION ARCHITECTURE FOR MORPHOLOGICAL SEGMENTATION OF SH-SY5Y NEUROBLASTOMA CELLS	BSc. Student, Eren Bilal YILDIZ BSc. Student, Atalay ŞAHAN Assoc. Prof. Dr. Volkan KILIÇ
		6	DEEP LEARNING–BASED NONLINEAR PEAK DECONVOLUTION FOR DOPAMINE QUANTIFICATION FROM MIXED ELECTROCHEMICAL SIGNALS	BSc Student, Ece AYFER BSc Student, Emir Ersel BİLGİÇ Assoc. Prof. Dr. Volkan KILIÇ
		7	NONLINEAR PEAK DECONVOLUTION OF MIXED ELECTROCHEMICAL SIGNALS USING MACHINE LEARNING FOR ACCURATE DOPAMINE QUANTIFICATION	BSc Student, Ece AYFER BSc Student, Emir Ersel BİLGİÇ Assoc. Prof. Dr. Volkan KILIÇ
		8	A TWO-STAGE GRADIENT BOOSTING PIPELINE FOR VOLTAMMETRIC SIGNAL DECONVOLUTION AND DOPAMINE CONCENTRATION CLASSIFICATION IN TERNARY ELECTROCHEMICAL MIXTURES	BSc Student, Emir Ersel BİLGİÇ BSc Student, Ece AYFER Assoc. Prof. Dr. Volkan KILIÇ

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HALL / SALON 2	**Prof. Dr., Elif Çağda Kandemir**	1	ASSESSMENT OF LIQUEFACTION POTENTIAL BASED ON SPT DATA IN KARSIYAKA, IZMIR	Asst. Prof. ESRA GÜNERİ Master's Student BATUHAN SERKAN TEKEOĞLU
		2	KAHRAMANMARAŞ DEPREMLERİ	Dr. Öğr. Üyesi ESRA GÜNERİ Lisans Öğrencisi EYLÜL DURMUŞ
		3	DOĞRUSAL OLMAYAN YAPI ANALIZINDE DEPREM ÖLÇEKLENDIRME FAKTÖRLERININ SONUÇLAR ÜZERINDEKI ETKILERI	AYŞE ÇELİK Doç. Dr. CENGİZHAN DURUCAN
		4	INVESTIGATION OF EARTHQUAKE GROUND MOTIONS RECORDED ON DIFFERENT SITE CONDITIONS	Prof. Dr., Elif Çağda Kandemir
		5	EVALUATION OF EARTHQUAKE GROUND MOTIONS ON DIFFERENT SOILS USING VARIOUS SIGNAL DECOMPOSITION FUNCTIONS	Prof. Dr., Elif Çağda Kandemir
		6	TEK PİLONLU BETONARME KABLO ASKILI BİR KÖPRÜDE KİRİŞ DERİNLİĞİNİN DÜŞEY YER DEĞİŞTİRME DAVRANIŞI ÜZERİNE ETKİSİ	Öğr. Gör., Şadiye Defne AKBAŞ Prof. Dr., Mehmet ÜLKER

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HALL / SALON 3	**Dr. Öğr. Üyesi Kelimetullah GEÇER**	1	PHYLOGENETIC COMPARISONS OF FISH BELONGING TO THE GENUS CAPOTEA IN TURNASUYU STREAM (ORDU, TÜRKİYE)	Assoc. Prof. Dr. Serdar YEDİER Merve KURD Assoc. Prof. Dr. Seda KONTAŞ YALÇINKAYA Prof. Dr. Derya BOSTANCI
		2	CONTROLLED RELEASE BEHAVIOR OF VIBURNUM OPULUS L. AND VACCINIUM MYRTILLUS L. LOADED CHITOSAN-COATED PCL NANOPARTICLES	Master of Science Student, İrem AKYOL Asst. Prof. Dr. Neslihan GÜLEÇ
		3	PRUNUS CERASİFERA MEYVESİNDE (ROSACEAE) BAZI ANTİOKSİDAN	Dr. Öğr. Üyesi Kelimetullah GEÇER Doç. Dr. Mustafa BİLİCİ
		4	SYNTHESIS OF NANOPARTICLES FROM FUSARIUM SPECIES AND THEIR APPLICATIONS	PhD student Nedaa M.M. Tanina Prof. Dr. Canan Can Prof. DR. Feyza N. KAFADAR

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HALL / SALON 4	**Prof. Dr. Mehmet Direk**	1	ANNUAL CHANGES IN TRAFFIC ACCIDENTS AND EVALUATION OF RISK FACTORS IN KONYA PROVINCE	Öğr. Gör. Tuba KALDIRIM Prof. Dr. Abdullah Engin ÖZÇELİK
		2	STRUCTURAL OPTIMIZATION AND PERFORMANCE ANALYSIS OF SLIM RELAY DESIGN	Yüksek Lisans Öğrencisi , Makine Mühendisi ,AYÇA KURT Dr.Öğr.Üyesi, İSMAİL TEMİZ
		3	DESIGN AND STRUCTURAL VIBRATIONAL ANALYSIS OF A WINDOW CLEANING DRONE USING FINITE ELEMENT METHOD	Mekatronik Mühendisi AZİZ UZMAN Doç. Dr. EMİR ESİM
		4	KÜÇÜK İNSANSIZ HAVA ARAÇLARI İÇİN KARBON/EPOKSİ KOMPOZİT MALZEME SEÇİMİ	ÜNAL YILMAZ PROF. DR. FİGEN BALO
		5	SABİT KANATLI MİNİ İHA SİSTEMLERİNİN AHP YAKLAŞIMIYLA PERFORMANS DEĞERLENDİRMESİ	ÜNAL YILMAZ PROF. DR. FİGEN BALO
		6	DESIGN AND PROTOTYPE FABRICATION OF A COST EFFECTIVE SUBSTRATE CLEANER FOR LAB SCALE SEMICONDUCTOR PROCESSES	Eng. FAHRETTIN ATIK Eng. MEHMET SUREYYA ARI R.A. Eng. EFE KARAAVCI R.A. M.Sc. Müh. MEHMET IZZEDDIN GULER Prof. Dr. TAMILA ANUTGAN Prof. Dr. MUSTAFA ANUTGAN
		7	HAVA KAYNAKLI ISI POMPASI TEST SİSTEMİNİN LABORATUVAR ISITILMASI İÇİN KURULUMU VE PERFORMANSININ DEĞERLENDİRİLMESİ	Prof. Dr. Mehmet Direk
		8	SERA İKLİMLENDİRME İÇİN GÜNEŞ ENERJİSİ TEKNOLOJİLERİ	Dr. Hasan Kaan KÜÇÜKERDEM Prof.Dr. Hasan Hüseyin ÖZTÜRK
		9	SICAK VE KURAK İKLİMLERDE SERA TASARIMI	Prof.Dr. Hasan Hüseyin ÖZTÜRK Dr. Hasan Kaan KÜÇÜKERDEM

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HALL / SALON 5	**Berna ÖZGÜR**	1	A DATA-DRIVEN APPROACH FOR FORECASTING AIRCRAFT EMISSIONS BASED ON LTO OPERATIONS	Zeynep İrem ÖZFİDAN Doç. Dr. Beyzanur ÇAYIR ERVURAL
		2	KATI YAKITLI BACALARDA YALITIMIN BACA PERFORMANSINA ETKİSİNİN SİMÜLASYONLA ANALİZİ; AFYON ÖRNEĞİ	Öğr.Gör. Ahmet KARAHAN Prof.Dr. Figen BALO
		3	FARKLI AÇILARDA GALVANİZ BORULARLA TASARLANAN BACA MEKANİZMALARININ PERFORMANS ANALİZİ	Öğr.Gör. Ahmet KARAHAN Prof.Dr. Figen BALO
		4	BETON VE YÜN ESASLI MALZEME KOMBİNASYONLARIYLA TASARLANMIŞ BİR KÖY OKULU BİNASI İÇİN ENERJİ PERFORMANSININ FİZİBİLİTESİ	Berna ÖZGÜR Prof. Dr. Figen BALO
		5	AHŞAP YAPI VE ATIK KÖKENLİ DOĞAL YALITIM MALZEMELERİNİN EMİSYON PERFORMANSININ SİMÜLASYON ANALİZİ	Berna ÖZGÜR Prof. Dr. Figen BALO
		6	MULTIDISCIPLINARY INTEGRATION AND STRATEGIC MANAGEMENT OF DIGITAL TWIN TECHNOLOGIES	Öğretim Görevlisi Dr. OSMAN ÖZDEMİR Öğretim Görevlisi Dr. MERVE ALADAĞ
		7	A NATURAL SHIELD AGAINST AIR CONDITIONING LOAD: STRUCTURAL AND THERMAL PERFORMANCE OF PHASE-CHANGING MATERIAL COMPOSITES	Öğretim Görevlisi Dr. MERVE ALADAĞ Öğretim Görevlisi Dr. OSMAN ÖZDEMİR
		8	INVESTIGATION OF THE INTERFACE PROPERTIES OF CdS/METAL (Au, Ag, Cu) JUNCTIONS	Res. Assist. Büşra ATA Assoc. Prof. Dr. Murat ÇALIŞKAN
		9	AKIM YAYMA TABAKASI OLARAK KATMANLI WO 3 /Ag/WO 3 FİLMLERİN MAGNETRON SAÇTIRMA YÖNTEMİYLE KAPLANMASI	Öğretim Görevlisi Dr. Ahmet Emre KASAPOĞLU
		10	KOBALT BAZLI OKSİT KOMPOZİTLERİN ADSORPSİYON PERFORMANSLARININ İNCELENMESİ	Doç.Dr., Mehmet BUĞDAYCI Doç.Dr.,Özlem TUNA Prof.Dr.,Pelin DEMİRÇİVİ BARAN
		11	MANGANEZ BAZLI OKSİT KOMPOZİTLERİN FOTOKATALİTİK GİDERİM PERFORMANSLARININ İNCELENMESİ	Doç.Dr., Mehmet BUĞDAYCI Doç.Dr.,Özlem TUNA Doç.Dr.,Şeyda KORKMAZ

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HALL / SALON 6	**Prof. Dr. BAŞAK HANEDAN**	1	MYCOPLASMA BOVIS INFECTION IN CATTLE	Prof. Dr. ALİ BİLGİLİ Prof. Dr. BAŞAK HANEDAN
		2	BAZI MISIR GENOTİPLERİNİN SİVAS EKOLOJİK KOŞULLARINDA AGRO-MORFOLOJİK VE KALİTE ÖZELLİKLERİNİN ORTAYA KONULMASI	Cansu GÜRCÜ Ömer SÖZEN
		3	FİTAZ UYGULAMASININ KETEN (Linum usitatissimum L.) TOHUMLARINDA ÇİMLENME VE KÖK GELİŞİMİ ÜZERİNE ETKİLERİ	YL. Öğrencisi SEDA ŞAHİN Prof. Dr. HÜLYA TORUN
		4	PLANT PROTEINS: REDUCTION OF ANTINUTRITIONAL FACTORS AND ENHANCEMENT OF PROTEIN QUALITY	Dr. DOĞA PEKSEVER Prof. Dr. Sedef Nehir El
		5	THE NUTRITIONAL POTENTIAL OF A FOOD LIES NOT ON THE LABEL, BUT IN ITS POST DIGESTIVE EFFECTS	Prof. Dr. SEDEF NEHİR EL

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HALL / SALON 7	**Doç. Dr. Hatice Aylin KARAHAN TOPRAKÇI**	1	ARTIRILMIŞ GERÇEKLİK TABANLI OYUNLAŞTIRILMIŞ UÇAK GÖVDE PARÇALARI EĞİTİMİ İÇİN MOBİL UYGULAMA GELİŞTİRME	Tahir Çağrı ÖZBEN Dr. Öğr. Üyesi Osman GÜLER Dr. Öğr. Üyesi Mustafa TEKE
		2	A HYBRID DIFFERENTIABLE SURROGATE AND BIASED-RANDOMIZED OPTIMIZATION FRAMEWORK FOR NON-SMOOTH AND NONCONVEX PROBLEMS	Asst. Prof. Dr., Dinçer ATASOY
		3	NON-SMOOTH OPTIMIZATION AND HEURISTIC ALGORITHMS: THEORETICAL FOUNDATIONS AND ADVANCED APPLICATIONS	Asst. Prof. Dr., Dinçer ATASOY
		4	TRAFO SEKTÖRÜNE UYARLANMIŞ DAVRANIŞ, ÖLÇEK VE FİYAT BOYUTLU BİR B2B SEGMENTASYON MODELİ: LRFCPG	Ahmet GÜRGAŞİN
		5	ENERJİ SEKTÖRÜNDE ÖRGÜTSEL ZEKA İÇİN YENİ BİR MİMARİ ÇERÇEVE: DATAOPS TEMELLİ KARAR ZEKASI	Ahmet GÜRGAŞİN
		6	HAZELNUT SHELL FILLED SUSTAINABLE POLY(LACTIC ACID) COMPOSITES	Ghufran Mudhafar Abdulrazaq Doç. Dr. Hatice Aylin KARAHAN TOPRAKÇI
		7	POLYMER BASED PRESSURE SENSORS	Doç. Dr. Hatice Aylin KARAHAN TOPRAKÇI Doç. Dr. Ozan TOPRAKÇI

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HALL / SALON 8	**Asst. Prof. Dr. Neslihan AYDIN YÖNET**	1	RECONSTRUCTING CONTINUITY: FAÇADE DESIGN, URBAN DENSITY, AND MEMORY IN POST-WAR BEIRUT	Tanya HAQI Abdullah ALOBAIDI Asst. Prof. Dr. Neslihan AYDIN YÖNET
		2	YENİ DÖNEMDE İSLAM BAHÇELERİ: GELENEKSEL ESTETİĞİN MODERN ŞEKİLLERİ VE KULLANIM YÖNTEMLERİ	Prof. Dr., Hilal TURGUT Dr. Öğr. Üyesi, Aysel YAVUZ Prof. Dr., Habibe ACAR
		3	HİBRİT KAMUSAL MEKÂNLAR: GENÇLERİN DİJİTAL KÜLTÜRLE ŞEKİLLENEN KENTSEL MEKÂN DENEYİMİ	Dr. Öğr. Üyesi, Aysel YAVUZ Prof. Dr., Hilal TURGUT Prof. Dr., Habibe ACAR
		4	THE PRODUCTION OF SPATIAL MEANING: AN EXAMINATION THROUGH BASIC DESIGN ELEMENTS AND DESIGN PRINCIPLES IN LANDSCAPE ARCHITECTURE	Prof. Dr. SERAP YILMAZ Res.Asst. Nida KURAK SEZGİN
		5	THE SOCIAL GENDER OF SPACE: AN ANALYSIS OF THE FEMALE EXPERIENCE IN PEARL S. BUCK'S NOVEL THE MOTHER WITHIN THE CONTEXT OF FEMINIST SPACE THEORY	Res.Asst., Nida KURAK SEZGİN, Prof.Dr., Serap YILMAZ
		6	NANO İLAVELİ POLİÜRETAN KÖPÜK KATMANININ AHŞAP KOMPOZİT SANDVİÇ PANELLERİN FİZİKSEL ÖZELLİKLERİ ÜZERİNE ETKİSİ	Pelinsu Melisa AYDOĞDU Doç. Dr. Arif Çağlar KONUKÇU

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HALL / SALON 1	**Prof. Dr. Timur Zharkenov**	1	APPLICATION OF FLEXIBLE ELECTRONICS FOR WEARABLE HEALTH MONITORING SYSTEMS	Nurlan Sarsembayev Dr. Akmaral Yessimova
		2	DESIGN AND PERFORMANCE ANALYSIS OF ENERGY-EFFICIENT INTERNET OF THINGS (IOT) SENSOR NODES FOR SMART AGRICULTURE	Prof. Dr. Timur Zharkenov
		3	DEVELOPMENT OF LOW-POWER VLSI ARCHITECTURES FOR AI-ENABLED EDGE COMPUTING DEVICES	Dr. Saifur Rahman Assoc. Prof. Dr. Farhana Parvin Md. Moniruzzaman
		4	INTELLIGENT SMART GRID CONTROL USING DEEP LEARNING ALGORITHMS FOR POWER DISTRIBUTION OPTIMIZATION	Prof. Dr. Nasima Akter Assis. Prof. Dr. Tarik Hasan
		5	RECONFIGURABLE ANTENNA DESIGN FOR MILLIMETER WAVE 5G COMMUNICATION APPLICATIONS	Assoc. Prof. Dr. Alvin Lim Kai Yee Tan Rachel Liew
		6	SILICON PHOTONICS INTEGRATED CIRCUITS FOR ULTRA-FAST OPTICAL TELECOM NETWORKS	Dr. Wei Ming Tan Prof. Dr. Siang Hwa Tan
		7	DEVELOPMENT OF GRAPHENE-BASED NANOELECTRONIC DEVICES FOR NEXT-GENERATION SENSORS	Dr. Rania Bouzid Prof. Dr. Mourad Benamara Assoc. Prof. Dr. Samir Bensaid Farida Lazreg Dr. Ahmed Yacine

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HALL / SALON 2	**Assis. Prof. Dr. Lilit Grigoryan**	1	INNOVATIVE STRATEGIES IN THE SEISMIC DESIGN OF URBAN INFRASTRUCTURE IN YEREVAN	Prof. Dr. Arman Hakobyan Assis. Prof. Dr. Lilit Grigoryan
		2	DEVELOPMENT OF ECO-FRIENDLY CONCRETE COMPOSITES WITH LOCALLY SOURCED MATERIALS	Prof. Dr. Arman Hakobyan Dr. Ani Babayan Prof. Dr. Gevorg Arakelyan Assis. Prof. Dr. Sargis Hunanyan
		3	INTELLIGENT FLOOD MANAGEMENT SYSTEMS FOR URBAN CENTERS IN LAHORE	Prof. Dr. Ahmad Ali Assis. Prof. Dr. Maryam Raza Muhammad Ayub
		4	ADVANCED OPTIMIZATION OF WIND ENERGY INFRASTRUCTURE IN COASTAL PAKISTAN	Dr. Samina Hassan Prof. Dr. Tariq Mahmood Assis. Prof. Dr. Waleed Akhtar
		5	APPLICATION OF NANOMATERIALS IN WATER PURIFICATION SYSTEMS FOR KARACHI	Dr. Hina Qureshi Prof. Dr. Faisal Ahmed Assis. Prof. Dr. Usman Khan
		6	SUSTAINABLE DESIGN OF EMBANKMENT DAMS UNDER ARID CLIMATE CONDITIONS	Dr. Salim Al-Harthy Prof. Dr. Fahad Al-Shidhani
		7	PERFORMANCE EVALUATION OF SMART TRAFFIC MANAGEMENT TECHNOLOGIES IN MUSCAT	Assis. Prof. Dr. Aisha Al-Balushi Dr. Sami Alkindi
		8	DEVELOPING SOLAR-POWERED MICROGRID SOLUTIONS FOR REMOTE COMMUNITIES IN OMAN	Prof. Dr. Hamood Al-Rawahi Dr. Nasser Al-Saadi

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HALL / SALON 3	**Dr. Suresh Chandrasekhar**	1	APPLICATION OF AUTOMORPHISM GROUPS IN GRAPH THEORY AND THEIR IMPLICATIONS FOR NETWORK STRUCTURES	Assis. Prof. Dr. Aram Karapetyan
		2	RECENT ADVANCES IN PARTIAL DIFFERENTIAL EQUATIONS: ANALYSIS AND COMPUTATION	Dr. Narine Melikyan
		3	ASYMPTOTIC ANALYSIS OF NONLINEAR DYNAMICAL SYSTEMS IN PHYSICAL MODELLING	Dr. Lilit Harutyunyan Prof. Dr. Vahan Manukyan
		4	RECENT METHODS IN ALGEBRAIC NUMBER THEORY: APPLICATIONS TO CRYPTOGRAPHY	Prof. Dr. Priya Deshpande Dr. Nikhil Raman Prof. Dr. Anjali R. Mehta
		5	ADVANCES IN MACHINE LEARNING APPROACHES FOR MATHEMATICAL OPTIMIZATION	Dr. Suresh Chandrasekhar
		6	MODELING SPATIOTEMPORAL PHENOMENA WITH PARTIAL DIFFERENTIAL EQUATIONS IN ENVIRONMENTAL SCIENCES	Prof. Dr. Avinash Kumar Dr. Sneha Patil Assis. Prof. Dr. Kartik Sharma Dr. Deepak Joshi
		7	STABILITY AND SPECTRAL ANALYSIS OF NONLINEAR OPERATORS IN FUNCTION SPACES	Dr. Aisha Al-Harthy Assis. Prof. Dr. Ahmed Salim
		8	FUZZY LOGIC SYSTEMS AND THEIR APPLICATION IN UNCERTAIN REAL-WORLD DATA MODELLING	Assoc. Prof. Dr. Waleed Al-Lamki Dr. Sara Al-Rawahi

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HALL / SALON 4	**Dr. Yasuyuki Konishi,**	1	COMPARISON OF PHYSICO-CHEMICAL PROPERTIES AND FATTY ACID COMPOSTION OF ELATERIOSPERMUM TAPOS (BUAH PERAH), PALM OIL AND SOYBEAN OIL	Siti Hamidah, Lee Nian Yian, Azizi Mohd
		2	PHYSICAL PROPERTIES AND STABILITY OF EMULSIONS AS AFFECTED BY NATIVE AND MODIFIED YAM STARCHES	Nor Hayati Ibrahim, Shamini Nair Achudan
		3	OPTIMIZATION OF EXTRACTION OF PHENOLIC COMPOUNDS FROM AVICENNIA MARINA (FORSSK.)VIERH USING RESPONSE SURFACE METHODOLOGY	V.Bharathi, Jamila Patterson, R.Rajendiran
		4	CHEMICAL AND BIOLOGICAL PROPERTIES OF LOCAL COWPEA SEED PROTEIN GROWN IN GIZAN REGION	Assoc. Prof. Abdelatief S. H. El-Jasser
		5	INTERACTION EFFECT OF DGAT1 AND COMPOSITE GENOTYPE OF BETA-KAPPA CASEIN ON ECONOMIC MILK PRODUCTION TRAITS IN CROSSBRED HOLSTEIN	A. Molee, N. Duanghaklang, P. Mernkrathoke
		6	REVEA LING CASEIN MICELLE DISPERSION UNDER VARIOUS RANGES OF NACL: EVOLUTION OF PARTICLES SIZE AND STRUCTURE	Raza Hussain, Claire Gaiani, Joël Scher
		7	PROCESS DEVELOPMENT OF SAFE AND READY-TO-EAT RAW OYSTER MEAT BY IRRADIATION TECHNOLOGY	Pattama Ratana-Arporn, Pongtep Wilaipun

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HALL / SALON 5	**Assoc. Prof. Dr. Suman Sharma**	1	SHED SNAKE SKINS: A NATURAL RESOURCE FOR BIOMIMETIC MEMBRANES – ADVANCING PERMEATION STUDIES AND DRUG DELIVERY APPLICATIONS	Emma Grigoryan, Ashot Khachatryan, Karapet Flora Avjyan Savchenko,
		2	PRECISION DRUG DELIVERY OF GLIBENCLAMIDE: EXPLORING THE IMPACT OF POLYVINYL PYRROLIDONE AND ETHYL CELLULOSE CONCENTRATION ON RELEASE PROFILES AND KINETICS	Dr. Stepan Arakelova, Assis. Prof. Dr. Lilia Arsenyan
		3	INVESTIGATING THE EFFECTS OF AMINOPOLYETHER ON 18F-FDG PROPERTIES AND ITS IMPLICATIONS FOR PET IMAGING APPLICATIONS	Dr. Sunil Kamboj, Dr. Vipin Saini, Lecture GauravBala,
		4	ENDOPHYTES AS A NEW SOURCE OF BIOACTIVE COMPOUNDS: ISOLATION AND IDENTIFICATION OF FIBRINOLYTIC PROTEASE-PRODUCING FUNGI FROM HIBISCUS LEAVES	Assoc. Prof. Dr. Suman Sharma
		5	FROM CONCEPT TO REALITY: THE DESIGN AND DEVELOPMENT OF A MECHANICAL FORCE GAUGE FOR SQUARE WATERMELON MOLDING	Dr. Bedi Neayti Singh Phd. Candidate Balvinder Thakur,
		6	THE ROLE OF EXERCISE IN IMPROVING SEXUAL PERFORMANCE AND SEMEN QUALITY OF SAHIWAL BULLS: A PRACTICAL GUIDE FOR BREEDERS	Assis. Prof. Dr. Rathapon Dr.Sorrachaitawatwong, Nardauma Pouthai
		7	INVESTIGATING THE IMPACT OF DIETARY HERBAL SEED SUPPLEMENTATION ON CARCASS CHARACTERISTICS, IMMUNE RESPONSE, AND ANTIOXIDANT STATUS OF BROILER CHICKENS	Sirijit Tipchuwong, Chayanid Asasutjarit

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HALL / SALON 6	**Prof. Dr. Ezenwa Chinenye Amanamba**	1	EVALUATION OF URBAN LAND DEVELOPMENT DIRECTION İN KABUL CITY, AFGHANISTAN	Ahmad Sharif Ahmadi Yoshitaka Kajita
		2	INFLUENCE OF PLACE IDENTITY ON WALKABILITY: A COMPARATIVE STUDY BETWEEN TWO MIXED USED STREETS CHAHARBAGH ST. ISFAHAN, IRAN AND DEREBOYU ST. LEFKOSA, NORTH CYPRUS	Assis. Prof. Dr. R. Rafiemanzelat
		3	RENEWED URBAN WATERFRONT: SPATIAL CONDITIONS OF A CONTEMPORARY URBAN SPACE TYPOLOGY	Assis. Prof. Dr. Beate Niemann, Fabian Pramel
		4	URBAN ECOLOGICAL INTERACTION: AIR, WATER, LIGHT AND NEW TRANSIT AT THE HUMAN SCALE OF BARCELONA'S SUPERILLES	Philip Speranza
		5	PERFORMANCE EVALUATION OF A 'PRIORITY-CONTROLLED' INTERSECTION CONVERTED TO SIGNAL-CONTROLLED INTERSECTION	Prof. Dr. Ezenwa Chinenye Amanamba
		6	DISCUSSION ABOUT FREQUENT ADJUSTMENT OF URBAN MASTER PLANNING İN CHINA: A CASE STUDY OF CHANGSHOU DISTRICT, CHONGQING CITY	Sun Ailu Zhao Wanmin
		7	HYBRID LIVING: EMERGING OUT OF THE CRISES AND DIVISIONS	Yiorgos Hadjichristou
		8	CORPORATE GOVERNANCE STRUCTURES AND OVERLAPPING DIRECTORATES IN THE CZECH REPUBLIC	Assis. Prof. Dr. Ondřej Nowak

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HALL / SALON 7	**Dr. Gunay Rasulova**	1	IMPACT OF MIDWIFERY-LED CARE ON MATERNAL OUTCOMES IN AZERBAIJANI RURAL COMMUNITIES	Prof. Dr. Leyla Mammadova Mehriban Aliyeva
		2	ASSESSING NUTRITIONAL KNOWLEDGE AND PRACTICES AMONG PREGNANT WOMEN IN BAKU	Dr. Gunay Rasulova
		3	EFFECTIVENESS OF CONTINUING EDUCATION PROGRAMS IN MIDWIFERY PRACTICE IN FRANCE	Prof. Dr. Claire Dubois Dr. Pierre Martin Amelie Rousseau
		4	TRAINING MIDWIVES TO MANAGE OBSTETRIC EMERGENCIES IN RURAL ETHIOPIA: CHALLENGES AND OUTCOMES	Prof. Dr. Alemu Wondimu Dr. Genet Abebe
		5	COMMUNITY-BASED ANTENATAL CARE INITIATIVES IN SOUTHERN ETHIOPIA AND IMPACT ON BIRTH OUTCOMES	Dr. Miriam Tadesse Zerihun Mekonnen Assis. Prof. Dr. Kalkidan Endale Prof. Dr. Gebeyehu Bekele
		6	MIDWIFERY STUDENTS' ATTITUDES TOWARD EVIDENCE-BASED PRACTICE IN IRANIAN UNIVERSITIES	Dr. Nasrin Ghasemi Assis. Prof. Dr. Marjan Jafari Prof. Dr. Shahla Hassani
		7	WOMEN'S EXPERIENCES WITH HOME BIRTH ASSISTED BY MIDWIVES IN URBAN IRAN	Dr. Elham Shams Samira Tavakoli
		8	INTEGRATION OF MIDWIFERY INTO PRIMARY HEALTH CARE POLICY IN IRAN: PROGRESS AND CHALLENGES	Prof. Dr. Farzaneh Rahimi Dr. Zahra Sadeghi Mohammadreza Nouri Assis. Prof. Dr. Fatemeh Shafiei Maryam Hadian

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HALL / SALON 8	**Assis. Prof. Dr. Daria Stepanova**	1	EPIDEMIOLOGICAL STUDY OF FOOT-AND-MOUTH DISEASE OUTBREAKS IN CATTLE HERDS IN NORTHERN KYRGYZSTAN	Prof. Dr. Bakytbek Toktoraliev Dr. Cholpon Sattarova Dr. Nurlan Akmatov
		2	ASSESSMENT OF ANTIMICROBIAL RESISTANCE IN SMALL RUMINANTS ACROSS RURAL REGIONS OF KYRGYZSTAN	Dr. Aiperi Esenamanova Assis. Prof. Dr. Timur Bektursunov
		3	CLINICAL MANAGEMENT OF AVIAN RESPIRATORY DISEASES IN COMMERCIAL POULTRY FARMS IN SYRIA	Prof. Dr. Samira Al-Tahan Assoc. Prof. Dr. Jamal Suleiman Dr. Lina Omar Bashar Al-Khalil
		4	PREVALENCE AND CONTROL OF ENDOPARASITIC INFECTIONS IN SHEEP HERDS OF CENTRAL SYRIA	Dr. Rasha Haddad Assis. Prof. Dr. Fawaz Saeed Dr. Hassan Kassab
		5	COMPARATIVE ANALYSIS OF FELINE INFECTIOUS DISEASES IN URBAN AND RURAL SETTINGS OF RUSSIA	Prof. Dr. Viktor Lebedev Assis. Prof. Dr. Daria Stepanova
		6	SURVEILLANCE OF TICK-BORNE DISEASES IN LIVESTOCK THROUGHOUT SOUTHWESTERN RUSSIA	Assoc. Prof. Dr. Irina Smirnova Dr. Sergei Voronin Dr. Ola Timofeeva
		7	VETERINARY APPROACHES TO ZOONOTIC DISEASE PREVENTION IN SMALL RUMINANT POPULATIONS IN PALESTINE	Dr. Amal Rabea Assis. Prof. Dr. Hani Shalaby Dr. Ghada Hanoun

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HALL / SALON 9	**Assis. Prof. Dr. Anil Chandra**	1	MOLECULAR CHARACTERIZATION OF WILD AZERBAIJANI PLANTS FOR DROUGHT TOLERANCE	Prof. Dr. Leyla Huseynova Dr. Samir Quliyev Farida Mammadzade
		2	ANALYSIS OF GENOMIC DIVERSITY IN AZERBAIJANI LANDRACE WHEAT POPULATIONS	Dr. Vugar Aliyev Assoc. Prof. Dr. Nigar Mammadova
		3	IMPACTS OF CONFLICT ON AQUATIC BIODIVERSITY IN THE JORDAN VALLEY	Prof. Dr. Hanan Al-Kurd Dr. Marwan Samara
		4	GENE FLOW AND POLLINATOR DYNAMICS IN OLIVE ORCHARDS UNDER PALESTINIAN CLIMATE CONDITIONS	Assoc. Prof. Dr. Faten Jarrar Dr. Ahmad Tamimi Maha Sabri
		5	INVESTIGATION OF SYMBIOTIC NITROGEN FIXATION IN JAPANESE SOYBEAN CULTIVARS	Dr. Yumi Nakamura Assis. Prof. Dr. Kenji Tanaka
		6	EXPLORING GENETIC RESISTANCE TO RICE BLAST DISEASE IN JAPANESE PADDY FIELDS	Prof. Dr. Takashi Sato Dr. Haruka Yoshida Taro Yamaguchi
		7	INTEGRATED MODELLING OF MONSOON DRIVEN ECOSYSTEM PROCESSES IN COASTAL SOUTH INDIA	Assis. Prof. Dr. Anil Chandra

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HALL / SALON 10	**Assis. Prof. Dr. Sana Al-Mansouri**	1	NONLINEAR DIFFERENTIAL EQUATIONS AND THEIR APPLICATIONS IN AZERBAIJANI ECOLOGICAL MODELING	Prof. Dr. Farhad Valiyev Dr. Leyla Mammadova
		2	QUANTUM OPTICS PHENOMENA IN PHOTONIC CRYSTAL STRUCTURES: INVESTIGATIONS AT BAKU STATE UNIVERSITY	Assoc. Prof. Dr. Elchin Karimov
		3	MATHEMATICAL APPROACHES TO EPIDEMIC SPREAD: CASE STUDY FROM INDONESIAN URBAN POPULATIONS	Dr. Arya Dharmadji Assis. Prof. Dr. Putri Wulandari Anisa Kurnia
		4	OPTIMIZATION ALGORITHMS IN MACHINE LEARNING FOR LARGE-SCALE FINANCIAL DATA ANALYSIS IN INDONESIA	Prof. Dr. Surya Pranata Dr. Nia Rahmawati
		5	DEEP LEARNING ARCHITECTURES FOR IMAGE ANALYSIS IN CHINESE MEDICAL DIAGNOSTICS	Prof. Dr. Wei Zhang Dr. Liu Yan Xin Wen Mei Zhou
		6	THEORETICAL INVESTIGATIONS OF NOVEL MATERIALS IN QUANTUM INFORMATION PROCESSING IN CHINA	Dr. Bo Chen Assoc. Prof. Dr. Li Hua
		7	MULTI-SCALE MATHEMATICAL MODELS OF URBAN TRANSPORTATION NETWORKS IN QATAR	Prof. Dr. Faisal Al-Kuwari Amal Al-Thani Yousef Abdulrahman
		8	ADVANCED QUANTUM MECHANICS IN PHOTON-BASED COMPUTING SYSTEMS IN QATAR	Assis. Prof. Dr. Sana Al-Mansouri Nasser Ali

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		2	APPLICATION OF MACHINE LEARNING IN PREDICTIVE HEALTHCARE ANALYTICS IN AZERBAIJAN	Assoc. Prof. Dr. Kamala Ismailova Elshan Aliyev
		3	ROBOTICS EDUCATION AND AI CURRICULUM DESIGN IN PALESTINIAN UNIVERSITIES: DEVELOPMENT AND CHALLENGES	Dr. Yasmeen Mansour Assoc. Prof. Dr. Khalid Al-Qassam
		4	DEEP LEARNING ALGORITHMS FOR AGRICULTURAL DATA ANALYSIS IN PALESTINE	Dr. Rania Zayed Hisham Abu-Hasan Ahmed Al-Najjar
		5	MULTI-MODAL DEEP LEARNING SYSTEMS FOR AUTONOMOUS VEHICLE NAVIGATION IN URBAN JAPAN	Prof. Dr. Takashi Morimoto Dr. Haruka Sano Keiji Tanaka
		6	SOCIAL ROBOTICS FOR ELDERLY CARE: SOLUTIONS AND LIMITATIONS IN THE JAPANESE HEALTHCARE CONTEXT	Assoc. Prof. Dr. Yumi Nakamura Hiroshi Kato Miyuki Suzuki Momoka Shiraishi
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ISBN NR: 978-625-5694-92-8

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BALKAN 15th INTERNATIONAL CONFERENCE ON APPLED SCIENCES
March 20 – 22, 2026 – SKOPJE
ISBN NR: 978-625-5694-92-8

EVALUATION OF SOME AGRONOMIC TRAITS OF MAIZE HYBRID COMBINATIONS

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Abstract

This study aimed to evaluate the agronomic performance of maize hybrid combinations under Çukurova ecological conditions. Fifteen grain maize hybrid combinations and two commercial cultivars used as controls were grown during the 2025 maize growing season at the Research and Application Area of the Department of Field Crops, Faculty of Agriculture, Çukurova University. The experiment was conducted in a randomized complete block design with three replications.

The evaluated traits included ear weight, ear length, ear diameter, number of rows per ear, number of kernels per row, number of kernels per ear, kernel weight per ear, and grain yield. Significant differences were observed among hybrid combinations for all investigated traits. The D1 × D15 and D14 × D15 hybrids showed superior ear weight, while the D14 × D15 hybrid exhibited the highest values for ear length and ear diameter. The control cultivars D6980 and P1921 recorded higher number of rows per ear compared to the hybrid combinations. The D14 × D15 hybrid was prominent for number of kernels per row and per ear, whereas D1 × D15 and D14 × D15 hybrids had higher kernel weight per ear. In terms of grain yield, the D17 × D9 and D14 × D15 hybrids outperformed the other combinations. Overall, the results indicate that certain hybrid combinations, particularly D14 × D15, have high yield potential and could be promising candidates for further multi-location yield trials and maize breeding programs.

Keywords: maize, hybrid combinations, agronomic traits, grain yield

ISBN NR: 978-625-5694-92-8

ASMA (*Vitis vinifera* L.)'DA SALİSİLİK ASİT VE POTASYUM SİLİKAT UYGULAMALARININ TOPLAM PROTEİN VE FLAVONOİD İÇERİĞİ ÜZERİNE ETKİLERİ

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ÖZET

Bu çalışmanın amacı, *Vitis vinifera* L. cv. Horoz Karası (renkli) ve *Vitis vinifera* L. cv. Şire (beyaz) üzüm çeşitlerinde salisilik asit ve potasyum silikat uygulamalarının, toplam protein ve flavonoid birikimi üzerine etkilerini belirlemektir. Deneme, Batman (Kozluk) ilinde üretici bağı koşullarında gerçekleştirilmiş ve uygulamalar tane tutumu başlangıcında, tane tutumundan iki hafta sonra ve 45 gün sonra olmak üzere üç kez omcalara püskürtme şeklinde uygulanmıştır. Çalışmada kontrol, salisilik asit (SA; 500 ppm), potasyum silikat (K_2SiO_3; 2000 ppm) ve kombine uygulamaların etkisi değerlendirilmiştir. Elde edilen bulgulara göre, toplam protein içeriği hem çeşit, hem de uygulama faktöründen istatistik olarak anlamlı düzeyde etkilenmiştir ($p<0.05$). Benzer şekilde flavonoid içeriği üzerinde de çeşit ve uygulama etkisi istatistik olarak önemli bulunmuştur ($p<0.05$). Buna karşın çeşit × uygulama interaksiyonu, her iki parametre için de istatistik olarak önemli bulunmamıştır. Bu durum, uygulamaların farklı üzüm çeşitlerinde benzer biyokimyasal yanıt modeli oluşturduğunu göstermektedir. Genel olarak SA ve K_2SiO_3 uygulamalarının, flavonoid birikimini artırdığı ve protein içeriğinde iyileşme sağladığı belirlenmiştir. Sonuçlar, adı geçen uygulamaların, asmada sekonder metabolit üretimini teşvik ederek, biyokimyasal kaliteyi olumlu yönde etkileyebileceğini göstermekte ve bağcılıkta çevre dostu biyostimülant uygulamalarının, kalite artırıcı stratejiler kapsamında değerlendirilebileceğine işaret etmektedir.

Anahtar Kelimeler: *Vitis vinifera* L., biyostimülant, silikon, tane gelişimi, fenolik bileşik

ISBN NR: 978-625-5694-92-8

EFFECTS OF SALICYLIC ACID AND POTASSIUM SILICATE APPLICATIONS ON TOTAL PROTEIN AND FLAVONOID CONTENT IN GRAPEVINE (*Vitis vinifera* L.)

ABSTRACT

The aim of this study is to determine the effects of salicylic acid and potassium silicate applications on total protein and flavonoid accumulation in *Vitis vinifera* L. cv. 'Horoz Karası' (colored) and *Vitis vinifera* L. cv. 'Şire' (white) grape varieties. The experiment was carried out under vineyard conditions in Batman (Kozluk) province, and the applications were applied three times as sprays: at the beginning of berry set, two weeks after berry set, and 45 days after berry set. The study evaluated effect of control, salicylic acid (SA; 500 ppm), potassium silicate (K_2SiO_3; 2000 ppm), and combined applications. According to the findings, total protein content was affected statistically significant by both variety and application factors ($p<0.05$). Similarly, the effect of variety and application on flavonoid content was also found significant ($p<0.05$). However, the “variety × application” interaction was found statistically insignificant for both variables. This situation indicates that the applications produced a similar biochemical response pattern in different grape varieties. In general, it was determined that SA and K_2SiO_3 applications increased flavonoid accumulation and improved protein content. The results show that the aforementioned applications can positively affect biochemical quality by promoting secondary metabolite production in grapevines, and indicate that environmentally friendly biostimulant applications in viticulture can be considered within the scope of quality-enhancing strategies.

Keywords: *Vitis vinifera* L., biostimulant, silicon, berry development, phenolic compounds

1. GİRİŞ

Asma (*Vitis vinifera* L.) dünya genelinde ekonomik değeri yüksek olan önemli bir kültür bitkisi olup, meyve kalitesi büyük ölçüde içerdiği biyokimyasal bileşiklerle de ilişkilidir. Üzümde bulunan proteinler ve flavonoidler, hem bitkinin fizyolojik süreçlerinde hem de meyve kalitesi ve insan sağlığı açısından değerlidir. Flavonoidler, özellikle antioksidan özellikleri sayesinde bitkinin stres koşullarına karşı savunmasında önemli rol oynarken, aynı zamanda üzüm ve şarap kalitesini belirleyen temel fenolik bileşikler arasında yer almaktadır [1].

Son yıllarda sürdürülebilir tarım uygulamaları kapsamında bitkisel büyüme düzenleyicileri ve biyostimülantların kullanımı giderek artmaktadır. Bu kapsamda, salisilik asit (SA) bitkilerde stres toleransını artıran, protein sentezini ve antioksidan savunma

mekanizmalarını teşvik eden önemli bir fitohormon olarak bilinmektedir [2]. Yapılan çalışmalarda, dışsal SA uygulamalarının asmada protein içeriği, enzim aktivitesi ve kalite parametrelerini artırdığı bildirilmiştir [3,4].

Benzer şekilde, silisyum uygulamaları da bitkilerde abiyotik streslere karşı dayanıklılığı artırmakta ve kalite özelliklerini iyileştirmektedir. Silisyumun bitkilerde fenolik bileşikler, antioksidan aktivite ve pigment içerikleri üzerinde olumlu etkiler oluşturduğu, özellikle üzümde verim ve kaliteyi artırdığı ortaya konmuştur [5]. Ayrıca, K_2SiO_3 uygulamalarının üzümde toplam fenolik bileşik ve antosiyanin miktarını artırdığı da bildirilmiştir [6]. Bununla birlikte, SA ve K_2SiO_3'ün birlikte uygulanmasının üzümde biyokimyasal parametreler üzerindeki etkilerine ilişkin çalışmalar sınırlıdır.

Bu çalışma SA ve K_2SiO_3 uygulamalarının bireysel ve kombinasyon halinde uygulandığında üzüm tanesinde toplam protein ve flavonoid içeriği üzerindeki etkilerini belirlemeyi amaçlamaktadır.

2. MATERYAL VE YÖNTEM

2.1. Materyal

Çalışma, 2025 yılı vejetasyon döneminde Batman ilinin Kozluk ilçesinde bulunan bir üretici bağında yürütülmüştür. Bitkisel materyal olarak, 1103 Paulsen anacı üzerine aşılı, 14 yaşındaki Horoz Karası (renkli) ve Şire (sinonimleri: Mazrume, Mazrune, Mazrumi; beyaz) üzüm çeşitleri kullanılmıştır.

Omcalar 3.5 × 2.0 m dikim aralığı ve mesafesinde tesis edilmiş olup, 80 cm gövde yüksekliği üzerinden çift kollu kordon sistemine göre budanmış ve çift T terbiye sistemi ile yetiştirilmiştir. Araştırma süresince tüm çeşitlere standart kültürel bakım uygulamaları düzenli olarak gerçekleştirilmiş, sulama işlemleri ise damla sulama sistemiyle sağlanmıştır.

Deneme kapsamında, SA için 500 ppm ve K_2SiO_3 için ise 2000 ppm konsantrasyonlarında hazırlanan çözeltiler; tane tutumu başlangıcında, tane tutumundan iki hafta sonra ve tane tutumundan 45 gün sonra olmak üzere toplam üç kez yapraktan püskürtme yöntemiyle uygulanmıştır [7]. Uygulama öncesinde yüzey gerilimini azaltarak kaplama etkinliğini artırmak amacıyla çözeltilere %0.01 oranında Tween 20 ilave edilmiştir. Kontrol grubundaki omcalara ise yalnızca su püskürtülmüştür.

Hasat zamanı, el refraktometresi ile yapılan ölçümler doğrultusunda belirlenmiş; suda çözünür kuru madde (SÇKM) değeri Horoz Karası çeşidinde %18'e, Şire çeşidinde ise %20'ye ulaştığında hasat gerçekleştirilmiştir.

ISBN NR: 978-625-5694-92-8

2.2. Yöntem

2.2.1 Ekstraksiyon işlemi: Her bir üzüm çeşidinde, hasat döneminde örnekleme yöntemiyle salkımların omuz kısımlarından 3, orta kısımlarından 2 ve uç kısımlarından 1 adet olmak üzere salkım başına toplam 6 tane alınmıştır [8]. Taneler, 50 °C sıcaklıktaki etüvde bir hafta süreyle kurutulmuştur. Kurutma işlemini takiben taneler el tipi öğütücü kullanılarak toz haline getirilmiştir.

Toz haline getirilen taneler, etanol içerisinde 24 saat süreyle maserasyona bırakılmıştır. Maserasyon sonrasında ekstraktlar Whatman No:1 filtre kâğıdından süzülmüş, ardından çözücü faz rotary evaporatör yardımıyla uzaklaştırılmıştır. Elde edilen ekstreden toplam flavonoid tayininde kullanılmak üzere 1000 µg/mL konsantrasyonda stok çözelti hazırlanmıştır [9].

2.2.2 Toplam çözünebilir protein ve toplam flavonoid içeriğinin belirlenmesi:

Üzüm tanelerinin toplam çözünebilir protein miktarı, Bradford yöntemi esas alınarak belirlenmiştir [10]. Toz haline getirilen tane örneklerinden 1 g alınmış ve soğutulmuş havanda homojenize edilmiştir. Homojenizasyon işlemi, %1 (w/v) polivinilpirolidon (PVP), 10 mM Na_2EDTA, 10 mM KCl, 1 mM $MgCl_2$ ve 2 mM DTT içeren 100 mM fosfat tamponu (pH 7.0) kullanılarak gerçekleştirilmiştir. Elde edilen homojenatlar süzüldükten sonra, +4 °C'de 14.000 rpm'de 20 dakika süreyle santrifüj edilmiştir. Santrifüj işlemi sonrasında elde edilen süpernatanttan 20 µL alınarak üzerine 480 µL distile su ve 5.000 µL Bradford reaktifi ilave edilmiştir. Reaksiyon karışımı vorteks yardımıyla homojen hale getirildikten sonra, karanlık ortamda 20 dakika inkübasyona bırakılmıştır. İnkübasyon süresi sonunda örneklerin absorbans değerleri, UV-Vis spektrofotometre kullanılarak 595 nm dalga boyunda ölçülmüştür. Toplam çözünebilir protein miktarı, bovin serum albümini (BSA) kullanılarak oluşturulan standart eğri yardımıyla hesaplanmış ve sonuçlar mg g^{-1} kuru ağırlık (KA) cinsinden ifade edilmiştir.

Toplam flavonoid miktarının belirlenmesinde alüminyum nitrat kolorimetrik yöntemi kullanılmıştır [11]. Hazırlanan stok çözeltisinden 100 µL alınarak %80 (v/v) etanol ile toplam hacim 4.8 mL'ye tamamlanmıştır. Karışıma 100 µL 1 M potasyum asetat ilave edilmiş, bir dakika sonra ise 100 µL %10 (w/v) alüminyum nitrat çözeltisi eklenmiştir. Aynı işlem, standart eğrinin oluşturulması amacıyla farklı konsantrasyonlarda hazırlanan kuersetin çözeltileri için de uygulanmıştır. Reaksiyon karışımları 40 dakika süreyle inkübasyona bırakılmış ve inkübasyon sonunda absorbans değerleri 415 nm dalga boyunda spektrofotometrik olarak ölçülmüştür. Toplam flavonoid miktarı, kuersetin standart eğrisinden elde edilen kalibrasyon

ISBN NR: 978-625-5694-92-8

denklemi kullanılarak hesaplanmış ve sonuçlar kuersetin eşdeğeri (QE) cinsinden µg QEs/mg ekstre olarak ifade edilmiştir

2.3. İstatistik Analiz

Çalışma, üç tekerrürlü ve her tekerrürde 5 omca olacak şekilde tesadüf blokları deneme desenine göre 60 asma üzerinde gerçekleştirilmiştir. Üzerinde durulan özellikler için tanımlayıcı istatistikler; Ortalama, Standart hata, Minimum ve Maksimum değer olarak ifade edilmiştir. Bu özellikler için grup ortalamalarını karşılaştırmada Tek yönlü Varyans analizi yapılmıştır. Varyans analizini takiben farklı grupları belirlemede Duncan çoklu karşılaştırma testi kullanılmıştır. Hesaplamalarda istatistik anlamlılık düzeyi %5 olarak alınmış ve hesaplamalar için SPSS (ver: 21) istatistik paket programı kullanılmıştır.

3. BULGULAR VE TARTIŞMA

Özellikler için çeşit ve uygulamaya göre tanımlayıcı istatistikler ve karşılaştırma sonuçları Tablo 1'de verilmiştir.

Tablo 1. Özellikler için çeşit ve uygulamaya göre tanımlayıcı istatistikler ve karşılaştırma sonuçları

	Uygulama	Şire				Horoz Karası				
		Mean	SEM	Min.	Max.	Mean	SEM	Min.	Max.	p
Toplam Protein (mg g^{-1} KA)	Kontrol	0.476 c	0.010	0.467	0.486	0.632 c	0.008	0.624	0.639	0.006
	SA	0.523 b	0.010	0.513	0.533	0.681 ab	0.018	0.663	0.699	0.018
	K_2SiO_3	0.503 bc	0.006	0.497	0.509	0.652 bc	0.005	0.647	0.657	0.016
	SA + K_2SiO_3	0.559 a	0.008	0.551	0.567	0.712 a	0.001	0.711	0.713	0.007
	p	0.01				0.018				
Toplam Flavonoid (µg QEs/mg ekstre)	Kontrol	11.324 b	0.405	10.919	11.730	17.946 b	0.811	17.135	18.757	0.003
	SA	14.027 a	0.676	13.351	14.703	22.541 a	0.270	22.270	22.811	0.015
	K_2SiO_3	12.541 ab	0.270	12.270	12.811	20.514 ab	0.946	19.568	21.459	0.003
	SA + K_2SiO_3	14.162 a	0.270	13.892	14.432	23.216 a	0.946	22.270	24.162	0.012
	p	0.028				0.030				

Her özellik için aynı sütunda farklı harfi alan çeşit ortalamaları arası fark önemlidir ($p<0.05$)

ISBN NR: 978-625-5694-92-8

Tablo 1'de görüldüğü üzere Şire çeşidinde, en yüksek toplam protein içeriği SA + K_2SiO_3 uygulamasında (0.559 mg g^{-1} TA) gözlemlenirken, bunu SA (0.523 mg g^{-1} TA) ve K_2SiO_3 (0.503 mg g^{-1} TA) uygulamaları takip etmiştir. Horoz Karası çeşidinde de benzer şekilde, SA + K_2SiO_3 uygulaması en yüksek protein içeriğini (0.712 mg g^{-1} TA) sağlamış, bunu SA (0.681 mg g^{-1} TA) ve K_2SiO_3 (0.652 mg g^{-1} TA) uygulamaları izlemiştir. Her iki çeşitte de SA + K_2SiO_3 kombinasyonunun protein içeriğini anlamlı düzeyde artırdığı belirlenmiştir ($p<0.05$).

Şire çeşidinde, toplam flavanoid içeriği açısından SA (14.027 µg QEs/mg ekstre) ve SA + K_2SiO_3 (14.162 µg QEs/mg ekstre) uygulamaları kontrol grubuna (11.324 µg QEs/mg ekstre) göre anlamlı bir artış göstermiştir ($p<0.05$). K_2SiO_3 uygulaması (12.541 µg QEs/mg ekstre) ise kontrol grubuna göre daha yüksek olmakla birlikte istatistik olarak anlamlı bir fark yaratmamıştır. Horoz Karası çeşidinde de SA (22.541 µg QEs/mg ekstre) ve SA + K_2SiO_3 (23.216 µg QEs/mg ekstre) uygulamaları en yüksek flavanoid içeriğini sağlamış ve kontrol grubuna (17.946 µg QEs/mg ekstre) göre anlamlı farklılıklar göstermiştir ($p<0.05$). K_2SiO_3 uygulaması (20.514 µg QEs/mg ekstre) bu çeşitte de flavanoid içeriğini artırmıştır (Tablo 1).

4. TARTIŞMA VE SONUÇ

4.1. Toplam Protein İçeriği Üzerine Etkiler

Salisilik asit, özellikle stres tepkileri sırasında protein sentezini ve metabolizmasını önemli ölçüde düzenleyen bir bitki hormonu ve sinyal molekülü olarak işlev görür. Bazı proteinaz inhibitörlerinin sentezini engelleyebilir, ısı şok proteini (HSP) üretimini düzenleyebilir ve stresle ilgili protein birikimini etkileyebilir [12]. Literatürde, SA uygulamalarının bitkilerde strese bağlı proteinlerin ve savunma enzimlerinin üretimini artırdığı bildirilmektedir [13]. Bu çalışmada Şire ve Horoz Karası çeşitlerinde SA ve SA + K_2SiO_3 uygulamalarıyla gözlemlenen protein artışı, SA'nın bu rolüyle uyumludur. Potasyum silikat ise bitkilerde silisyum birikimini sağlayarak hücre duvarı yapısını güçlendirebilir ve bitkileri biyotik/abiyotik streslere karşı daha dirençli hale getirebilir [14]. Ayrıca K_2SiO_3'ün protein sentezini ve azot metabolizmasını iyileştirerek bitki büyümesini desteklediği de bilinmektedir [15]. Bu bağlamda, K_2SiO_3'ün tek başına veya SA ile kombinasyon halinde protein içeriğini artırması, silisyumun bitki metabolizması üzerindeki genel olumlu etkileriyle açıklanabilir.

4.2. Flavanoid İçeriği Üzerine Etkiler

Flavanoidler, bitkilerde antioksidan özelliklere sahip ikincil metabolitlerdir ve UV ışını, patojen saldırıları ve oksidatif stres gibi çeşitli stres koşullarına karşı koruma sağlarlar [16].

SA'nın fenilalanin amonyak liyaz (PAL) gibi fenolik biyosentez yolaklarındaki anahtar enzimleri aktive ettiği bilinmektedir [17]. Silisyumun ise fenolik birikimi teşvik ederek ve bu bileşiklerin stabilitesini artırarak antioksidan kapasiteyi desteklediği bildirilmiştir [14]. Özellikle Horoz Karası çeşidinde SA + K_2SiO_3 kombinasyonunun en yüksek flavanoid içeriğini sağlaması, bu iki bileşiğin sinerjistik bir etki göstererek bitkinin savunma mekanizmalarını güçlendirdiğini düşündürmektedir.

4.3. Çeşit Etkisi

Horoz Karası çeşidinin hem kontrol grubunda hem de uygulama gruplarında Şire çeşidine göre daha yüksek protein ve flavanoid içeriğine sahip olması, çeşitler arası genetik farklılıkların biyokimyasal bileşiklerin birikimi üzerindeki etkisini vurgulamaktadır. Her iki çeşidin de uygulamalara benzer şekilde yanıt vermesi, bu uygulamaların genel olarak asma için faydalı olabileceğini göstermektedir.

Sonuç olarak, bu çalışma, SA ve K_2SiO_3'ün üzüm tanesinde toplam protein ve toplam flavanoid içeriklerini artırmada etkili olduğunu ortaya koymuştur. Özellikle SA ve K_2SiO_3'ün birlikte uygulanması, her iki üzüm çeşidinde de en belirgin artışları sağlamıştır. Bu bulgular, söz konusu uygulamaların asmanın meyvesi üzümün besin değerini ve stres toleransını artırma potansiyeline sahip olduğunu göstermektedir. Gelecekteki çalışmalarda, bu uygulamaların üzüm kalitesi, verim ve farklı stres koşulları altındaki etkileri daha detaylı incelenebilir.

Teşekkür

Bu çalışmaya, FYL-2025-11977 no'lu proje kapsamında destek sağlayan Van Yüzüncü Yıl Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimi'ne teşekkür ederiz.

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ISBN NR: 978-625-5694-92-8

SU DESTEKLİ UV-C DEZENFEKSİYON SİSTEMİNİN TASARLANMASI VE GELİŞTİRİLMESİ

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ÖZET

Su kaynakları yaşam için temel faktör olarak büyük öneme sahiptir. **[1,2]** Artan şehirleşme, iklim değişikliği tükenmesi gibi sebeplerle su tasarrufu sağlanması günümüzün önemli konuları arasındadır. Buna bağlı olarak gıda güvenliği konusu ön plana çıkmış ve mümkün olduğunca az işlem görmüş sebze meyvelere talep artmıştır. **[3,4]** Bu gıdaların taze özelliklerinin korunmasında ve mikrobiyolojik açıdan güvenliğinin sağlanmasında termal olmayan yöntemler uygulanmaktadır.

Bu çalışmada endüstriyel alanda kullanılan klor ve ısıl işlem gibi temizleme yöntemlerine daha güvenli bir alternatif olarak kullanılan su destekli UV-C sistem tasarımı yapılmıştır. **[5]** Büyük ölçekli işletmelere ek olarak daha küçük hacimlerde yeterli temizleme sağlanabilirliği ve tasarım uygunluğu göz önünde bulundurularak tasarım ve analiz tamamlanmıştır.**[6]** Tasarım ana aksamları; yıkama tankı ve UV dezenfeksiyon tankı olarak iki parçadan oluşmakta ve yardımcı aksamlar ile desteklenmektedir. İş güvenliği ve insan sağlığı dikkate alınarak yapılan hesaplamalarda 10 Litre hacminde ve 3.5 kg sebze kapasitesine sahip bir yıkama tankı ve 1.5 Litre su kapasitesine sahip UV dezenfeksiyon tankı tasarlanmıştır. Yıkama ve UV dezenfeksiyon tanklarının ayrı tutulmasındaki temel sebepler; suyun tekrar kullanılabilirliğini sağlamak, yıkama esnasında gölgeleme etkisini azaltmak, UV ışığın penetrasyon derinliğini arttırmaktır. Yapılan analiz sonucunda belirtilen ölçüler için tasarlanan bu sistemin istenen yeterlilikleri karşıladığı görülmüştür.

Mikroorganizmaların inaktivasyonunda kullanılan UV ışık, termal yöntemler ve klorla temizlemeye alternatif bir yöntemdir.**[9]** Bunun yanı sıra UV ışığın penetrasyon derinliği, sebzenin yüzey pürüzlülüğü gibi faktörler temizlemeye etki etmektedir. Temizleme kalitesini arttırmak ve sınırlayıcı faktörlerin etkisini azaltmak amacıyla su destekli sistemler geliştirilmiştir.**[3,4]**

Yüksek enerjisi ve kısa dalga boyu nedeniyle UV-C ışığı, küf ve zararlı mikroorganizmaların inaktivasyonunda oldukça etkilidir.**[9]** UV ışık, klorla dezenfekte yönteminin aksine kalıntı

ISBN NR: 978-625-5694-92-8

bırakmamaktadır. **[8,10,11]** Aynı zamanda ısı uygulamadığı için gıda kalitesinin bozulmasına sebep olmamaktadır.**[8,11]**

Sebze meyve dezenfeksiyonunda kullanılan yöntemler arasında kalıntı riski olmaması ve suyun geri kullanımını sağlaması ile UV-C sistemlerin ön planda olduğu açıkça görülmektedir. Bu çalışmada su destekli UV-C dezenfeksiyon tankının ideal tasarımı konusu çalışılmış ve geliştirilmesi hedeflenmiştir.

Anahtar Kelimeler: UV Temizleme, Akışkanlar Mekaniği, Tasarım Modelleme

DESIGN AND DEVELOPMENT OF A WATER-BASED UV-C DISINFECTION SYSTEM

Water resources are of paramount importance as a fundamental factor for life. [1,2] Water conservation is one of the key issues of our time, driven by factors such as increasing urbanisation and climate change. Consequently, food safety has come to the fore, and demand has risen for fruit and vegetables that have undergone as little processing as possible. [3,4] Non-thermal methods are employed to preserve the freshness of these foods and ensure their microbiological safety.

In this study, a water-based UV-C system has been designed as a safer alternative to cleaning methods such as chlorine and thermal treatment used in industrial settings. [5] The design and analysis were completed taking into account the feasibility of achieving adequate cleaning in smaller volumes, as well as design suitability, in addition to large-scale facilities. [6] The main components of the design consist of two parts: a washing tank and a UV disinfection tank, supported by auxiliary components. Taking occupational safety and human health into account, calculations were performed to design a washing tank with a volume of 10 litres and a vegetable capacity of 3.5 kg, and a UV disinfection tank with a water capacity of 1.5 litres. The primary reasons for keeping the washing and UV disinfection tanks separate are to ensure the reusability of the water, to minimise the shading effect during washing, and to increase the penetration depth of the UV light. Analysis has shown that the system designed with these specified dimensions meets the required performance criteria.

UV light, used for the inactivation of microorganisms, is an alternative method to thermal methods and chlorine-based disinfection.[9] Furthermore, factors such as the penetration depth of UV light and the surface roughness of vegetables influence the disinfection process. Water-assisted systems have been developed to improve disinfection quality and reduce the impact of limiting factors.[3,4]

Due to its high energy and short wavelength, UV-C light is highly effective in inactivating mould and harmful microorganisms.[9] Unlike chlorine-based disinfection methods, UV light leaves no residues.[8,10,11] Furthermore, as it does not apply heat, it does not cause deterioration in food quality.[8,11]

It is clear that UV-C systems are at the forefront among the methods used for fruit and vegetable disinfection, owing to the absence of residue risk and their ability to facilitate water reuse. This study has investigated the ideal design of a water-supported UV-C disinfection tank and aimed to develop it.

ISBN NR: 978-625-5694-92-8

Keywords: UV Cleaning, Fluid Mechanics, Design Modelling

1. GİRİŞ

Elektromanyatik radyasyon enerjisinin bir türü olan UV ışık enerjisini güneşten almaktadır. Işık yelpazesinde görünür ışık UV ışıktan daha uzun dalga boyuna sahip, X ışını ise daha kısa dalga boyuna sahiptir. UV ışın 10-200nm aralığında uzak, UV 200-400nm aralıklarında yakın olarak gruplandırılmaktadır. Yüksek enerjisi ile bakteriler için öldürücü etkiye sahip olan UV ışık, spor formlu mikroorganizmalarda yüksek doz uygulaması ile öldürücü etki etmektedir.250-260nm aralıkları UV ışığın germisidal(öldürücü) etkisinin en yüksek aralık olduğu belirlenmiştir. DNA tarafından en etkin absorve edildiği doz ise 253,7nm olarak belirlenmiştir. **[2,8,11,14]**

Uygulama suyunun fazla bulanık olması UV ışının çalışmasını olumsuz etkilemektedir. UV ışık temelli sistemlerin, görünümü bulanık olan sularda kullanılması durumunda, suyun UV ünite öncesinde hassas partikül tutma kabiliyetine sahip tortu filtrelerinden geçirilerek bulanıklılığının giderilmesi şarttır. Bunun sebebi büyük parçaların UV ışının geçişini engellemesini önlemektir. Sistem içinde büyük partikül bulunması UV ışının yüzeye temasını engelleyebilir ve verimli çalışmasını olumsuz etkileyebilir. UV lambanın sistem içinde darbe almasını önlemek amacıyla kuvars cam olarak üretilmektedir. Bu lambanın içinde katı halde civa bulunmaktadır. **[1,13]**

Üretici firmanın önerdiği saat ve sürede UV lamba değişimi ve ham su kalitesine bağlı olarak, periyodik olarak kuvars cam temizliğinin yapılması çok önemlidir. Gerekli temizliğin yapılmadığı durumlarda lambanın çalışma verimi düşecek ve gıda yüzeyine teması sınırlanacaktır. UV lambanın dışında yer alan kuvars cam mükemmel bir şekilde UV ışınını suya geçirirse UV ışını dezenfeksiyon görevini yapar. Bu yüzden kuvars cam yüksek kalitede olmalıdır. **[1]**

Kirli suyun dezenfekte edilmesinde UV ışığın gıdaya uzaklığı ve suya temas süresi önemlidir. UV dezenfeksiyon tankındaki kirli su işlem öncesi kaba filtrasyona tabii tutulmalı ve UV ışığa ideal hızda temas ettirilmelidir.**[1]**

'Joule/m^2', UV dozunun SI birimidir. **[1,15]** Dezenfeksiyon işleminde gerekli UV dozu aşağıda verilen formülle hesaplanmaktadır:**[1]**

$$\text{UV dozu}\left[{}^{J}/_{m^2}\right] = \text{UV ışın yoğunluğu}\left[{}^{W}/_{m^2}\right] \times \text{Temas süresi [saniye]}$$

UV tankının hacmi ile UV reaktörü birbirini etkileyen faktörlerdir. Sistemin verimli çalışabilmesi için UV dozu minimum 400 J/m^2 kapasiteli bir UV cihazı seçilmelidir. Tasarımda UV reaktörün ve sistemin iç hacmi temas süresini etkileyen faktörlerdir. Ortalama temas süresini, hesaplayabilmek için UV reaktörün hacminin suyun debisine bölünmesi gerekmektedir. Sistemin içinde akan suyun debisi ne kadar fazlaysa UV cihazının dozu düşmektedir. **[1,7]**

Bu çalışmanın amacı doğrultusunda, UV ışık yardımıyla kalıntısız şekilde dezenfeksiyon yapabilecek bir sistemin küçük ölçekli tasarımı ve analizi yapılmıştır.

ISBN NR: 978-625-5694-92-8

2. YÖNTEM VE ANALİZ

Yöntem

Büyük ölçekli işletmelerde kullanılan UV dezenfeksiyon tanklarının daha küçük ölçekli tasarımı ve analizi üzerine çalışılmıştır. Sistemde bulunan yıkama tankı ve UV temizleme tankı için AISI 304 paslanmaz çeliği seçilmiştir.**[12]** Yüksek korozyon direnci, kaynak yapılabilirliği, gıda sanayisinde kullanıma uygun olması gibi etkenler göz önünde bulundurularak tercih edilmiştir. Çizelge 1 ve Çizelge 2'de AISI 304 paslanmaz çeliğin özellikleri verilmiştir.

Çizelge 1. Oda Sıcaklığındaki Mekanik Özellikleri [18]

Oda Sıcaklığındaki Mekanik Özellikleri	
Kalite	304 (1.4301) X5CrNi18-10
Kopma mukavemeti	515 – 720 MPa
Akma mukavemeti (%0,2)	210 MPa (min)
Sertlik, Rockwell (HB)	201

Çizelge 2. Oda Sıcaklığındaki Fiziksel Özellikleri [18]

Oda Sıcaklığındaki Fiziksel Özellikleri	
Öz kütlesi (Özgül ağırlığı)	8000 kg/m^2
Erime Sıcaklığı	1450˚C
Elastisite Modülü	193 GPa
Elektriksel Direnç Miktarı	0,072*10^{-6} Ωm
Isı Geçirgenliği	17,2 W/m*K

Sistemde silindirik levha içerisine yıkama sepeti yerleştirildi. Motor bağlantısı ile dönme hareketi sepet aracılığıyla gerçekleştirildi. Bu sayede olası kalıntıların temizlenmesi ve sebzenin tüm yüzeyine su temas etmesi sağlandı. Yıkama tankının alt bölümünde bulunan pirinç boru bağlantı elemanı ile kirli su pompaya taşınır ardından UV temizleme tankına eğimli şekilde aktarılmaktadır. Suyun UV tankına eğimli aktarılmasının sebebi iç hareketliliği sağlayarak ışığın ulaşamayacağı karanlık bölge oluşumunu engellemektir. UV tankında dezenfekte işlemi gören su, pompalar ile yıkama tankına aktarılarak suyun geri kullanımı sağlanmaktadır. UV lamba, temizleme tankına kuvars cam içerisinde yerleştirilerek homojen bir dezenfeksiyon sağlanmaktadır.
Yıkama tankı ve UV tankı hacimleri ve temel yükleri Çizelge 3'te verilmiştir.

Çizelge 3. Yıkama tankı ve UV tankı hacimleri ve temel yükler

	Yıkama Tankı	**UV Tankı**
Hacim	10 Litre su ve 3,5 kg sebze kapasitesi	1,5 Litre su kapasitesi
Yük	134,4 N	15 N

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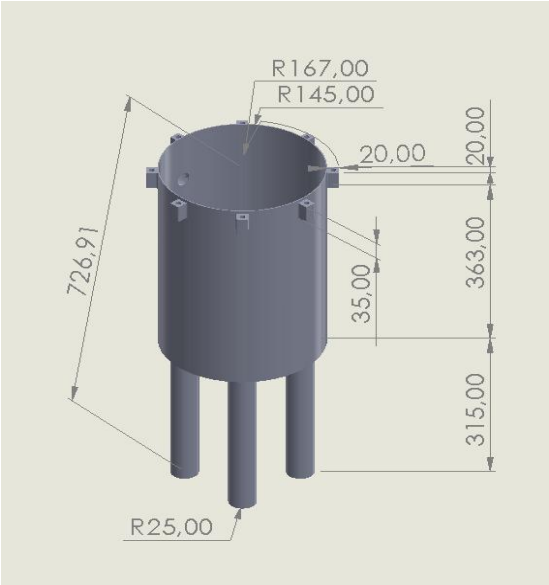
Sisteme uygulanacak temel yük su sebze ağırlığından kaynaklanmaktadır. Sistem yükleri aşağıdaki formül ile hesaplanmıştır.

$$\mathbf{F = m \times g}$$

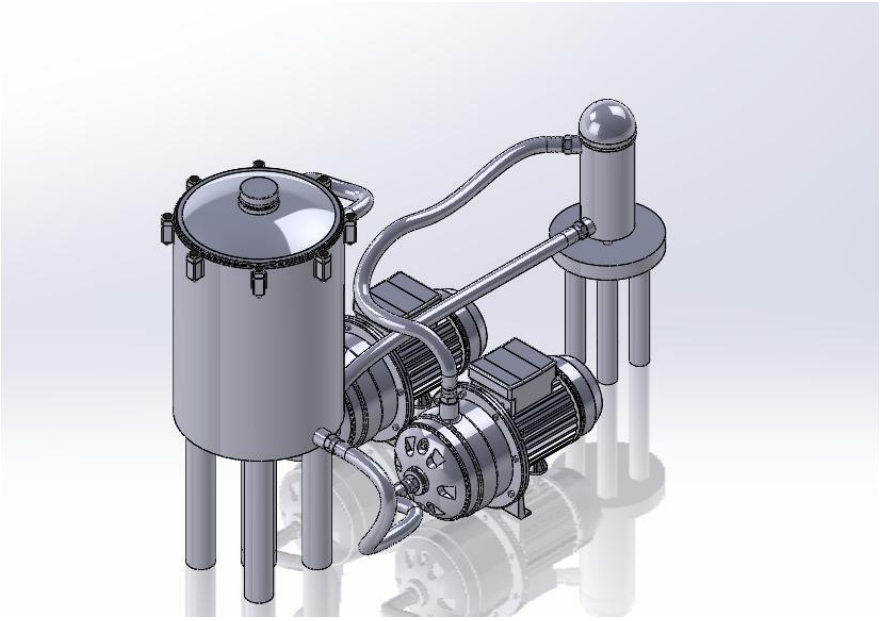
F: Kuvvet(N)
m: Kütle (kg)
g: Yerçekimi ivmesi (9,81 m/s²)

SolidWorks uygulaması ile CAD modelleri oluşturulmuştur. CAD çizimleri ve ölçüleri Görsel 1, Görsel 2, Görsel 3'te verilmiştir.



Görsel 1. Yıkama Tankı Teknik Resimi

Görsel 2. UV Temizleme Tankı Teknik Resimi



Görsel 3. Tüm Sistem Montajı

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2. SONUÇLAR VE DEĞERLENDİRME

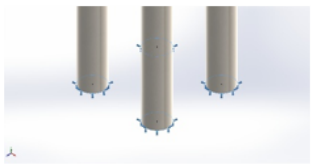
2.1 STATİK ANALİZ

Tankı analiz edebilmek için toplam yük hesaplanmıştır. Tasarım ve analiz SolidWorks üzerinden yapılmıştır. Hesaplanan yük etkilediği yüzeylere yerleştirildi ve sistem zemine sabitlenmiştir. Sistem de ince mesh oluşturulmuştur. Tankın içi su ve sebze ile dolu durumda iken tankta oluşacak stres (von misses), gerinim, yer değiştirme değerleri hesaplanmış ve rapor oluşturulmuştur.

2.1.1 YIKAMA TANK STATİK ANALİZİ

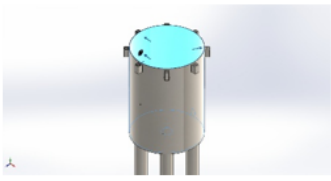
Yıkama tankı hacmi 10 Litre su, 3.5 Kg gıda kapasiteli tasarlanmıştır. Malzeme ataması yapıldıktan sonra tasarıma etki eden kuvvete karşı mukavemet sağlayıp sağlamadığı statik analiz yapılarak kontrol edilmiştir.

Sabitleme noktaları ve yükün uygulandığı yüzey verileri Görsel 4'te Yükler ve Fikstürlerde verilmiştir.

Fikstür adı	Fikstür Resmi	Fikstür Detayları
Sabitlenmiş-1		Objeler: 4 yüzler Tip: Sabit Geometri

Sonuç Kuvvetleri

Bileşenler	X	Y	Z	Sonuç
Tepki kuvveti(N)	-0,212902	134,401	-0,211729	134,402
Tepki Momenti(N.m)	0	0	0	0

Yük adı	Resim Yükle	Yük Detayları
Kuvvet-1		Objeler: 2 yüzler Tip: Normal kuvvet uygula Değer: 134,4 N

Görsel 4. Yükler ve Fikstürler

Yıkama tankı mesh bilgileri Çizelge 4'te ve mesh kalitesi Görsel 5'te verilmiştir.

Çizelge 4. Yıkama Tankındaki Mesh Bilgisi

Mesh Bilgisi	
Mesh Tipi	Katı Mesh
Kullanılan Meshleyici:	Karışık eğrilik tabanlı mesh
Yüksek Kaliteli Mesh İçin Jakoben Noktalar	16 Noktalar
Maksimum Eleman Boyutu	21,2198 mm
Minimum Eleman Boyutu	1,06099 mm

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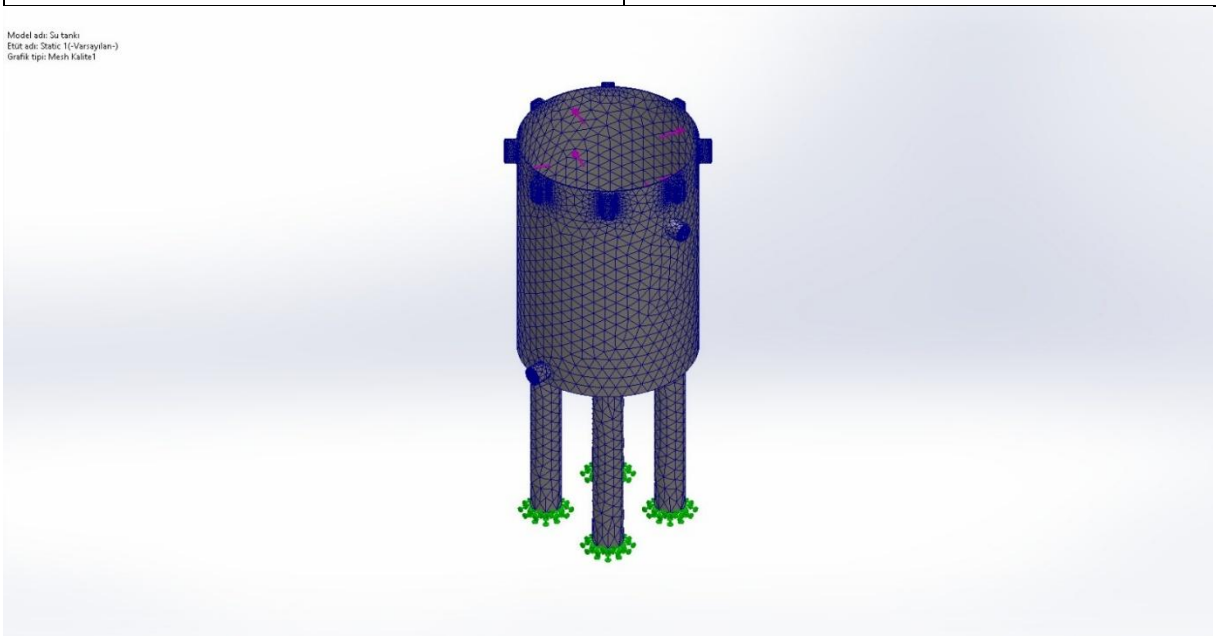
Mesh Kalitesi	Yüksek
Toplam Düğüm	88849
Toplam Elemanlar	49246
Maksimum En Boy Oranı	6041,1
En-Boy Oranı < 3 Olan Elemanların % Oranı	61,5
En-Boy Oranı > 10 Olan Elemanların Yüzdesi	12,7
Şekli Bozulmuş Elemanların Yüzdesi	0



Görsel 5. Temizle Tankı Mesh Kalitesi

Sistem analizi sonucu elde edilen stres,yer değiştirme ve gerinim değerleri sırasıyla Görsel 6,Görsel 7 ve Görsel 8’de verilmiştir.

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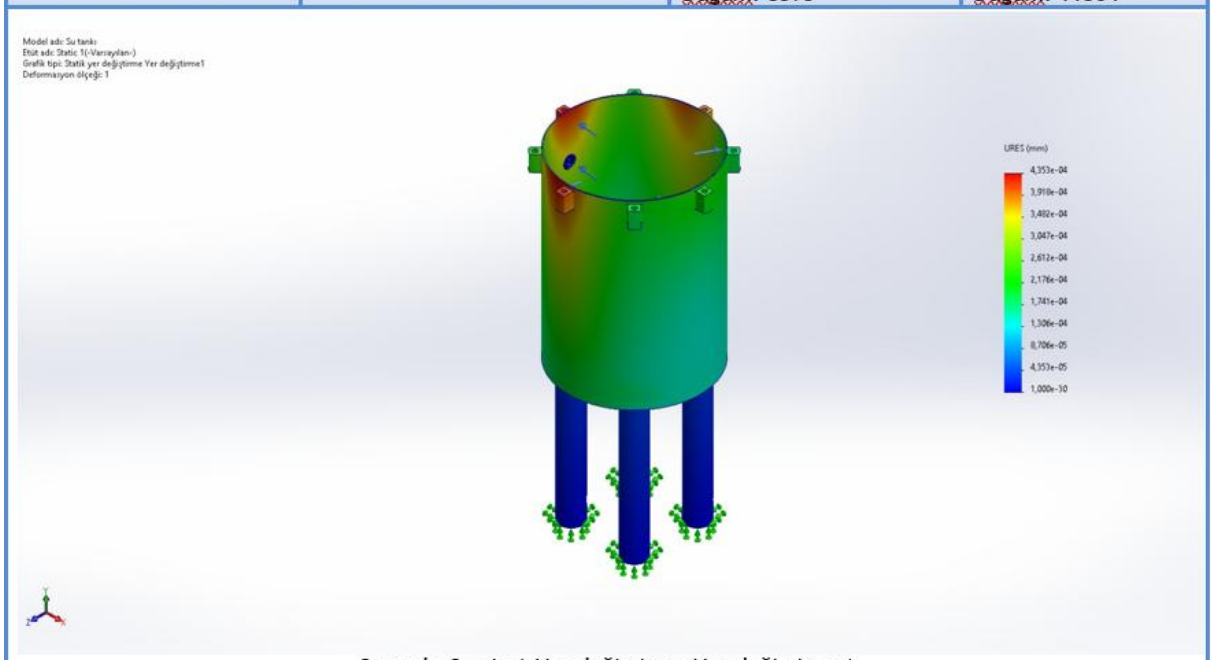
Ad	Tip	Min	Maks.
Stres1	VON: von Mises Stresi	7,400e+00N/m^2 Düğüm: 29327	2,819e+05N/m^2 Düğüm: 46948

Su tankı-Static 1-Stres-Stres1

Görsel 6. Yıkama Tankının Statik Analizindeki Stres Değerleri

Ad	Tip	Min	Maks.
Yer değiştirme1	URES: Sonuc Yer Değiştirmesi	0,000e+00mm Düğüm: 8393	4,353e-04mm Düğüm: 11364

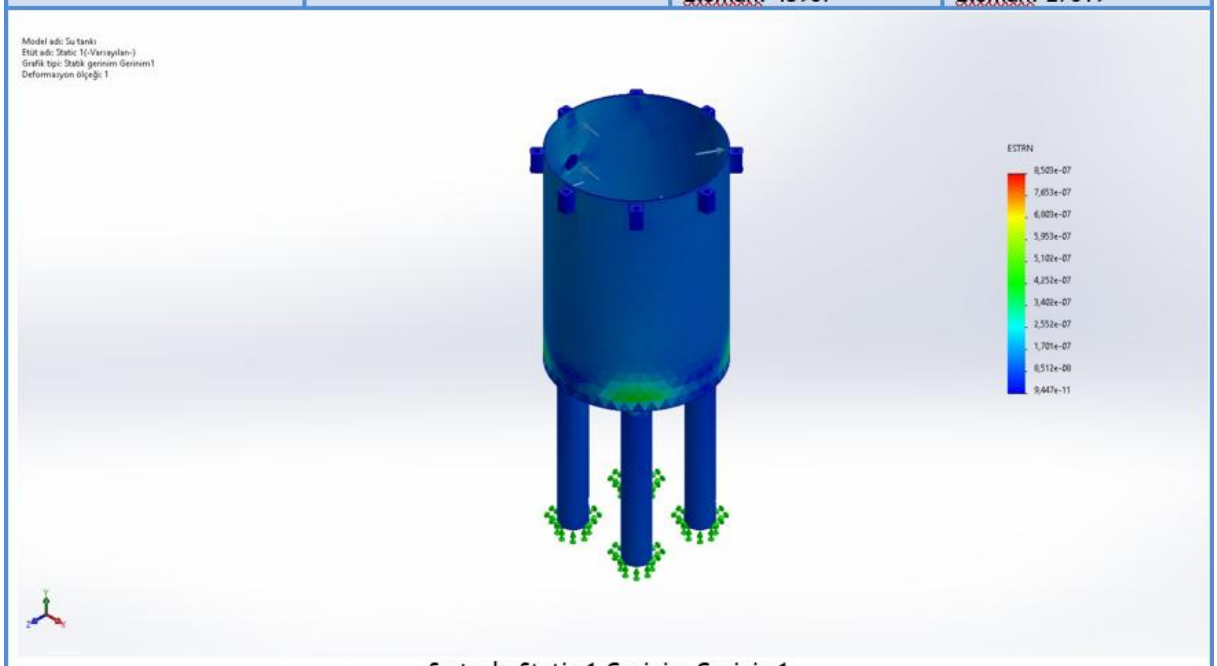


Su tankı-Static 1-Yer değiştirme-Yer değiştirme1

Görsel 7. Yıkama Tankının Statik Analizindeki Yer Değiştirme Değerleri

ISBN NR: 978-625-5694-92-8

Ad	Tip	Min	Maks.
Gerinim1	ESTRN: Eşdeğer Gerilme	9,447e-11 Eleman: 45907	8,503e-07 Eleman: 27019



Su tankı-Static 1-Gerinim-Gerinim1

Görsel 8. Yıkama Tankının Statik Analizindeki Gerinim Değerleri

2.1.2 UV DEZENFEKSİYON TANK STATİK ANALİZ

UV dezenfeksiyon tankı hacmi 1,5 Litre su kapasiteli tasarlanmıştır. Malzeme ataması yapıldıktan sonra tasarıma etki eden kuvvete karşı mukavemet sağlayıp sağlamadığı statik analiz yapılarak kontrol edilmiştir.

Sabitleme noktaları ve yükün uygulandığı yüzey verileri Görsel 9'te Yükler ve Fikstürlerde verilmiştir.

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Fikstür adı	Fikstür Resmi	Fikstür Detayları
Sabitlenmiş-1		Objeler: 4 yüzler Tip: Sabit Geometri

Sonuç Kuvvetleri

Bileşenler	X	Y	Z	Sonuç
Tepki kuvveti(N)	0,106196	14,9984	-0,256873	15,001
Tepki Momenti(N.m)	0	0	0	0

Yük adı	Resim Yükle	Yük Detayları
Kuvvet-1		Objeler: 2 yüzler Tip: Normal kuvvet uygula Değer: 15 N

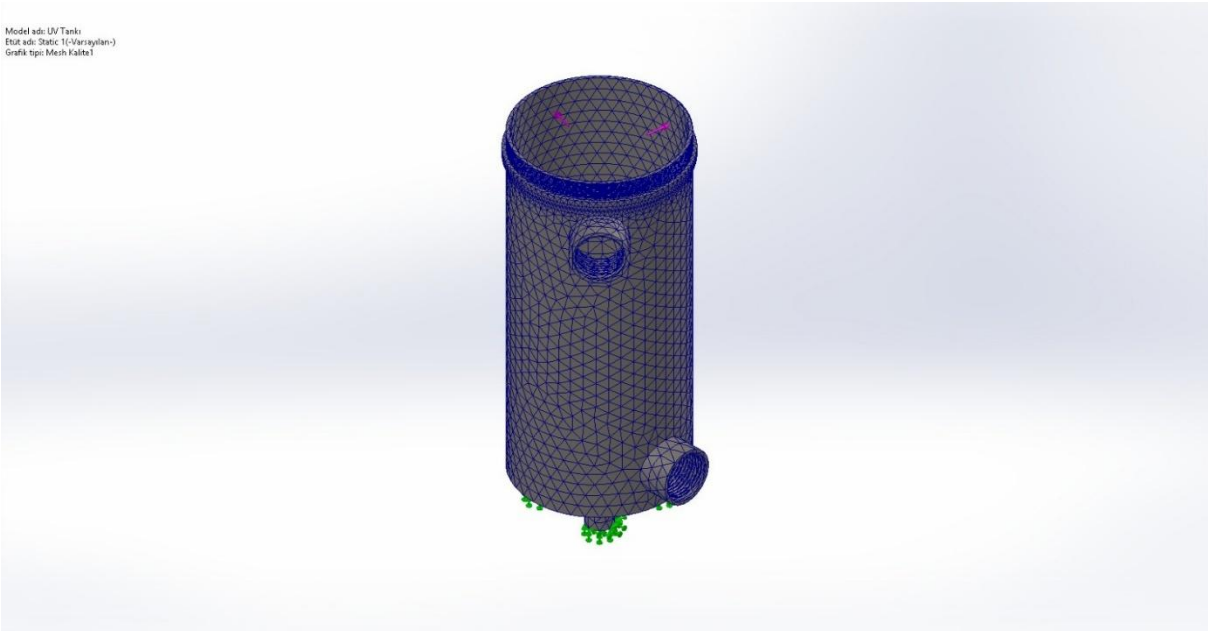
Görsel 9. Yükler ve Fikstürler

UV dezenfeksiyon tankı mesh bilgileri Çizelge 5'te, mesh kalitesi Görsel 10'da verilmiştir.

Çizelge 5. UV Tankındaki Mesh Bilgisi

Mesh Bilgisi	
Mesh Tipi	Katı Mesh
Kullanılan Meshleyici:	Karışık eğrilik tabanlı mesh
Yüksek Kaliteli Mesh İçin Jakoben Noktalar	16 Noktalar
Maksimum Eleman Boyutu	7,53571 mm
Minimum Eleman Boyutu	0,956709 mm
Mesh Kalitesi	Yüksek
Toplam Düğüm	42331
Toplam Elemanlar	22076
Maksimum En Boy Oranı	308,87
En-Boy Oranı < 3 Olan Elemanların % Oranı	27,2
En-Boy Oranı > 10 Olan Elemanların Yüzdesi	36,5
Şekli Bozulmuş Elemanların Yüzdesi	0

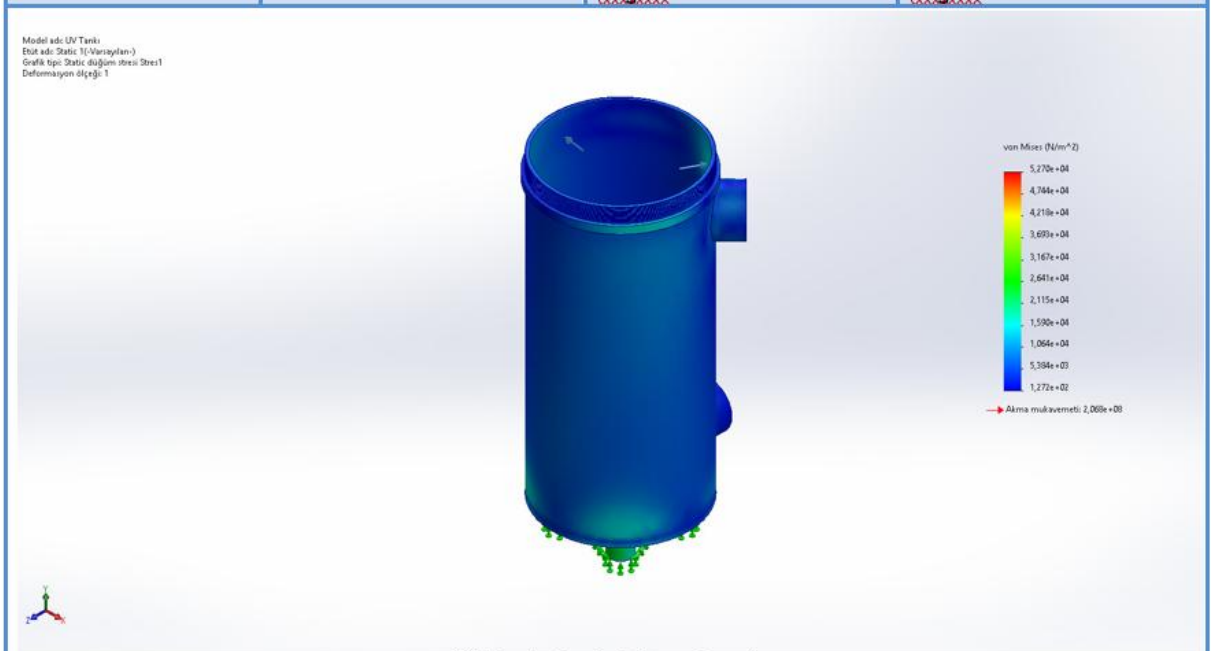
ISBN NR: 978-625-5694-92-8



Görsel 10. UV Tank Mesh Kalitesi

Sistem analizi sonucu elde edilen stres,yer değiştirme ve gerinim değerleri sırasıyla Görsel 11, Görsel 12 ve Görsel 13'de verilmiştir.

Ad	Tip	Min	Maks.
Stres1	VON: von Mises Stresi	1,272e+02N/m^2 Düğüm: 29147	5,270e+04N/m^2 Düğüm: 123

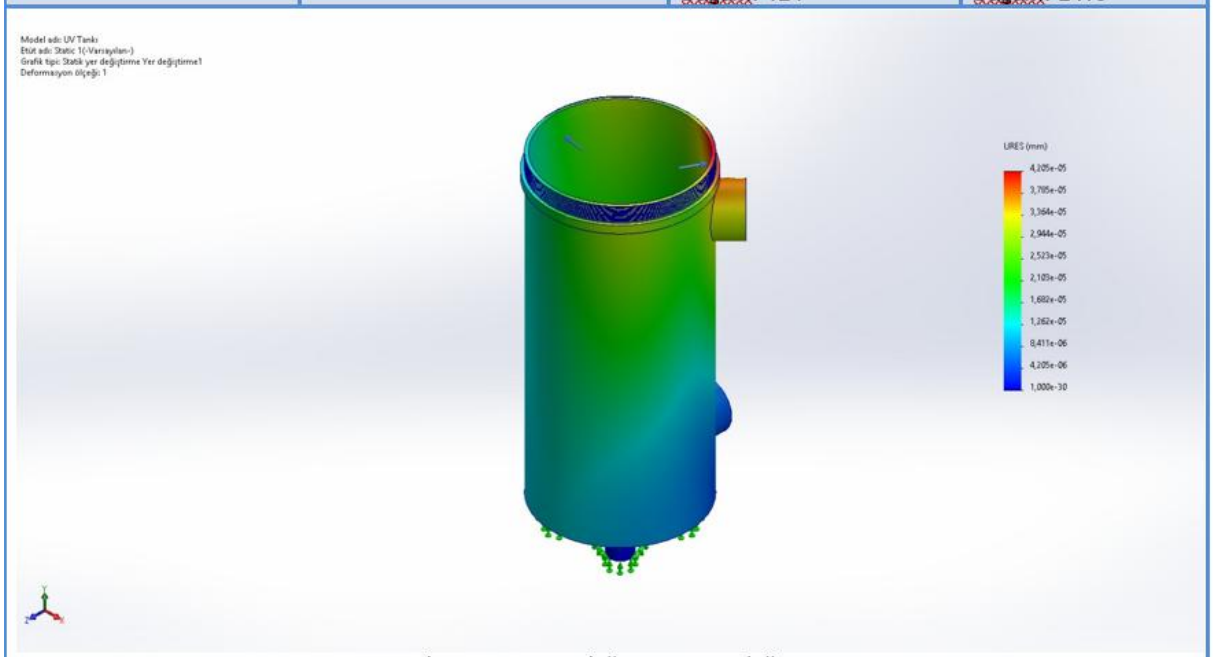


UV Tankı-Static 1-Stres-Stres1

Görsel 11. UV Tankının Statik Analizindeki Stres Değerleri

ISBN NR: 978-625-5694-92-8

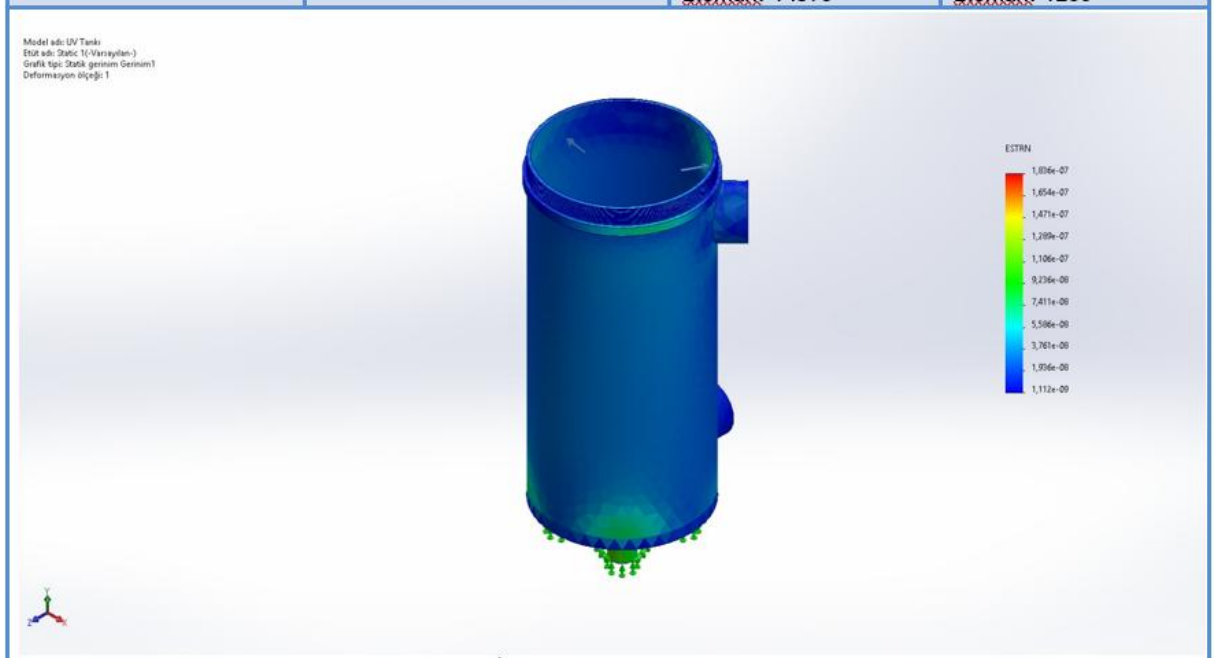
Ad	Tip	Min	Maks.
Yer değiştirme1	URES: Sonuç Yer Değiştirmesi	0,000e+00mm Düğüm: 124	4,205e-05mm Düğüm: 2416



UV Tankı-Static 1-Yer değiştirme-Yer değiştirme1

Görsel 12. UV Tankının Statik Analizindeki Yer Değiştirme Değerleri

Ad	Tip	Min	Maks.
Gerinim1	ESTRN: Eşdeğer Gerilme	1,112e-09 Eleman: 14596	1,836e-07 Eleman: 1260



UV Tankı-Static 1-Gerinim-Gerinim1

Görsel 13. UV Tankının Statik Analizindeki Gerinim Değerleri

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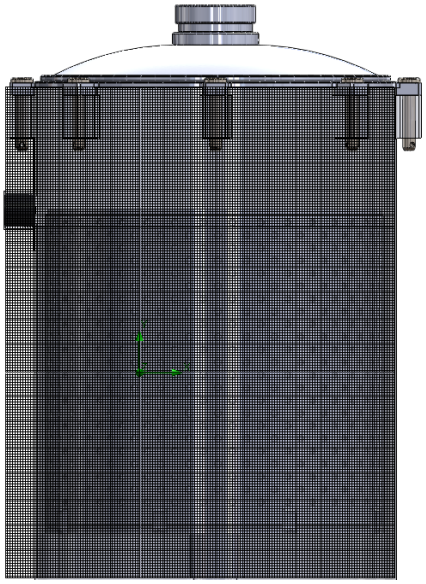
2.2 AKIŞ ANALİZİ

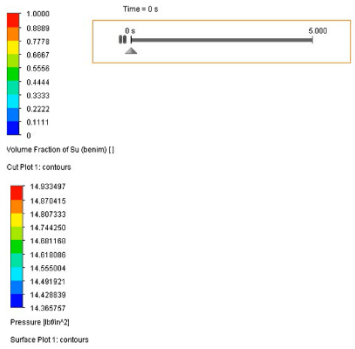
2.2.1 YIKAMA TANK AKIŞ ANALİZİ

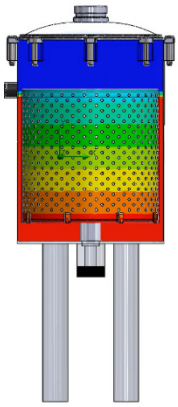
Sisteme Solidworks Flow Simulation uygulamasından akış analiz yapılmıştır. Sepetin içinde bulunan sebzelerin tamamıyla temizlenebilmesi için 30 RPM açısal hızı kullanılmıştır.Sistemimizin yerel bölgelerinde yanlızca zamana bağımlı analizi yapılabilmektedir. Bu yüzden sistem 0-5 saniye aralığındaki zaman bağımlı olarak yapılmıştır. Akışkanın olduğu alanı tanımlanmıştır. Dönen bölgeyi, başlangıç koşullarını,hedefleri de tanımladıktan sonra ortalama mesh atılmıştır. Akış analizindeki mesh kalitesi Görsel 14.'de verilmiştir.

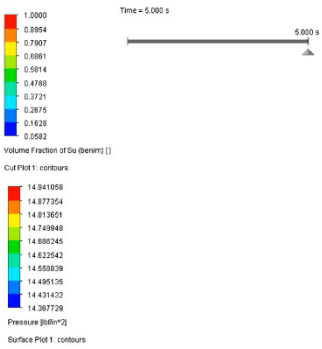


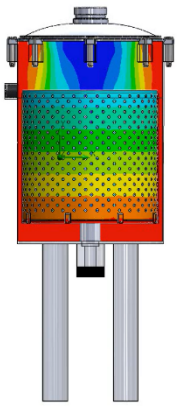
Görsel 14. Yıkama Tankının Akış Analizindeki Mesh

Dönen kısmı ve saniyesini sisteme tanımladıktan sonra kesik ve yüzey grafiklerini oluşturup sistem çalıştırılmıştır. İlk durumdaki ve son durumdaki halleri aşağıdaki Görsel 15. ve Görsel 16.'de verilmiştir.









Görsel 15. Akış Analizindeki İlk Saniye Durum |**Görsel 16.** Akış Analizindeki Son Saniyedeki Durum

3.GENEL DEĞERLENDİRME VE SONUÇLAR

Çoğunlukla büyük ölçekli işletmelerde kullanılan UV-C sistemlerin daha küçük boyutlarda tasarımı ve analizi yapılmıştır. Stres, gerinim ve yer değiştirme sonuçları Solidworks üzerinden

detaylı incelenmiştir. AISI 304 malzemeden imal edilen yıkama ve temizleme tankı belirlenen yükler altında dayanım göstererek sistemin belirlenen yükler altında çalışabileceği görülmüştür. Dönme hareketinin sisteme zarar vermeden gerçekleştirildiği belirlenmiştir. Bu sayede sistemin dezenfeksiyon işlemini daha verimli gerçekleştirmesi sağlanmıştır.

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ISBN NR: 978-625-5694-92-8

ÖĞRENME GÜÇLÜĞÜ OLAN ÖĞRENCİLERDE DOĞA TEMELLİ UYGULAMALARIN VE GEVŞEME TEKNİKLERİNİN DUYGU DÜZENLEMEYE VE BENLİK SAYGISINA ETKİSİ[1]

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ÖZET

Öğrenme güçlüğü (ÖG) olan öğrencilerde doğa temelli uygulamaların ve gevşeme tekniklerinin duygu düzenlemeye ve benlik saygısına etkisinin incelenmesi amaçlanmıştır. Ardahan ilindeki özel eğitim ve rehabilitasyon merkezlerine başvuran ve ÖG tanısı almış, 10-12 yaş arası, gönüllü, projeye katılmaya engel bir hastalığı olmayan 25 öğrenci ile yürütülmüştür. Tek grup öntest-sontest, kontrol grupsuz deneysel desenin kullanıldığı çalışma, 06 Eylül – 25 Ekim 2025 tarihleri arasında her hafta bir oturum (40 dakika oturum + 20 dakika ara öğün + 40 dakika oturum) olmak üzere toplam sekiz oturum şeklinde yürütülmüştür. Çalışmaya katılan öğrencilere öntest-sontest için Kişisel Bilgi Formu, Çocuklar için Rosenberg Benlik Saygısı Ölçeği ve Çocuk ve Ergenlerde Duygu Düzenleme Ölçeği uygulanmıştır. Öğrencilerin yaş ortalaması 11,12±0,88'dir. Katılımcıların %72'i erkek, %40'ı iki kardeşe sahip ve %48'i ortanca çocuktur. Katılımcıların %72'sinin ailesinde özel gereksinimli veya bakıma muhtaç birey bulunmadığı, öğrencilerin %20'sinin 5. sınıf ve 7. sınıfta eğitimine devam ettiği ve

[1] Bu çalışma, Türkiye Bilimsel ve Teknolojik Araştırma Kurumu (TÜBİTAK) Bilim ve Toplum Başkanlığı tarafından yürütülen 4008 Özel Gereksinimli Bireylere Yönelik Kapsayıcı Toplum Uygulamaları Destekleme Programı'nın 2025/3 döneminde 125B160 proje numarası ile destek almaya hak kazanmıştır.

ISBN NR: 978-625-5694-92-8

%36'sının Rehberlik ve Araştırma Merkezi'nde bir yıldır bulunduğu belirlenmiştir. Öğrencilerin benlik saygıları başlangıç puanı 17,64±2,91 olup gerçekleştirilen program sonrasında benlik saygılarının (34,80±2,24) yükseldiği belirlenmiştir. Öğrencilere uygulanan programın öğrencilerin yeniden değerlendirme puanını arttırdığı (Medyan ön test: 13; Medyan son test: 25), bastırma puanını ise azalttığı (Medyan ön test: 17; Medyan son test: 8) belirlenmiştir. Çalışmada doğa temelli uygulamaların ve gevşeme tekniklerinin ÖG olan öğrencilerin duygu düzenlemelerini geliştirdiği ve benlik sayısını arttırdığı saptanmıştır. Duygu düzenlemeleri gelişen ve benlik sayısı artan öğrencilerin sosyal hayat ve okula psikososyal uyumlarının artacağı düşünülmektedir. Bunun için eğitim müfredatlarına doğa temelli uygulamaların ve gevşeme tekniklerinin eklenmesi önerilmektedir.

Anahtar Kelimeler: Öğrenme Güçlüğü, Doğa Temelli Uygulamalar, Gevşeme Teknikleri, Duygu Düzenleme, Benlik Saygısı, Öğrenci

ISBN NR: 978-625-5694-92-8

THE EFFECTS OF NATURE-BASED INTERVENTIONS AND RELAXATION TECHNIQUES ON EMOTION REGULATION AND SELF-ESTEEM IN STUDENTS WITH LEARNING DISABILITIES[2]

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ABSTRACT

This study aimed to examine the effects of nature-based interventions and relaxation techniques on emotion regulation and self-esteem in students with learning disabilities (LD). The study was conducted with 25 voluntary students aged 10–12 years who had been diagnosed with LD, applied to special education and rehabilitation centers in Ardahan, and had no health conditions preventing participation. A single-group pretest–posttest experimental design without a control group was employed. The intervention was carried out between September 6 and October 25, 2025, consisting of eight weekly sessions, each including two 40-minute sessions separated by a 20-minute snack break. Data were collected using the Personal Information Form, the Rosenberg Self-Esteem Scale for Children, and the Emotion Regulation Questionnaire for Children and Adolescents as pretests and posttests. The mean age of the students was 11.12±0.88 years. Of the participants, 72% were male, 40% had two siblings, and 48% were middle children. It was determined that 72% of the participants did not have a family member with special needs or requiring care, 20% were attending the 5th and 7th grades, and 36% had

[2] This study was supported by the Scientific and Technological Research Council of Türkiye (TÜBİTAK) through the 4008 Inclusive Science and Social Practices Support Programme for Individuals with Special Needs, implemented by the Directorate of Science and Society, during the 2025/3 call period (Project No. 125B160).

been registered at the Guidance and Research Center for one year. The baseline self-esteem score of the students was 17.64±2.91, which significantly increased to 34.80±2.24 after the intervention. The program was found to increase students' cognitive reappraisal scores (median pretest: 13; median posttest: 25) while decreasing suppression scores (median pretest: 17; median posttest: 8). The findings indicate that nature-based interventions and relaxation techniques improve emotion regulation and enhance self-esteem in students with learning disabilities. Improved emotion regulation and increased self-esteem are expected to contribute positively to students' psychosocial adjustment to school and social life. Therefore, it is recommended that nature-based interventions and relaxation techniques be integrated into educational curricula.

Keywords: Learning Disability, Nature-Based Interventions, Relaxation Techniques, Emotion Regulation, Self-Esteem, Student

ISBN NR: 978-625-5694-92-8

HEMODİYALİZ HASTALARINDA İLAÇ GÜVENLİĞİ VE AKILCI İLAÇ KULLANIMINDA HEMŞİRENİN ROLÜ

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ÖZET

Kronik böbrek hastalığı (KBH), artan prevalansı ve yüksek komorbidite yükü ile küresel bir halk sağlığı sorunudur. Son dönem böbrek yetmezliği tedavisinde uygulanan hemodiyaliz, hastaların yaşam süresini uzatırken, çoklu ilaç kullanımını zorunlu kılmaktadır. Bu derlemenin amacı; hemodiyaliz hastalarında ilaç güvenliğini tehdit eden risk faktörlerini, hastaların ilaç kullanım davranışlarındaki eksiklikleri ve akılcı ilaç kullanımı sürecinde hemşirenin rolünü son beş yılın literatürü ışığında incelemektir. Literatür verileri, hemodiyaliz hastalarının yoğun polifarmasi yükü altında olduğunu, ancak hastaların akılcı ilaç kullanımı konusundaki bilgi düzeylerinin genel olarak düşük olduğunu göstermektedir. Güncel çalışmalarda hastaların önemli bir kısmının (%96,5) ilaçları yanlış koşullarda sakladığı, prospektüs okuma alışkanlıklarının düşük olduğu (%21,1) ve ilaç kullanımı konusunda hemşirelerden yeterince bilgi almadıkları (%6,6) belirlenmiştir. Azalmış renal klirens ve değişen protein bağlanma oranları ilaçların toksisite riskini artırırken, hastaların bu tür yanlış kullanım alışkanlıkları tedavi başarısını doğrudan etkilemektedir. Bu süreçte hemşireler; sadece ilacı uygulayan değil, hastaların yanlış saklama ve kullanım alışkanlıklarını düzelten, "8 doğru ilke"yi diyaliz dinamiklerine göre uygulayan ve multidisipliner ekip içinde akılcı ilaç yönetimini sağlayan kilit profesyonellerdir. İlaç güvenliğinin ve akılcı ilaç kullanımının sağlanması, hemşirelerin farmakolojik okuryazarlığının artırılmasına ve hasta eğitiminde daha aktif rol almalarına bağlıdır.

Anahtar Kelimeler: Hemodiyaliz, Akılcı İlaç Kullanımı, İlaç Güvenliği, Polifarmasi, Hasta Güvenliği, Hemşirelik Bakımı.

ISBN NR: 978-625-5694-92-8

THE ROLE OF NURSES IN MEDICATION SAFETY AND RATIONAL DRUG USE IN HEMODIALYSIS PATIENTS

ABSTRACT

Chronic kidney disease (CKD) is a global public health concern due to its increasing prevalence and high comorbidity burden. Hemodialysis, a treatment for end-stage renal disease, prolongs patient survival but necessitates complex medication regimens. This review aims to examine the risk factors that threaten medication safety, patients' deficiencies in medication use behaviors, and the role of nurses in promoting rational drug use, based on literature from the past five years. The evidence indicates that hemodialysis patients are subjected to a high polypharmacy load, while their knowledge regarding rational medication use remains generally low. Recent studies reveal that a significant proportion of patients (96.5%) store medications improperly, have low adherence to reading drug leaflets (21.1%), and receive insufficient information from nurses regarding medication use (6.6%). Reduced renal clearance and altered protein binding increase the risk of drug toxicity, and patients' improper usage behaviors directly affect treatment outcomes. In this context, nurses play a pivotal role not only in drug administration but also in correcting patients' misuse and storage habits, applying the "8 rights" principle adapted to dialysis dynamics, and ensuring rational drug management within a multidisciplinary team. Ensuring medication safety and rational drug use depends on enhancing nurses' pharmacological literacy and their active engagement in patient education.

Keywords: Hemodialysis, Rational Drug Use, Medication Safety, Polypharmacy, Patient Safety, Nursing Care

1. GİRİŞ

Kronik böbrek hastalığı (KBH), 21. yüzyılda prevalansı hızla artan, mortalite ve morbidite oranları yüksek, sağlık sistemleri üzerinde önemli klinik ve ekonomik yük oluşturan başlıca kronik hastalıklardan biridir. Global Burden of Disease (GBD) 2023 iş birliği grubunun yayınladığı en güncel rapora göre, 1990 yılında dünya genelinde 378 milyon olan KBH'li birey sayısı, 2023 yılı itibarıyla 788 milyona ulaşmıştır. Yaşa standardize edilmiş prevalansın %14,2 gibi yüksek bir düzeyde bildirilmesi, kronik böbrek hastalığının sadece nefrolojik bir fonksiyon kaybı ile sınırlı olmaktan öte, diyabet ve hipertansiyon gibi yaygın kronik sistemik hastalıkların oluşturduğu multimorbidite sürecinin bir yansımasıdır. Son dönem böbrek yetmezliği (SDBY) aşamasında temel tedavi olarak uygulanan hemodiyaliz, hastaların yaşam süresini uzatmada önemli bir rol üstlense de beraberinde getirdiği karmaşık tedavi süreci nedeniyle hastaları yoğun bir farmakolojik yükle karşı karşıya bırakmaktadır.

Literatürde polifarmasi; genellikle günde beş veya daha fazla ilacın kullanımı olarak tanımlansa da hemodiyaliz hastaları için bu durum istisnai bir süreç değil, klinik standartın bir parçasıdır. Oosting ve ark. (2024) tarafından yapılan geniş kapsamlı meta-analiz, KBH hastalarında polifarmasi prevalansının %80'in üzerinde olduğunu ve en yüksek ilaç yükünün diyaliz hastalarında görüldüğünü ortaya koymaktadır. Bu hasta grubunda polifarmasi, sadece ilaç sayısındaki artış değil; ilaç-ilaç etkileşimleri, düşme riski, bilişsel fonksiyon kaybı ve tedaviye

ISBN NR: 978-625-5694-92-8

uyumsuzluk gibi ciddi komplikasyonlara neden olan, yönetimi güçleştiren bir klinik durum olarak ele alınmalıdır. Ayrıca üremik ortam, özellikle renal klirensin azalması nedeniyle, ilaçların farmakokinetik özelliklerini, metabolizmasını ve eliminasyon yarı ömrünü değiştirerek toksisite riskini kritik düzeyde artırırken; diyaliz süreci ise, suda çözünen ilaçların seans sırasında kaybına yol açarak, doz ayarlamalarında ciddi hatalara zemin hazırlamaktadır.

İlaç güvenliği zincirinin en zayıf halkası ise hastaların ilacı yönetim sürecidir. Akılcı İlaç Kullanımı (AİK), hastaların klinik ihtiyaçlarına ve bireysel özelliklerine uygun ilacı, gereksinimlerini karşılayacak doğru dozda, yeterli süre boyunca ve en düşük maliyetle kullanması olarak tanımlanır; ancak pratik uygulamada durum oldukça farklıdır. Boyacı Uysal'ın (2023) çalışması, hastaların %96,5'inin soğuk zincir ilaçlarını, ısı değişiminin en yoğun olduğu buzdolabı kapağında saklayarak ilacın etkinliğini riske attığını göstermektedir. Buna ek olarak, hastaların %56,1'inin "ileride lazım olur" düşüncesiyle evde ilaç stokladığı ve %21,1'inin kullandığı ilacın prospektüsünü hiç okumadığı belirlenmiştir. Bayram ve İbrahimoğlu (2022) ise hastaların %58'inin evlerinde hiç kullanılmamış veya yarım kalmış artık ilaç bulundurduğunu, bu durumun hem ekonomik israf hem de kontrolsüz ilaç kullanımı açısından ciddi bir halk sağlığı sorunu oluşturduğunu raporlamıştır.

Bu karmaşık tabloda, sağlık sistemi ile hasta arasındaki kilit rolü hemşire üstlenmektedir. Ancak mevcut veriler, hemşirelerin bu kritik rolü tam anlamıyla üstlenemediğine işaret etmektedir. Yurtsever ve Tiftik (2025), Türkiye'deki hemşirelerin AİK bilgi düzeylerini 2010-2024 yılları arasındaki veriler ışığında incelediklerinde, hemşirelerin en sık yaptığı hatanın %57 oranıyla "yanlış zamanda ilaç uygulama" olduğunu saptamıştır. Ayrıca hastaların ilaç kullanımı konusunda bilgiyi hemşireden alma oranının %6,6 (Uysal, 2024) gibi çok düşük seviyelerde kalması, hemşirelik bakımında eğitimci ve danışman rollerinin klinikte yeterince aktif kullanılamadığını kanıtlamaktadır.

Bu derlemenin amacı; hemodiyaliz hastalarında giderek artan polifarmasi yükünü, hastaların akılcı ilaç kullanımındaki bilgi ve davranışsal hatalarını ve bu süreçte hemşirenin üstlenmesi gereken kritik rollerini güncel ve kanıta dayalı verilerle bütüncül bir yaklaşımla incelemektir.

2.HEMODİYALİZ HASTALARINDA AKILCI İLAÇ YÖNETİMİ, GÜVENLİK RİSKLERİ VE HEMŞİRENİN ROLÜ

2.1. Hemodiyalizde Akılcı İlaç Kullanımı ve İlaç Güvenliği

Dünya Sağlık Örgütü (DSÖ), akılcı ilaç kullanımını; "hastaların klinik bulgularına ve bireysel özelliklerine uygun ilacı, doğru dozda, yeterli süre boyunca ve en düşük maliyetle temin edebilmeleri" olarak tanımlamaktadır. Ancak hemodiyaliz hastalarında bu tanım, standart bir reçete uyumunun çok ötesinde, dinamik ve çok boyutlu bir klinik yönetim sürecini ifade etmektedir.

Son dönem böbrek yetmezliği popülasyonunda ilaç güvenliği; fizyolojik yıkım, farmakokinetik hassasiyet ve artmış tedavi yükünün kesiştiği çok boyutlu bir süreçtir. Böbrek fonksiyonlarının kaybıyla birlikte renal klirensin azalması, ilaçların eliminasyon yarı ömrünü uzatarak

ISBN NR: 978-625-5694-92-8

metabolitlerin vücutta birikmesine (akümülasyon) neden olmakta; bu durum, özellikle dar terapötik aralığa sahip ilaçlarda, standart dozlarda dahi toksisite riskini anlamlı düzeyde artırmaktadır. Ayrıca üremik ortamın plazma proteinlerine bağlanmayı değiştirerek serbest ilaç fraksiyonunu artırması, ilacın kanda öngörülemez düzeylere ulaşmasına neden olabilmektedir.

Dolayısıyla hemodiyalizde "akılcı yaklaşım"; statik bir doz rejimi değil, ilacın dozunun kalan böbrek fonksiyonuna (GFR) ve diyalizle temizlenme oranına (diyalizabilite) göre dinamik olarak ayarlandığı, hemşire gözetiminde kesintisiz bir ilaç yönetimini zorunlu kılar.

2.2. Klinik Risk Alanları: Polifarmasi Yükü ve Zamanlama Hataları

Hemodiyaliz hastalarındaki en büyük risklerden biri polifarmasidir. Oosting ve ark. (2024) tarafından yapılan sistematik derlemede, kronik böbrek hastalığı olan bireylerde (KBH) polifarmasi prevalansının %80'in üzerinde olduğu ve ilaç yükünün en yoğun olduğu grubun hemodiyaliz hastaları olduğu raporlanmıştır. Bu yoğun yük; hastalarda bıkkınlık ve kafa karışıklığı yaratarak tedaviye uyumu zorlaştırmakta, advers etki ve çok boyutlu farmakolojik etkileşimlerine yol açarak klinik riski önemli ölçüde artırmaktadır.

Tedavi başarısını doğrudan etkileyen bir diğer kritik faktör ise "zamanlama"dır. İlacın moleküler ağırlığına ve suda çözünürlüğüne bağlı olarak diyalizle uzaklaştırılması, dozun seanstan sonra alınmasını gerektirebilir. Zamanlama hataları tedavi başarısızlığının sinsi bir nedenidir; örneğin diyaliz öncesi alınan bir antihipertansif, işlem sırasında diyalizör membranlarından süzülerek tedavinin yetersiz kalmasına (hipertansif kriz) yol açabileceği gibi, işlem sırasında kan basıncının ani düşmesiyle intradiyalitik hipotansiyon riskini de tetikleyebilir. Dolayısıyla ilaç uygulama zamanının doğru planlanması, hemodiyaliz hastalarında farmakoterapinin ayrılmaz bir bileşenidir.

2.3. Hasta Davranışları: Bilgi Eksikliği ve Tehlikeli Uygulamalar

Klinik ortamda mevcut olan fizyolojik ve farmakolojik riskler, hastaların evdeki hatalı ilaç yönetimi alışkanlıklarıyla birleştiğinde tablo daha da ağırlaşmaktadır. Boyacı Uysal'ın (2023) çalışması, hemodiyaliz hastalarının akılcı ilaç kullanımı konusundaki bilgi düzeylerinin yetersiz olduğunu ve evde tehlikeli uygulamalar yaptıklarını ortaya koymaktadır. Çalışmaya göre:

- Soğuk Zincir İhlali: Hastaların %96,5'i, soğuk zincir gerektiren ilaçları ısı değişiminin en yoğun olduğu buzdolabı kapağında yanlış şekilde saklamaktadır. Bu durum ilacın etkinliğini yitirmesine neden olmaktadır.
- Yanlış Saklama: Hastaların %64'ü, oda sıcaklığında saklanması gereken ilaçları gereksiz yere buzdolabına koyarak nem dengesini bozmakta ve ilacın kimyasal yapısının değişimine yol açmaktadır.
- Bilinçsiz Kullanım: Hastaların %21,1'i ilaç prospektüslerini hiç okumamakta ve %56,1'i "ileride lazım olur" düşüncesiyle evde ilaç stoklamaktadır.

Bu verilere ek olarak Bayram ve İbrahimoğlu (2022), hastaların %58'inin evlerinde hiç kullanılmamış veya yarım kalmış artık ilaç bulundurduğunu bildirmiştir. Bu durum kontrolsüz

ISBN NR: 978-625-5694-92-8

ve hatalı dozda ilaç kullanım riskini artırarak hem hasta güvenliği hem de ekonomik kayıp açısından önemli bir risk alanı oluşturmaktadır. Ayrıca hastaların semptom yükü arttıkça, reçetesiz ilaçlara veya bitkisel ürünlere yönelimlerinin artması, tedavi sürecinin bütüncül ve güvenli yönetimini zorlaştırmaktadır.

2.4. Hemşirelik Rolü: Klinik Sorumluluk ve Yapısal Yetersizlikler

Hemodiyaliz ünitelerinde hemşire, karmaşık farmakoterapi süreçleri ile hasta güvenliği arasındaki en kritik profesyoneldir. Bu rol, standart "8 doğru ilkesi"nin (doğru hasta, ilaç, doz, yol, zaman, eğitim, kayıt, yanıt) diyaliz dinamiklerine göre yeniden yorumlanmasını ve farmakokinetik değişkenlerin aktif biçimde izlenmesini gerektirmektedir. Ancak literatür, hemşirelik uygulamalarında, eğitimci ve danışman rollerinde ciddi aksaklıklar olduğuna dikkat çekmektedir.

- Uygulama Hataları (Zamanlama Krizi): Yurtsever ve Tiftik (2025) tarafından yapılan ve 2010-2024 yıllarını kapsayan geniş çalışmada, hemşirelerin ilaç güvenliğiyle ilgili en sık yaptığı hata %57 oranıyla "yanlış zamanlama" olduğu belirlenmiştir. Bu veri, hemşirelerin ilaçların farmakokinetik özelliklerine dair bilgi eksikliği yaşadığını ve ilaç uygulama saatlerini yönetmekte yetersiz kaldığını göstermektedir. Ayrıca çalışmada, hemşirelerin ilaç etkileşimleri konusunda eğitim gereksinimi duydukları belirtilmiştir.
- Eğitimdeki Yetersizlik (İletişim Kopukluğu): Hemşireler, diyaliz seansları nedeniyle hastayla en sık ve en uzun süre temas eden profesyoneller olmasına rağmen, hastaların bilgi kaynağı olarak hemşireyi tercih etme oranları anlamlı ölçüde düşüktür. Boyacı Uysal (2023), hastaların ilaç bilgisi için %38,2 oranında hekime, %28,5 oranında eczacıya başvurduğunu; buna karşılık hemşirelerden bilgi alma oranının sadece %6,6 seviyesinde kaldığını belgelemektedir.

3. SONUÇ VE ÖNERİLER

Hemodiyaliz hastaları; azalmış renal fonksiyonların neden olduğu fizyolojik kırılganlıklar ve yönetimi zorlu yüksek polifarmasi yükü nedeniyle tıbbi hatalar açısından yüksek risk grubundadır. Ancak hemodiyaliz hastalarında ilaç güvenliği ve akılcı ilaç kullanımı, yalnızca doğru reçetenin yazılmasıyla sağlanamaz. Mevcut veriler, hastaların evde ilaçları yanlış sakladığını, hemşirelerin ise klinik uygulamada zamanlama hataları yaptığını (%57) ve eğitimci rollerini etkin kullanamadıklarını (%6,6) somut olarak göstermektedir. Güner'in (2021) belirttiği gibi, yapılandırılmış hemşirelik eğitimi, hastaların sağlık okuryazarlığını artırarak bu riskleri minimize etmenin en etkili yoludur ve bu bağlamda mevcut boşluğun doldurulması bir tercih değil, hasta güvenliğinin sürdürülebilirliği açısından klinik bir gerekliliktir.

Bu doğrultuda, hemodiyaliz ünitelerinde ilaç güvenliği ve akılcı ilaç kullanım kültürünün güçlendirilmesine yönelik aşağıdaki öneriler geliştirilmiştir:

- Farmakolojik Okuryazarlığın Artırılması**:** Hemşirelerin ilaç-besin etkileşimleri, diyalizabilite, doz ayarlamaları ve doğru zamanlama konusundaki yetkinliklerini

ISBN NR: 978-625-5694-92-8

artırmak amacıyla, Yurtsever ve Tiftik (2025) verilerinde görülen eksiklikleri giderecek periyodik hizmet içi eğitimler zorunlu hale getirilmelidir.

- "İlaç Danışmanlığı" Rolünün Yapılandırılması: Hemşireler, bakım planlarında sadece uygulayıcı değil, hastanın farmakolojik sürecini yöneten "temel danışman" olarak konumlandırılmalı; hastaların diğer sağlık profesyonellerinden önce hemşireye danışabileceği bir iletişim köprüsü kurulmalıdır.
- Ev İçi Süreçlerin Denetimi**:** Hastaların evdeki ilaç saklama koşulları ve artık ilaç yönetimleri; tele-sağlık uygulamaları veya planlı ev ziyaretleri aracılığıyla hemşireler tarafından düzenli olarak takip edilmelidir. Bu yaklaşım, klinik ve ev ortamı arasındaki güvenlik boşluğunu azaltacaktır.
- Bütüncül ve Multidisipliner Yaklaşım: İlaç güvenliği sadece hastane sınırları içerisinde değil; hasta yakınlarının ve sosyal destek sistemlerinin sürece dahil edildiği, tüm sağlık profesyonellerinin iş birliğine dayalı bütüncül bir bakım modeliyle yönetilmelidir.

Sonuç olarak; ilaç güvenliği ve akılcı ilaç kullanımı, hemodiyaliz sürecinde birbirini tamamlayan ve sistematik yönetim gerektiren kavramlardır. Bu bağlamda, hemşirelerin farmakolojik okuryazarlığının ve klinik liderliğinin artırılması, sürdürülebilir güvenlik kültürünün temel bileşenidir. Hemşirelik rolünün bu yönde güçlendirilmesi hem klinik risklerin yönetimini sağlayacak hem de hasta odaklı bakımı ve yaşam kalitesini anlamlı biçimde yükseltecektir.

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ISBN NR: 978-625-5694-92-8

HEMŞİRELİK ÖĞRENCİLERİNİN TIBBİ CİHAZ İLİŞKİLİ BASINÇ YARALANMALARINI ÖNLEMEYE YÖNELİK BİLGİ DÜZEYLERİ İLE TUTUMLARI ARASINDAKİ İLİŞKİ

AN EXAMINATION OF THE RELATIONSHIP BETWEEN NURSING STUDENTS' KNOWLEDGE LEVELS AND ATTITUDES TOWARD THE PREVENTION OF MEDICAL DEVICE–RELATED PRESSURE INJURIES

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ÖZET

Giriş ve Amaç: Tıbbi cihaz ilişkili basınç yaralanmaları (TCİBY), sağlık bakım ortamlarında sık görülen ve büyük ölçüde önlenebilir komplikasyonlar arasında yer alan önemli bir hasta güvenliği sorunudur. Tanı, tedavi ve izlem süreçlerinde tıbbi cihazların yaygın kullanımı bu yaralanmaların gelişme riskini artırmaktadır. TCİBY'nin önlenmesi ve erken tanılanmasında hemşireler kritik bir role sahiptir. Bu nedenle hemşirelik öğrencilerinin konuya ilişkin bilgi ve tutumlarının belirlenmesi önem taşımaktadır. Bu araştırmanın amacı, hemşirelik öğrencilerinin TCİBY'nin önlenmesine yönelik bilgi düzeyleri ile tutumlarını belirlemek ve bu iki değişken arasındaki ilişkiyi incelemektir.

Yöntem: Tanımlayıcı ve ilişkisel tipte planlanan bu araştırma, 2025-2026 Eğitim Öğretim Dönemi Bahar yarıyılında bir üniversitenin hemşirelik bölümünde öğrenim gören ve araştırmaya katılmayı kabul eden 140 dördüncü sınıf hemşirelik öğrencisi ile gerçekleştirilmiştir. Araştırma verileri; Kişisel Bilgi Formu, Tıbbi Cihaz İlişkili Basınç Yaralanması Bilgi Ölçeği ve TCİBY'ye İlişkin Tutum Anketi kullanılarak yüz yüze görüşme yöntemi ile toplanmıştır. Verilerin analizi SPSS 27.0 paket programında yapılmış; tanımlayıcı istatistikler, parametrik ve nonparametrik testler ile korelasyon analizleri kullanılmıştır. İstatistiksel anlamlılık düzeyi $p < 0.05$ olarak kabul edilmiştir.

Bulgular: Araştırmaya katılan öğrencilerin %77,9'unun kadın, %22,1'inin erkek olduğu belirlenmiştir. Öğrencilerin TCİBY bilgi ölçeği toplam puan ortalaması 12,42±3,62 olup bilgi düzeylerinin orta düzeyde olduğu saptanmıştır. Alt boyutlar incelendiğinde en düşük puanın kavram ve evrelendirme, en yüksek puanın ise bakım ve pansuman alt boyutunda olduğu belirlenmiştir. TCİBY'ye yönelik tutum anketi toplam puan ortalaması 22,21±7,89 olarak bulunmuştur. Öğrencilerin %79,3'ünün olumsuz, %16,4'ünün tarafsız ve %4,3'ünün olumlu

tutuma sahip olduğu belirlenmiştir. Ayrıca öğrencilerin TCİBY gelişme riskini belirleme konusunda kendilerini yeterli görme düzeyleri ile bilgi puanları arasında pozitif yönlü zayıf bir ilişki olduğu saptanmıştır. Bununla birlikte bilgi düzeyi ile tutum puanları arasında negatif yönlü zayıf bir ilişki bulunmuştur ($p < 0.05$).

Sonuç: Araştırma bulguları, hemşirelik öğrencilerinin TCİBY'ye yönelik bilgi düzeylerinin orta düzeyde olduğunu ve öğrencilerin büyük çoğunluğunun TCİBY'nin önlenmesine yönelik olumsuz tutuma sahip olduğunu göstermektedir. Ayrıca bilgi düzeyi ile tutum arasında zayıf düzeyde bir ilişki olduğu belirlenmiştir. Bu sonuçlar, hemşirelik eğitim programlarında TCİBY'nin önlenmesine yönelik bilgi, farkındalık ve klinik becerilerin geliştirilmesine yönelik eğitim içeriklerinin güçlendirilmesi gerektiğine işaret etmektedir.

Anahtar Kelimeler: Hemşirelik öğrencileri, Tıbbi cihaz ilişkili basınç yaralanmaları, Önleme ve kontrol, Bilgi, Tutum

ABSTRACT

Introduction and Aim: Medical device–related pressure injuries (MDRPIs) are an important patient safety issue frequently encountered in healthcare settings and are largely preventable complications. The widespread use of medical devices in diagnostic, therapeutic, and monitoring processes increases the risk of developing these injuries. Nurses play a critical role in the prevention and early identification of MDRPIs. Therefore, determining nursing students' knowledge and attitudes regarding this issue is important. This study aimed to determine nursing students' knowledge levels and attitudes toward the prevention of MDRPIs and to examine the relationship between these two variables.

Methods: This descriptive and correlational study was conducted during the spring semester of the 2025–2026 academic year with 139 fourth-year nursing students studying in the nursing department of a university who agreed to participate in the study. The research data were collected through face-to-face interviews using three instruments: a Personal Information Form, the Medical Device-Related Pressure Injury Knowledge Scale, and the Attitude Questionnaire Toward MDRPIs. Data were analyzed using the SPSS 27.0 statistical package program. Descriptive statistics, parametric and nonparametric tests, and correlation analyses were performed. Statistical significance was accepted as $p < 0.05$.

Results: It was determined that 77.9% of the participating students were female and 22.1% were male. The mean total score of the MDRPI Knowledge Scale was 12.42 ± 3.62, indicating a moderate level of knowledge. When the subdimensions were examined, the lowest score was obtained in the concept and staging dimension, whereas the highest score was found in the care and dressing dimension. The mean total score of the Attitude Questionnaire Toward MDRPIs was 22.21 ± 7.89. It was found that 79.3% of the students had negative attitudes, 16.4% had neutral attitudes, and 4.3% had positive attitudes. In addition, a weak positive relationship was found between students' self-perceived competence in determining the risk of MDRPI development and their knowledge scores. However, a weak negative relationship was identified between knowledge levels and attitude scores ($p < 0.05$).

Conclusion: The findings of the study indicate that nursing students have a moderate level of knowledge regarding medical device–related pressure injuries (MDRPIs) and that the majority of students have negative attitudes toward the prevention of MDRPIs. In addition, a weak relationship was identified between knowledge levels and attitudes. These results suggest the need to strengthen educational content aimed at improving knowledge, awareness, and clinical skills related to the prevention of MDRPIs within nursing education programs.

Keywords: Nursing students, medical device-related pressure injuries, prevention and control, knowledge, attitude

1. GİRİŞ

Tıbbi cihazlarla ilişkili basınç yaralanmaları (TCİBY), hastane ortamlarında yaygın olarak görülen, hasta güvenliğini tehdit eden ve bakım kalitesini olumsuz etkileyen önemli bir klinik sorundur. Bu yaralanmalar, hastaların yaşam kalitesini düşürmenin yanı sıra hastanede kalış süresinin uzamasına ve sağlık hizmeti maliyetlerinin artmasına neden olmaktadır (Ayık ve ark., 2025). Klinik, psikososyal ve ekonomik boyutlarıyla TCİBY'ler, hem hastalar hem de sağlık profesyonelleri açısından giderek artan bir bakım yükü oluşturmaktadır (Aydın Kahraman ve ark., 2024).

TCİBY'ler, deri ve altta yatan dokuların tıbbi cihazlara bağlı olarak uzun süreli basınç, sürtünme veya kesme kuvvetlerine maruz kalması sonucunda gelişmektedir. Tanı, tedavi ve izlem süreçlerinde kullanılan tüm tıbbi cihazlar, kullanım süresi, yerleşimi ve sabitleme şekline bağlı olarak potansiyel basınç yaralanması riski taşımaktadır (Erbay ve ark., 2019). Bu yaralanmalar, etiyoloji ve yerleşim açısından klasik basınç yaralarından farklılık göstermekte; çoğunlukla kemikli çıkıntılar yerine cihazın temas ettiği cilt ve mukozal yüzeylerde ortaya çıkmaktadır (Kara ve ark., 2020).

Cihaz ile cilt arasında nem ve ısı birikiminin oluşması, cildin mikroiklimini bozarak doku toleransını azaltmaktadır. Ayrıca, tıbbi cihazların sızdırmazlık sağlamak amacıyla sıkı şekilde sabitlenmesi, kemikli çıkıntılar dışında alışılmadık anatomik bölgelerde basınç oluşmasına neden olabilmektedir. Cihaz sabitlemede kullanılan bant ve kayışların, cihaz altındaki cildin düzenli değerlendirilmesini zorlaştırması da basınç yarası gelişme riskini artıran faktörler arasında yer almaktadır (Black ve ark., 2010).

Literatürde, TCİBY'lerin hastane kaynaklı basınç yaralanmalarının önemli bir bölümünü oluşturduğu ve tüm basınç yaralarının %30'unu kapsayabildiği bildirilmektedir (Gou ve ark., 2023, Soysal ve ark., 2025). Tıbbi cihaza gereksinim duyan hastalarda TCİBY gelişme riskinin, bu gereksinimi olmayan hastalara göre 2,4 kat daha yüksek olduğu belirtilmektedir (Soysal ve ark., 2025). Özellikle yoğun bakım ve palyatif bakım üniteleri gibi tıbbi cihaz kullanımının yoğun olduğu kliniklerde bu yaralanmaların daha sık görüldüğü vurgulanmaktadır (Pamuk Cebeci ve ark., 2024).

Yoğun bakım hastalarında yapılan çalışmalarda; ileri yaş, diabetes mellitus, ödem varlığı, düşük Braden ölçeği puanı, yüksek SOFA ve APACHE II skorları, tıbbi cihazların uzun süreli kullanımı, vazokonstriktör tedavisi, cerrahi girişim, pron pozisyonu, pron pozisyonda ventilasyon ve subglottik aspirasyon kateteri kullanımı TCİBY gelişme riskini artıran başlıca faktörler olarak belirlenmiştir. Buna karşılık, hemoglobin ve serum albümin düzeyleri yüksek olan hastalarda TCİBY gelişme riskinin daha düşük olduğu bildirilmiştir (Gou ve ark., 2023). Bu bulgular, TCİBY gelişiminin çok faktörlü bir yapıya sahip olduğunu ve sistematik risk değerlendirmesinin gerekliliğini ortaya koymaktadır.

ISBN NR: 978-625-5694-92-8

TCİBY'lerin önlenmesi ve erken tanılanmasında hemşireler kilit bir role sahiptir. Tıbbi cihazların doğru yerleştirilmesi, düzenli cilt değerlendirmesi, riskli hastaların erken belirlenmesi ve koruyucu hemşirelik girişimlerinin uygulanması, TCİBY gelişimini önlemede temel stratejiler arasında yer almaktadır (Kurtgöz ve ark., 2024). Hemşirelik öğrencilerinde tıbbi cihaz ilişkili basınç yaralanmalarının önlenmesine yönelik bilgi ve tutumların öğrencilik döneminde kazandırılması önemlidir. Özellikle son sınıf öğrencilerinin klinik uygulamalarda hasta bakımına aktif olarak katılmaları ve mezuniyet sonrası profesyonel hemşirelik rollerini üstlenecek olmaları, bu konudaki bilgi ve tutumların bakım kalitesi üzerindeki etkisini artırmaktadır (Erzincanlı ve ark., 2025). Bu bağlamda, hemşirelik son sınıf öğrencilerinin tıbbi cihaz ilişkili basınç yaralanmalarını önlemeye yönelik bilgi düzeyleri ile tutumları arasındaki ilişkinin incelenmesi, hasta güvenliğinin artırılması, kanıta dayalı hemşirelik bakımının güçlendirilmesi ve hemşirelik eğitim programlarının geliştirilmesine katkı sağlayacak önemli bir bilimsel gereklilik olarak değerlendirilmektedir.

Araştırma Sorusu

1. Hemşirelik öğrencilerinin tıbbi cihaz ilişkili basınç yaralanmalarını önlemeye yönelik bilgi düzeyleri nasıldır?
2.Hemşirelik öğrencilerinin tıbbi cihaz ilişkili basınç yaralanmalarını önlemeye yönelik tutumları nasıldır?
3.Hemşirelik öğrencilerinin tıbbi cihaz ilişkili basınç yaralanmalarını önlemeye yönelik bilgi düzeyleri ile tutumları arasında ilişki var mıdır?

2. GEREÇ-YÖNTEM

Tanımlayıcı ve ilişkisel nitelikte olan bu araştırma, bir üniversitenin hemşirelik fakültesinde, gerekli etik kurul ve kurum izninin alınmasının ardından, 2025-2026 Eğitim Öğretim Dönemi Bahar yarıyılında yürütüldü. Araştırmanın evrenini hemşirelik bölümünde okuyan 4. sınıf öğrenciler (N=186) oluşturdu. Örneklem büyüklüğü evreni bilinen örneklem formülü kullanılarak %95 güven aralığı ve %5 hata payı ile 126 olarak hesaplandı. Olası veri kaybı dikkate alınarak en az 139 kişiye ulaşılması planlandı. Kolay ulaşılabilir örnekleme yöntemi kullanıldı ve toplam 140 öğrenciye ulaşıldı.

Araştırmaya Dahil Olma Kriterleri;

-Hemşirelik lisans programına kayıtlı olmak
- Hemşirelik son sınıf öğrencisi olmak
- Araştırmaya gönüllü olmak

Araştırmaya katılmayı kabul eden ve dâhil edilme kriterlerini karşılayan toplam 140 hemşirelik öğrencisinden yüz yüze görüşme yöntemi ile veri toplanmıştır.

Araştırmanın Değişkenleri;

Bağımlı Değişken: Hemşirelik öğrencilerinin tıbbi cihaz ilişkili basınç yaralanması bilgi ölçeği ve tıbbi cihaz ilişkili basınç yaralanmalarına ilişkin tutum anketi toplam puan ortalamalarıdır.

Bağımsız Değişken: Hemşirelik öğrencilerinin yaşı, cinsiyetı, vb. sosyodemografik özellikleri, tıbbi cihaz ilişkili basınç yaralarına (TDİBY) yönelik eğitim alma durumları, klinik deneyimleri ve kendilerini yeterli görme düzeyleridir.

Veri Toplama Araçları

ISBN NR: 978-625-5694-92-8

Araştırma verileri, Kişisel Bilgi Formu, Tıbbi Cihaz İlişkili Basınç Yaralanması Bilgi Ölçeği, Tıbbi Cihaz İlişkili Basınç aralanmalarına İlişkin Tutum Anketi ile yüz yüze görüşme yöntemi ile toplanacaktır.

Kişisel Bilgi Formu: Araştırmacı tarafından literatür doğrultusunda (Kahraman ve ark, 2024; Yüksel ve ark., 2023; Erzincanlı ve ark., 2025; Kır Biçer 2021; Gürlek ve ark., 2020) oluşturulan bu formda hemşirelik öğrencilerinin yaşı, cinsiyeti, TCİBY'ye yönelik eğitim alma durumu ve klinik deneyimlerini içeren toplam 15 sorudan oluşmaktadır.

Tıbbi Cihaz İlişkili Basınç Yaralanması Bilgi Ölçeği:Ölçek toplam beş alt boyut ve 25 maddeden oluşmaktadır. Alt boyutlar incelendiğinde;

•Faktör 1: Kavram ve evrelendirme (Madde 1 ve 2)
•Faktör 2: Risk değerlendirme (Madde 3, 4 ve 5)
•Faktör 3: Tıbbi cihazın seçimi ve uygunluğu (Madde 6, 7, 8, 9, 10, 11, 12)
•Faktör 4: Bakım ve pansuman (Madde 13, 14, 15, 16, 17, 18, 23, 24, 25)
•Faktör 5: Cilt değerlendirme (Madde 19, 20, 21, 22) şeklindedir.

Ölçüm aracı üçlü likert tiptedir. Madde 1, 2, 5, 8, 10, 12, 16, 18, 19, 21, 22, 24 ters puanlanmakta olup bu maddeler doğru= 0, bilmiyorum= 0 ve yanlış=1 şeklinde puanlanmaktadır. Geri kalan 3, 4, 6, 7, 9, 11, 13, 14, 15, 17, 20, 23, 25 maddeler doğru= 1, bilmiyorum= 0 ve yanlış= 0 olarak puanlanmaktadır.

Ölçekten alınabilecek en düşük puan 0 ve en yüksek puan 25'dir. Puanın artması Hemşirelik öğrencilerinin TCİBY'ye yönelik bilgi düzeyinin arttığını göstermektedir. (Baran ve ark., 2024)

Tıbbi Cihaz İlişkili Basınç aralanmalarına İlişkin Tutum Anketi: Tıbbi cihazlara bağlı basınç ülserine ilişkin tutum anketi (TCBBÜTA) Behnammoghadam tarafından İran'da çalışılmış ve Farsça dilinde doğrulanarak, İngilizce dil versiyonu yapılarak son şeklini almıştır. Tıbbi cihazlara bağlı basınç ülserine ilişkin tutum anketi toplam 11 sorudan oluşmaktadır. Tıbbi cihazla ilgili basınç ülseri önleme ve Tıbbi cihazla ilgili basınç yarası bakımı olmak üzere iki alt boyuttan oluşmaktadır. Tıbbi cihazla ilgili basınç ülseri önleme boyutunu 1., 2., 3., 5., 6., ve 7., sorular oluştururken, Tıbbi cihazla ilgili basınç yarası bakımı boyutunu ise 4., 8., 9., 10., ve 11., sorular oluşmuştur. Anket, 5'li Likert'e göre puanlanmaktadır.

Ölçeğin orijinal versiyonunda içerik geçerlilik oranı (CVR) her madde için 0.8'in üzerinde ve tüm anket ise CVR değeri 0,89 olarak saptanmıştır. Ayrıca Cronbach alfa değeri (α=0,77) kabul edilebilir düzeyde bir iç tutarlılık gösterildiği bildirilmiştir. Türkçe uyarlama çalışmasında ise içerik geçerlilik indeksi 0,9, Cronbach Alpha katsayısı ise 0,76 değerinde olduğu bulunmuştur. Ankette alınan puanlar minimum 11 puan, maksimum 55 puan arasında değişmektedir. Anketten alınan yüksek puan, hemşirelerin tıbbi araçların neden olduğu basınç ülserine karşı daha olumlu tutuma sahip olduklarını göstermektedir. Katılımcıların anketten alınan toplam puanları kategorize edildiğinde, "11-25" arası puanlar olumsuz tutum, 26-40 puan tarafsız tutum ve 41-55 puan ise hemşirelerin tıbbi cihazla ilgili gelişen basınç yaralanmasına ilişkin olumlu tutumu baskıya karşı olumlu bir tutumları olduğunu ifade etmektedir. (Zorlu ve ark., 2025)

Verilerin Analizi:

Toplanan veriler SPSS 27.0 programı kullanılarak analiz edilmiştir. Tanımlayıcı istatistikler frekans, yüzde, ortalama, standart sapma, medyan, minimum ve maksimum değerler ile ifade edilmiştir. Verilerin normal dağılıma uygunluğu çarpıklık ve basıklık değerleri ile

ISBN NR: 978-625-5694-92-8

değerlendirilmiştir. İki grup karşılaştırmalarında normal dağılım sağlanıyorsa Bağımsız Örneklem t testi, sağlanmıyorsa Mann Whitney U testi kullanılmıştır. İkiden fazla grup karşılaştırmalarında ise normal dağılım durumuna göre ANOVA veya Kruskal Wallis testi uygulanmıştır. Anlamlı fark bulunan durumlarda Bonferroni post-hoc testi ile ileri analiz yapılmıştır.

3. BULGULAR

Araştırmaya dahil edilen katılımcıların yaş ortalaması 23,19±1,57 (Min-Max: 21-35) olup, %77,9'u kadın, %22,1'i erkektir. Katılımcıların yalnızca %5,7'sinin Tıbbi Cihaz İlişkili Basınç Yaralanması'nın (TCİBY) önlenmesine yönelik bir eğitim programına katıldığı, %17,1'inin ulusal/uluslararası rehberlerden haberdar olduğu saptanmıştır. Klinik uygulamalarda katılımcıların %46,4'ü TCİBY'yi önlemeye yönelik girişimde bulunduğunu, %40,7'si TCİBY olan bir hastaya bakım verdiğini ve %41,4'ü hemşirelik süreci planlarken bu duruma yönelik tanı koyduğunu belirtmiştir. En sık konulan tanı %6,4 ile "Deri bütünlüğünde bozulma riski"dir.

Çizelge 1. Katılımcıların Tıbbi Cihaz İlişkili Basınç Yaralanması Bilgi Ölçeği ve Tıbbi Cihaz İlişkili Basınç Yaralanmalarına İlişkin Tutum Anketi Puanları

Ölçekler	X ± SS	M (Min - Max)	Çarpıklık	Basıklık	Cronbach Alpha
TCİBYBÖ					
Kavram ve Evrelendirme	0,66 ± 0,56	1,0 (0 - 2)	0,101	-0,717	0,661
Risk Değerlendirme	1,70 ± 0,65	2,0 (0 - 3)	-1,169	1,256	0,712
Tıbbi Cihazın Seçimi ve Uygunluğu	3,84 ± 1,47	4,0 (0 - 7)	-0,399	0,241	0,605
Bakım ve Pansuman	5,15 ± 1,75	6,0 (0 - 8)	-1,254	1,553	0,633
Cilt Değerlendirme	1,07 ± 0,64	1,0 (0 - 4)	1,922	7,032	0,730
TCİBYBÖ Toplam	12,42 ± 3,62	13,0 (0 - 20)	-1,194	2,083	0,842
TCBBÜTA					
Tıbbi Cihazla İlgili Basınç Ülseri Önleme	13,14 ± 4,20	13,0 (6 - 30)	1,106	1,892	0,796
Tıbbi Cihazla İlgili Basınç Yarası Bakımı	9,08 ± 4,15	8,0 (5 - 25)	1,507	2,699	0,876
TCBBÜTA Toplam	22,21 ± 7,89	21,0 (11 - 55)	1,386	2,278	0,904
	n	**%**			
TCBBÜTA'ya Göre Tutum Düzeyleri					
Olumsuz Tutum (11 - 25)	111	79,3			
Tarafsız Tutum (26 - 40)	23	16,4			
Olumlu Tutum (41 - 55)	6	4,3			

TCİBYBÖ: Tıbbi Cihaz İlişkili Basınç Yaralanması Bilgi Ölçeği, TCBBÜTA: Tıbbi Cihaz İlişkili Basınç Yaralanmalarına İlişkin Tutum Anketi

Katılımcıların TCİBY Bilgi Ölçeği (TCİBYBÖ) toplam puan ortalaması 12,42±3,62 (0-20 puan arası) olarak belirlenmiştir. Alt boyutlar incelendiğinde; Kavram ve Evrelendirme (0,66±0,56), Risk Değerlendirme (1,70±0,65), Tıbbi Cihaz Seçimi (3,84±1,47), Bakım ve Pansuman (5,15±1,75) ve Cilt Değerlendirme (1,07±0,64) puanları saptanmıştır. Katılımcıların Tıbbi Cihaz İlişkili Basınç Yaralanmalarına İlişkin Tutum Anketi toplam puan ortalamasının 22,21 ± 7,89 olduğu, çarpıklık değerinin 1,386 ve basıklık değerinin 2,278 olduğu bulunmuştur. Tutum düzeyleri incelendiğinde katılımcıların %79,3'ünün olumsuz tutum, %16,4'ünün tarafsız tutum ve %4,3'ünün olumlu tutum düzeyine sahip olduğu belirlenmiştir.

Korelasyon analizi sonuçlarına göre; katılımcıların TCİBY riskini belirleme ve önleyici uygulamaları gerçekleştirme konusundaki öz-yeterlilik algıları ile TCİBYBÖ toplam puanları

ISBN NR: 978-625-5694-92-8

arasında pozitif yönlü zayıf bir ilişki bulunmuştur (p< 0,05). Kliniklerde girişimde bulunulan hasta sayısı arttıkça, TCİBY önleme tutum puanlarının azaldığı (negatif yönlü zayıf ilişki, r=-0,367; p < 0,05) saptanmıştır. Karşılaştırmalı Analizler ve Engelleyici Faktörler Demografik özelliklere göre yapılan karşılaştırmalarda; Klinik Uygulama: Kliniklerde TCİBY önlemeye yönelik girişimde bulunanların, tanı koyanların ve TCİBY olan hastaya bakım verenlerin bilgi ölçeği toplam puanları, bu deneyimi olmayanlara göre istatistiksel olarak anlamlı düzeyde yüksek bulunmuştur (p<0,05). Öz-Yeterlilik Algısı: Kendi bilgi düzeyini yeterli bulanların bilgi puanları (14,5), yetersiz bulanlara (12,0) göre anlamlı derecede yüksektir (p<0,001). Cinsiyet: Kadınların cilt değerlendirme alt boyut puanları erkeklerden anlamlı derecede yüksek saptanmıştır (p=0,018).Klinik uygulamalarda TCİBY'yi önlemeyi zorlaştıran en temel faktörlerin; bilgi eksikliği (%47,1), klinik ortam koşulları (%40,7) ve zaman yetersizliği (%23,6) olduğu belirlenmiştir. Katılımcıların %77,9'u önlemeye yönelik hemşirelik girişimleri konusunda eğitim almayı talep etmektedir.

Çizelge 2. Katılımcıların Tıbbi Cihaz İlişkili Basınç Yaralanması Bilgi Ölçeği ile Tıbbi Cihaz İlişkili Basınç Yaralanmalarına İlişkin Tutum Anketi Puanları Arasındaki İlişki

TCİBYBÖ	TCBBÜTA					
	Tıbbi Cihazla İlgili Basınç Ülseri Önleme		Tıbbi Cihazla İlgili Basınç Yarası Bakımı		TCBBÜTA Toplam	
	r	p	r	p	r	p
Kavram ve Evrelendirme	-0,259	**0,002***	-0,241	**0,004***	-0,266	**0,001***
Risk Değerlendirme	-0,232	**0,006***	-0,260	**0,002***	-0,259	**0,002***
Tıbbi Cihazın Seçimi ve Uygunluğu	-0,153	0,072	-0,186	**0,028***	-0,180	**0,033***
Bakım ve Pansuman	-0,194	**0,022***	-0,241	**0,004***	-0,214	**0,011***
Cilt Değerlendirme	-0,074	0,383	-0,081	0,343	-0,089	0,293
TCİBYBÖ Toplam	-0,229	**0,006***	-0,272	**0,001***	-0,258	**0,002***

*TCİBYBÖ: Tıbbi Cihaz İlişkili Basınç Yaralanması Bilgi Ölçeği, TCBBÜTA: Tıbbi Cihaz İlişkili Basınç Yaralanmalarına İlişkin Tutum Anketi, Korelasyon Analizi, *p<0,05*

Yapılan korelasyon analizi sonucunda, katılımcıların Tıbbi Cihaz İlişkili Basınç Yaralanması Bilgi Ölçeği (TCİBYBÖ) toplam ve tüm alt boyut puanları ile Tutum Anketi (TCBBÜTA) toplam ve alt boyut puanları arasında negatif yönlü, zayıf/çok zayıf düzeyde anlamlı bir ilişki saptanmıştır (p< 0,05). Özellikle bilgi düzeyi arttıkça tutum puanlarının azaldığı (TCİBYBÖ toplam ve TCBBÜTA toplam; r = -0,258) görülmektedir. Bu şaşırtıcı sonuç, bilgi artışının her zaman olumlu tutum gelişimine yansımadığını ve tutumu etkileyen farklı klinik/çevresel faktörlerin olabileceğini düşündürmektedir.

4. SONUÇ VE ÖNERİLER

Araştırma bulguları, hemşirelik öğrencilerinin TCİBY'ye yönelik bilgi düzeylerinin orta düzeyde olduğunu ve öğrencilerin büyük çoğunluğunun TCİBY'nin önlenmesine yönelik olumsuz tutuma sahip olduğunu göstermektedir. Özellikle kavram, evrelendirme ve cilt değerlendirme alanlarında bilgi eksikliklerinin daha belirgin olduğu belirlenmiştir. Bununla

birlikte öğrencilerin klinik deneyim ve öz yeterlilik algısı arttıkça bilgi düzeylerinin de arttığı saptanmıştır. Ayrıca öğrencilerin bilgi düzeyleri ile tutumları arasında negatif yönlü zayıf bir ilişki bulunduğu belirlenmiş olup, bu durum tutumun yalnızca bilgi düzeyi ile açıklanamayacağını düşündürmektedir.

Araştırmadan elde edilen bulgular doğrultusunda;

-Hemşirelik öğrencilerinin TCİBY'ye yönelik bilgi ve farkındalıklarını artırmak amacıyla yapılandırılmış eğitim programlarının hemşirelik müfredatına dahil edilmesi,

-Eğitim içeriklerinin özellikle TCİBY kavramı ve evrelendirme, risk değerlendirme, cilt değerlendirmesi, klinik rehberlerin kullanımı ile önleyici hemşirelik girişimleri konularında güçlendirilmesi,

-Öğrencilerin TCİBY'nin önlenmesine yönelik klinik uygulama deneyimlerinin artırılması önerilmektedir.

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ISBN NR: 978-625-5694-92-8

CERRAHİ HASTALARIN SAĞLIK OKURYAZARLIĞI İLE TABURCU OLMAYA HAZIR OLUŞ DURUMU ARASINDAKİ İLİŞKİ

THE RELATIONSHIP BETWEEN HEALTH LITERACY AND READINESS FOR HOSPITAL DISCHARGE IN SURGICAL PATIENTS

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ÖZET

Giriş/Amaç: Sağlık okuryazarlığı, bireylerin sağlıkla ilgili bilgileri edinme, anlama ve bu bilgileri karar süreçlerinde etkin biçimde kullanma becerisini ifade ederken; taburcu olmaya hazır oluş, hastanın evde sürdürülecek bakım sürecine kendini ne ölçüde hazır hissettiğini yansıtmaktadır. Cerrahi girişim geçiren hastalar açısından her iki durum da tedavi sürecinin başarısı, komplikasyonların önlenmesi ve yeniden hastaneye yatışların azaltılması açısından kritik önem taşımaktadır. Bu araştırma, cerrahi hastaların sağlık okuryazarlığı düzeyleri ile taburcu olmaya hazır oluş durumları arasındaki ilişkiyi belirlemeyi amaçlamaktadır.

Yöntem: Tanımlayıcı ve kesitsel tipteki bu araştırma, Aralık 2025-Şubat 2026 tarihleri arasında bir üniversite hastanesinin genel cerrahi servisinde taburculuk sürecinde olan ve dahil edilme kriterlerine uygun 113 hasta ile yürütülmüştür. Veriler, araştırmacı tarafından geliştirilen Hasta Tanıtıcı Bilgi Formu, Sağlık Okuryazarlığı Ölçeği ve Taburcu Olmaya Hazır Olma Hasta Özdeğerlendirme Formu ile yüz yüze görüşme yöntemi kullanılarak toplanmıştır. Elde edilen veriler, tanımlayıcı istatistikler ve korelasyon analizi ile değerlendirilmiştir.

Bulgular: Araştırmaya katılan hastaların yaş ortalaması 56,96±15,36'dır. Hastaların %56,6'sı kadın, %78,8'i evlidir. Sağlık Okuryazarlığı Ölçeği toplam puan ortalaması 102,53±8,65; Taburcu Olmaya Hazır Olma Ölçeği toplam puan ortalaması 8,18±1,46 olarak saptanmıştır. Taburcu olmaya hazır olma düzeyinin hastaların %31'inde çok yüksek, %35,4'ünde yüksek, %15,9'unda orta ve %17,7'sinde düşük olduğu belirlenmiştir. Cerrahi hastaların sağlık okuryazarlığı ile taburcu olmaya hazır olma düzeyi arasında pozitif yönlü ve istatistiksel olarak anlamlı bir ilişki saptanmıştır ($p<0,05$).

Sonuç: Bu çalışmada cerrahi hastaların sağlık okuryazarlığı düzeyinin iyi, taburcu olmaya hazır olma düzeyinin ise yüksek olduğu belirlenmiştir. Ayrıca sağlık okuryazarlığı düzeyi arttıkça taburcu olmaya hazır olma düzeyinin de arttığı saptanmıştır.

ISBN NR: 978-625-5694-92-8

Anahtar Kelimeler: Hemşirelik, Cerrahi, Sağlık Okuryazarlığı, Taburculuk

ABSTRACT

Introduction/Aim:
Health literacy refers to individuals' ability to obtain, understand, and effectively use health-related information in decision-making processes, whereas readiness for discharge reflects the extent to which patients feel prepared to continue their care at home. For patients undergoing surgical procedures, both factors are critically important for the success of treatment, prevention of complications, and reduction of hospital readmissions. This study aimed to determine the relationship between health literacy levels and readiness for hospital discharge among surgical patients.

Method:
This descriptive and cross-sectional study was conducted with 113 patients who met the inclusion criteria and were in the discharge process at the general surgery clinic of a university hospital between December 2025 and February 2026. Data were collected through face-to-face interviews using the Patient Information Form developed by the researchers, the Health Literacy Scale, and the Readiness for Hospital Discharge Scale–Patient Self-Assessment Form. The obtained data were analyzed using descriptive statistics and correlation analysis.

Results:
The mean age of the patients participating in the study was 56.96±15.36 years. Of the patients, 56.6% were female and 78.8% were married. The mean total score of the Health Literacy Scale was 102.53±8.65, while the mean total score of the Readiness for Hospital Discharge Scale was 8.18±1.46. It was determined that the level of readiness for discharge was very high in 31% of the patients, high in 35.4%, moderate in 15.9%, and low in 17.7%. A positive and statistically significant relationship was found between surgical patients' health literacy levels and their readiness for hospital discharge ($p<0.05$).

Conclusion:
In this study, it was determined that the health literacy level of surgical patients was good and their readiness for discharge was high. Additionally, as the level of health literacy increased, the level of readiness for discharge also increased.

Keywords: Nursing, Surgery, Health Literacy, Discharge

ISBN NR: 978-625-5694-92-8

1. GİRİŞ

Sağlık okuryazarlığı, bireylerin sağlık durumlarını sürdürmeleri ve geliştirmeleri için sağlıkla ilgili bilgileri edinme, anlama, değerlendirme ve bu bilgileri sağlıkla ilgili kararlarında etkin biçimde kullanma becerisini ifade etmektedir (Nutbeam, 2000). Bu kavram yalnızca temel okuma-yazma becerilerinin ötesinde; sağlık hizmetlerine erişim, sağlık bilgisini kullanma ve karar verme süreçlerine aktif katılım yeterliliğini de içermektedir (Sørensen ve ark., 2012).

Sağlık okuryazarlığı, ilaç prospektüslerini yorumlamaktan hekim açıklamalarını anlamaya; randevu bilgilerini takip etmekten uygun sağlık birimlerine başvurabilmeye kadar geniş bir beceri yelpazesi gerektirir. Ayrıca bireylerin yaşadıkları çevredeki potansiyel sağlık tehditlerini fark edebilmesi, bu tehditlere karşı önlem alabilmesi ve tedavi süreçlerini bütüncül bir şekilde değerlendirebilmesi de sağlık okuryazarlığı kapsamında değerlendirilmektedir (Sezer ve Kadıoğlu, 2014).

Sağlık okuryazarlığı, bireylerin sağlık davranışlarını, tedaviye uyumlarını, hastalıkların önlenmesi ve yönetimini doğrudan etkileyen önemli bir belirleyicidir (Berkman ve ark., 2011). Yetersiz sağlık okuryazarlığı; ilaçların yanlış kullanımı, sağlık sisteminin doğru anlaşılmaması ve hizmetlerden etkin yararlanamama gibi sorunlara neden olabilir. Bununla birlikte, taburculuk sonrası bakımda eksiklikler ve yeniden hastaneye yatış oranlarının artması gibi sonuçlar da yetersiz sağlık okuryazarlığı ile ilişkilidir (Paasche-Orlow ve Wolf, 2007).

Taburculuk; hastanın hastanede aldığı tedavi sürecinin tamamlanmasının ardından, evde ya da başka bir sağlık kuruluşunda sürdürülecek bakım için hastaneden ayrılması sürecidir (Weiss ve ark., 2007). Taburculuğa hazır oluş ise, "hastanın hastaneden ayrılmadan önceki sağlık durumu, bilgi düzeyi, başa çıkma becerisi ve beklentileri doğrultusunda taburculuğa ilişkin algısı" şeklinde tanımlanmaktadır (Weiss, Yakusheva & Bobay, 2010). Bu kavram yalnızca tıbbi iyileşmeyi değil; hastanın evde bakım sürecine ilişkin kendine güvenini, sosyal destek kaynaklarına erişimini ve bilgiye dayalı karar verme becerilerini de kapsamaktadır.

Literatürde, taburculuk sonrası dönemde yaşanan sorunların çoğunun, hastaların yeterince hazırlanmadan taburcu edilmesinden kaynaklandığı belirtilmektedir (Weiss ve ark., 2007). Etkili bir taburculuk planlaması, hastaneye yeniden yatış oranlarını azaltmakta ve hasta memnuniyetini artırmaktadır (Jack ve ark., 2009). Özellikle cerrahi hastalar açısından, taburculuk süreci; iyileşme dönemindeki komplikasyonların önlenmesi, ilaçların doğru kullanımı ve kişisel bakım uygulamalarının sürdürülmesi açısından kritik öneme sahiptir (Naylor ve ark., 2011). Bu nedenle, hastaların taburculuk öncesi hazır oluş düzeylerinin değerlendirilmesi, hasta güvenliği ve bakımın sürekliliği açısından önem arz etmektedir.
Cerrahi girişim geçiren bireyler için sağlık okuryazarlığı ve taburcu olmaya hazır oluş düzeyi, cerrahi öncesi bilgilendirme, hastane sürecinde tedaviye uyum, cerrahi sonrası bakım talimatlarını anlama, komplikasyon belirtilerini ayırt edebilme ve taburculuk sonrası süreci etkin yönetme açısından belirleyici faktörlerdir. Taburculuk sonrası sürecin başarılı bir şekilde yönetilmesi, hasta güvenliğini doğrudan desteklemektedir. Bu bağlamda, cerrahi hastalarda sağlık okuryazarlığı düzeyinin belirlenmesi ve geliştirilmesi; cerrahi girişimlerin başarısını

ISBN NR: 978-625-5694-92-8

artırmakta, sağlık hizmetlerinin kalitesine ve etkinliğine anlamlı katkılar sunmaktadır. Bu araştırmanın amacı, cerrahi hastaların sağlık okuryazarlığı düzeyleri ile taburcu olmaya hazır oluş durumları arasındaki ilişkiyi belirlemektir.

Araştırma Sorusu

1. Cerrahi hastaların sağlık okuryazarlığı düzeyi nasıldır?
2. Cerrahi hastaların taburcu olmaya hazır oluş durumu nasıldır?
3. Cerrahi hastaların sosyodemografik özelliklerine göre sağlık okuryazarlığı ve taburcu olmaya hazır oluş durumu bakımından fark var mıdır?
4. Sağlık okuryazarlığı ile taburcu olmaya hazır oluş durumu arasında anlamlı bir ilişki var mıdır?

2. GEREÇ-YÖNTEM

Tanımlayıcı, kesitsel tipte olan bu araştırma, Aralık 2025-Şubat 2026 tarihleri arasında bir üniversitesi hastanesinin genel cerrahi kliniklerinde yürütülmüştür. Araştırmanın evrenini, Aralık 2025-Şubat 2026 tarihleri arasında bir üniversitesi hastanesinin genel cerrahi kliniklerinde tedavi görmekte olan hastalar oluşturmuştur. Örneklem büyüklüğü, çalışmanın amacına uygun olarak sağlık okuryazarlığı düzeyi ile taburcu olmaya hazır oluş durumu arasındaki ilişkiyi belirlemeye yönelik korelasyonel analiz esas alınarak G*Power 3.1.9.7 programı ile hesaplanmıştır. Yapılan hesaplamada, orta düzeyde ilişki beklentisi ($r = 0.30$), %95 güven düzeyi ($\alpha = 0.05$) ve %80 test gücü ($1-\beta = 0.80$) esas alınarak minimum örneklem büyüklüğü 84 kişi olarak belirlenmiştir. İstatistiksel gücü artırmak ve olası eksik/veri dışlama durumlarını karşılamak amacıyla örneklem sayısının %10–15 oranında artırılarak, araştırma en az 97 cerrahi hasta ile yürütülmesi planlanmış olup, araştırma 113 hastanın katılımı ile tamamlanmıştır.

Araştırmada yer alan hastaların dahil edilme kriterleri:

-Araştırmaya katılmaya gönüllü olmak,
-18 yaş ve üzeri yetişkin olmak,
-Hastanede en az 24 saat yatış süresi bulunmak,
-Genel cerrahi servisinden taburcu edilme sürecinde olmak,

Araştırmanın bağımlı değişkenleri: Katılımcıların Sağlık Okuryazarlığı Ölçeği ve Taburcu olmaya hazır olma ölçeği puan ortalamaları bağımlı değişkeni oluşturmaktadır.

Araştırmanın bağımsız değişkenleri: Araştırmanın bağımsız değişkenlerini; katılımcıların yaşı, cinsiyeti, eğitim durumu, medeni durumu, en uzun süre yaşadığı yer, çalışma durumu, gelir durumu, hastanede yatış süresi, evde bakım verecek yakının varlığı, kronik hastalık durumu, daha önce hastaneye yatma durumu, daha önce ameliyat geçirme durumu ve sağlıkla ilgili bilgileri en sık aldığı kaynak oluşturmaktadır.

Veri toplama araçları:

Araştırmanın verileri 'kişisel bilgi formu', 'sağlık okuryazarlığı ölçeği' ve 'taburcu olmaya hazır olma hasta özdeğerlendirme formu' kullanılarak yüz yüze görüşme ve anket yöntemi ile toplanacaktır.

Tanıtıcı Bilgi Formu: Araştırmacı tarafından verilerin toplanmasında ilgili literatür doğrultusunda hazırlanan bu form sosyodemografik özellikleri, yaşı, cinsiyeti, medeni durumu, eğitim durumu gibi katılımcıyı tanımlamak için hazırlanan sorulardan oluşmaktadır.

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Sağlık Okuryazarlığı Ölçeği: Sorensen tarafından 2013 geliştirilen 47 maddelik HLS-E. U (Health Literacy in Europe) formu Toçi, Bruzari ve Sorensen tarafından tekrar çalışılarak sadeleştirilmiş ve form dilimize sağlık okuryazarlığı ölçeği (Health Literacy İndex) olarak çevrilmiştir. (Sorensen ve ark. 2013; Toçi ve ark. 2013a). Bu ölçeğin Türkçe geçerlik ve güvenirliği 2017 yılında Ayla Bayık Temel ve Zuhal Aras tarafından test edilmiştir. (Aras ve Bayık Temel, 2017).

Tüm sağlık kuruluşlarında sağlık hizmeti almak üzere başvuran sağlıklı ya da hasta bireylerin tanılaması sürecinde sağlık okuryazarlığı düzeyinin değerlendirilmesinde yararlanılabilen bu ölçek toplam 25 madde ve dört alt ölçekten oluşmaktadır. Bilgiye erişim beş maddedir (1.-5.maddeler) ve bu alt ölçekten en düşük 5, en yüksek 25 puan alınacaktır. Bilgiyi anlama yedi madde (6.-12.maddeler) içermektedir ve bu alt ölçekten alınacak en düşük puan 7, en yüksek puan 35'tir. Değer Biçme/Değerlendirme alt ölçeği 8 maddeden (13.-30. Maddeler) oluşmaktadır ve bu alt ölçekten alınacak en düşük puan 8, en yüksek puan 40'tır. Uygulama/Kullanma alt ölçeği de beş madde (21.-25. maddeler) içermektedir ve bu alt ölçekten en düşük 5 puan, en yüksek 25 puan alınacaktır. Tüm ölçek için en düşük puan 25, en yüksek puan 125'tir. Ölçek maddeleri katılımcılar tarafından "5: Hiç zorluk çekmiyorum, 4: Az zorluk çekiyorum, 3: Biraz zorluk çekiyorum, 2: Çok zorluk çekiyorum, 1: Yapamayacak durumdayım/ hiç yeteneğim yok/ olanaksız" seklinde likert yapıda yanıtlanır. Ölçeğin tüm maddeleri olumlu yapıdadır, ters madde bulunmamaktadır (Aras ve Bayık Temel, 2017). Özgün ölçeğin standart sapması 0.95 ve alt ölçekleri için belirlenen iç tutarlılık katsayıları (Cronbach alfa) 0.90 ile 0,94 arasında değişmektedir (Toçi ve ark. 2013b). Ölçeğin Türkçe versiyonunda Cronbach Alfa değeri .92 saptanmış olup alt boyutların Alfa değerlerinin de .62 ile .79 arasında değiştiği belirlenmiştir. Alt boyutların puanlar ile toplam ölçek puanları arasında ilişkiler için güvenirlik katsayılarının .74 ile 91 arasında olduğu ve tüm maddeler için anlamlı olduğu ($p<.01$) bulunmuştur. (Aras ve Bayık Temel, 2017). Düşük puanlar sağlık okuryazarlığı durumunun yetersiz, sorunlu ve zayıf olduğunu, yüksek puanlar ise yeterli ve çok iyi olduğunu göstermektedir. Alınacak puan arttıkça bireyin sağlık okuryazarlık düzeyi artmaktadır (Toçi ve ark. 2013b).

Taburcu olmaya hazır olma ölçeği hasta özdeğerlendirme formu: Taburcu Olmaya Hazır Olma Ölçeği" hastaların hastaneden taburcu olmaya hazırlık durumuna ilişkin algılarını değerlendirmektedir. Bu ölçek Weiss ve arkadaşları tarafından geliştirilmiş olup 8 soru ve 4 boyuttan oluşmaktadır: Ölçeğin boyutları hastanın kişisel durumu, hastanın bilgisi, hastanın baş etme becerisi ve hastanın beklenen desteğidir. Cevaplar 0-10 aralığındaki bir ölçek üzerinden verilmektedir. Ortalamaların 9 ile 10 arasında olması hastaların taburcu olmaya çok yüksek düzeyde hazır olduğunu, 8 ile 8,9 arasında olması yüksek düzeyde hazır olduğunu, 7 ile 7,9 arasında olması orta düzeyde hazır olduğunu, 7'den az olması ise düşük düzeyde hazır olduğunu göstermektedir (Weiss ve ark. 2014). Formun Türkçe geçerlik güvenirliğini Kaya ve arkadaşları tarafından test etmiştir. Kaya ve arkadaşları ölçeğin Cronbach Alfa değerini 0,74 olarak belirlemiştir (Kaya ve ark. 2018).

Araştırma verilerinin değerlendirilmesi: Bu araştırmadan elde edilen veriler bilgisayar ortamında Statistical Package for the Social Sciebces (SPSS) programı kullanılarak analiz edildi. Araştırmadan elde edilen verilerin tanımlayıcı istatistikler (sayı, yüzde, ortalama, standart sapma) ile normal dağılıma uygunluğu değerlendirildi. Değerlendirme sonucuna göre

ISBN NR: 978-625-5694-92-8

parametrik veya non-parametrik testler uygulandı. Karşılaştırmalarda $p<0.05$ değeri istatistiksel olarak anlamlı kabul edildi. Ölçekler arasındaki ilişki korelasyon analizi ile değerlendirildi.

3. BULGULAR

Araştırmada yer alan hastaların; yaş ortalamasının 56,96 ± 15,36 olduğu, %56,6'sının kadın, %43,4'ünün ilköğretim, mezunu olduğu, %78,8'inin evli olduğu, %63,7'sinin çalışmadığı saptanmıştır. Hastaların hastanede ortalama yatış süresinin 6,98 ± 7,86 gün olduğu, hastaların %54,0'ının 5 gün ve üzeri, %46,0'sının 5 gün altı süreyle hastanede yattığı belirlenmiştir. Evde bakımıyla ilgilenen bir yakını olanların oranının %92,9 olduğu, %37,2'sinin sağlık çalışanlarından, %23,9'unun internet/sosyal medyadan, %23,0'ının aile üyeleri ve arkadaşlarından, %10,6'sının televizyondan ve %5,3'ünün kitap/gazete/dergiden sağlıkla ilgili bilgi aldığı belirlenmiştir. Hastaların %99,1'ine sağlık durumu, tedavisi ve taburculuk süreci ile ilgili bilgi verildiği, sağlıkla ilgili verilen bilgileri anlamakta zorlanma durumuna bakıldığında %58,4'ünün zorlanmadığı, %36,3'ünün bazen zorlandığı ve %5,3'ünün zorlandığı bulunmuştur. Hastaların %61,1'inin kronik hastalığının olduğu, %76,1'inin daha önce hastanede yatış öyküsünün bulunduğu, %71,7'sinin daha önce ameliyat geçirdiği bulunmuştur.

Çizelge 1. Hastaların Sağlık Okuryazarlığı Ölçeği ve Taburcu Olmaya Hazır Olma Ölçeği Puanları

	X ± SS	M (Min - Max)	Çarpıklık	Basıklık
Sağlık Okuryazarlığı Ölçeği				
Bilgiye Erişim	21,20 ± 4,29	23,0 (5 - 25)	-1,282	1,635
Bilgiyi Anlama	27,56 ± 6,24	28,0 (12 - 35)	-0,731	-0,214
Değer Biçme / Değerlendirme	32,65 ± 6,53	33,0 (15 - 40)	-0,657	-0,352
Uygulama / Kullanma	21,12 ± 3,45	22,0 (12 - 25)	-0,661	-0,326
SOYÖ Toplam	102,53 ± 18,65	104,0 (51 - 125)	-0,812	0,063
Taburcu Olmaya Hazır Olma Ölçeği				
Kişisel Durum	7,77 ± 1,89	8,0 (1 - 10)	-1,139	1,574
Bilgi	8,40 ± 1,72	9,0 (2 - 10)	-1,291	1,637
Başa Çıkma Yeteneği	7,85 ± 1,94	8,0 (1 - 10)	-0,851	0,506
Beklenen Destek	8,71 ± 1,75	9,0 (3 - 10)	-1,467	1,426
TOHOÖ Toplam	8,18 ± 1,46	8,5 (4 - 10)	-1,019	0,556

Taburcu Olmaya Hazır Olma Durumu	**n**	**%**
Çok Yüksek Düzey Hazır Oluş (9 - 10)	35	31,0
Yüksek Düzey Hazır Oluş (8 - 8,9)	40	35,4
Orta Düzey Hazır Oluş (7 - 7,9)	18	15,9
Düşük Düzey Hazır Oluş (<7)	20	17,7

SOYÖ: Sağlık Okuryazarlığı Ölçeği, TOHOÖ: Taburcu Olmaya Hazır Olma Ölçeği

Hastaların Sağlık Okuryazarlığı Ölçeği ve Taburcu Olmaya Hazır Olma Ölçeği puanları Çizelge 1'de verilmiştir. SOYÖ alt boyutlarının aldıkları puanların ortalaması 102.12± 18,65 olarak tespit edilmiştir. TOHOÖ toplamından aldıkları puanların ortalaması 8,18 ± 1,46 olarak saptanmıştır. Hastaların sağlık okuryazarlığı düzeyinin iyi, taburcu olmaya hazır olma düzeyinin ise yüksek olduğu bulunmuştur.

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Taburcu olmaya hazır olma durumunun hastaların %31'inin çok yüksek düzeyde, %35,4'ünün yüksek düzeyde, %15,9'unun orta düzeyde ve %17,7'sinin düşük düzeyde olduğu belirlenmiştir.

Hastaların yaşları ile Sağlık Okuryazarlığı Ölçeği toplam puanları arasında negatif yönlü zayıf düzey ilişki tespit edilmiştir (p<0,05). Hastaların yaşları ile Taburcu Olmaya Hazır Olma Ölçeği toplam puanları arasında negatif yönlü zayıf düzey ilişki tespit edilmiştir (p<0,001).

Cinsiyet, eğitim durumu, medeni durum, hastanede yatış süresi, evde bakımıyla ilgilenen yakının varlığı ve sağlık durumu, tedavisi ve taburculuk süreci hakkında bilgi verilme durumuna göre SOYÖ alt boyutları ve toplam puanları arasında istatistiksel olarak anlamlı bir fark bulunmamıştır (p>0,05). Şehirde yaşayan hastaların Sağlık Okuryazarlığı Ölçeği puanlarının kasabada yaşayan hastalara göre daha yüksek olduğu bulunmuştur (p<0,001). Hastaların SOYÖ ortalama puanı geliri durumu fazla olanlarda daha yüksek olarak belirlenmiştir. Sağlıkla ilgili verilen bilgileri anlamakta zorlanmayan hastaların SOYÖ puanlarının daha yüksek olduğu tespit edilmiştir (p<0,001).

Cinsiyet, eğitim, medeni durum ve gelir durumu açısından TOHOÖ toplam puanı bakımından anlamlı fark bulunmamıştır (p>0,05). Yaşadığı yer, çalışma durumu, hastanede yatış süresi, evde bakımıyla ilgilenen yakını bulunması, sağlık bilgisi kaynağı ve verilen bilgileri anlamakta zorlanma durumuna göre TOHOÖ toplam puanı açısından istatistiksel olarak anlamlı fark saptanmıştır (p<0,05).

Hastaların klinik özelliklerine göre SOYÖ ve TOHOÖ puanları karşılaştırılmıştır. Elde edilen sonuçlara göre; hastaların klinik özelliklerine göre Sağlık Okuryazarlığı Ölçeği ve Taburcu Olmaya Hazır Olma Ölçeği puanları arasında anlamlı fark bulunmamıştır (p>0,05).

Çizelge 2. Hastaların Sağlık Okuryazarlığı Ölçeği ile Taburcu Olmaya Hazır Olma Ölçeği Puanları Arasındaki İlişki

	Taburcu Olmaya Hazır Olma Ölçeği									
	Kişisel Durum		**Bilgi**		**Başa Çıkma Yeteneği**		**Beklenen Destek**		**TOHOÖ Toplam**	
	r	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**
Sağlık Okuryazarlığı Ölçeği										
Bilgiye Erişim	0,116	0,219	0,383	**<0,001****	0,263	**0,005***	0,360	**<0,001****	0,345	**<0,001****
Bilgiyi Anlama	0,129	0,174	0,423	**<0,001****	0,288	**0,002***	0,258	**0,006***	0,338	**<0,001****
Değer Biçme / Değerlendirme	0,114	0,231	0,429	**<0,001****	0,284	**0,002***	0,294	**0,002***	0,345	**<0,001****
Uygulama / Kullanma	0,174	0,065	0,391	**<0,001****	0,459	**<0,001****	0,304	**0,001***	0,414	**<0,001****
SOYÖ Toplam	0,142	0,134	0,452	**<0,001****	0,341	**<0,001****	0,328	**<0,001****	0,390	**<0,001****

*SOYÖ: Sağlık Okuryazarlığı Ölçeği, TOHOÖ: Taburcu Olmaya Hazır Olma Ölçeği, Pearson Korelasyon, *p<0,05, **p<0,001*

Sağlık okuryazarlığı ile taburcu olmaya hazır oluş durumu arasında pozitif yönlü, zayıf–orta düzeyde ve istatistiksel olarak anlamlı ilişkiler saptanmıştır (p<0,05). Taburcu olmaya hazır olma ölçeği kişisel durum alt boyutu ile sağlık okuryazarlığı alt boyutları arasında anlamlı ilişki bulunmamıştır.

4. SONUÇ VE ÖNERİLER

Bu çalışmada, cerrahi hastaların sağlık okuryazarlığı düzeyi iyi, taburcu olmaya hazır olma düzeyi ise yüksek olarak bulunmuştur. Hastaların yaşı arttıkça sağlık okuryazarlığı düzeyinin ve taburculuğa hazır olma durumunun düştüğü görülmektedir. Hastaların sağlık okuryazarlığı düzeyi arttıkça taburcu olmaya hazır olma düzeyinin arttığı belirlenmiştir.

Araştırma bulguları doğrultusunda;

- Cerrahi kliniklerde taburculuk planlaması yapılırken hastaların sağlık okuryazarlığı düzeylerinin değerlendirilmesi,
- Taburculuk eğitiminin hastanın sağlık okuryazarlığı düzeyine göre düzenlenmesi,
- Etkili taburculuk planlamasının sağlanabilmesi için özellikle ileri yaş grubu, gelir düzeyi düşük, sağlıkla ilgili bilgileri anlamakta zorlanan ve evde bakım desteği bulunmayan hastaların daha yakından desteklenmesi önerilmektedir.

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ISBN NR: 978-625-5694-92-8

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ISBN NR: 978-625-5694-92-8

‘ADLİ OTOPSİLERDE YAPAY ZEKÂ DESTEKLİ SİSTEMLERİN OLASI KULLANIM ALANLARI’

‘Potential Applications of Artificial Intelligence–Assisted Systems in Forensic Autopsies’

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ÖZET

Adli otopsi, ölüm nedeninin ve ölüm mekanizmasının ortaya konulmasında temel bir uygulama olup, bu süreçte çok sayıda makroskopik, mikroskopik ve yardımcı inceleme bulgusunun birlikte değerlendirilmesi gerekmektedir. Otopsi sırasında elde edilen bu verilerin bütüncül olarak ele alınması, adli sürecin sağlıklı yürütülmesi açısından kritik öneme sahiptir. Bu çok boyutlu yapı, otopsi sürecinde sistematik değerlendirme yaklaşımlarının önemini artırmakta ve karar destekleyici yöntemlere olan ihtiyacı gündeme getirmektedir.

Son yıllarda sağlık ve adli bilimler alanında giderek yaygınlaşan yapay zekâ destekli sistemler, büyük hacimli ve karmaşık verilerin analiz edilmesi, örüntülerin tanımlanması ve değerlendirme süreçlerinin yapılandırılması açısından önemli olanaklar sunmaktadır. Adli otopsilerde bu sistemlerin; postmortem görüntüleme bulgularının değerlendirilmesi, makroskopik ve mikroskopik bulguların birlikte ele alınması, yardımcı inceleme sonuçlarının bütüncül biçimde analiz edilmesi ve raporlama sürecinin daha sistematik olarak yürütülmesi gibi alanlarda destekleyici bir rol üstlenebileceği değerlendirilmektedir.

Bu bildiride, adli otopsilerde yapay zekâ destekli sistemlerin mevcut ve potansiyel kullanım alanları, sahadaki uygulamalara olası yansımaları açısından ele alınmıştır. Yapay zekâ uygulamalarının, otopsi sürecinde karar veren bir mekanizma olmaktan ziyade, uzman değerlendirmesini destekleyen ve değerlendirme sürecinde hangi unsurların birlikte ele alınması gerektiğini hatırlatan yardımcı araçlar olarak kullanılabileceği öngörülmektedir. Bu yaklaşımın, özellikle karmaşık olgularda değerlendirme sürecinin daha sistematik yürütülmesine, bulguların birlikte yorumlanmasına ve raporlama kalitesinin güçlendirilmesine katkı sağlayabileceği düşünülmektedir.

Sonuç olarak, yapay zekâ destekli sistemlerin adli otopsi uygulamalarına uygun ve kontrollü biçimde entegre edilmesi, uzman sorumluluğunu devretmeden, sahadaki değerlendirme süreçlerinin desteklenmesine yönelik tamamlayıcı bir yaklaşım olarak değerlendirilmektedir.

Anahtar Kelimeler: Adli otopsi, yapay zekâ, karar destek sistemleri, postmortem değerlendirme

ISBN NR: 978-625-5694-92-8

DİYABETİK HASTALARDA CRP/ALBÜMİN ORANININ PROGNOZDAKİ YERİ

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Özet

Diyabetes mellitus, yalnızca glukoz metabolizmasındaki bozulmayla sınırlı olmayan; kronik inflamasyon, endotel disfonksiyonu ve artmış oksidatif stres ile karakterize sistemik bir hastalıktır. Bu inflamatuvar zemin, diyabetin hem akut klinik tablolarında hem de uzun dönem mikrovasküler ve makrovasküler komplikasyonlarının gelişiminde temel belirleyicilerden biridir. Bu nedenle inflamasyonun güvenilir biçimde değerlendirilmesi, hastalığın prognozunun anlaşılmasında önemli bir yer tutmaktadır.

C-reaktif protein (CRP), akut faz yanıtının en duyarlı göstergelerinden biri olup diyabetik bireylerde sıklıkla subklinik inflamasyonu yansıtır. Serum albümin düzeyi ise yalnızca beslenme durumunu değil, aynı zamanda inflamatuvar yük, hepatik sentez kapasitesi ve genel fizyolojik rezerv hakkında da önemli bilgiler sunar. Albüminin negatif akut faz reaktanı olması, inflamasyon varlığında düzeyinin azalmasına yol açmaktadır.

CRP ve albüminin birlikte değerlendirilmesiyle elde edilen CRP/albumin oranı, inflamasyonun şiddeti ile organizmanın bu sürece karşı yanıt kapasitesini aynı anda yansıtan bütüncül bir parametre olarak öne çıkmaktadır. Bu oran, diyabetik hastalarda artmış inflamatuvar aktiviteyi daha dengeli ve anlamlı biçimde ortaya koyabilmektedir.

Yüksek CRP/albumin oranı; kötü metabolik kontrol, artmış enfeksiyon eğilimi, kardiyovasküler risk yükü ve genel klinik kırılganlık ile ilişkilendirilmektedir. Tek başına CRP yüksekliği veya albümin düşüklüğü sınırlı yorum imkânı sunarken, oransal yaklaşım klinik tabloyu daha doğru biçimde yansıtmaktadır.

Bu yönüyle CRP/albumin oranı, diyabetin inflamatuvar doğasını anlamada ve prognozun öngörülmesinde pratik, kolay uygulanabilir ve düşük maliyetli bir biyobelirteçtir. Klinik değerlendirmeye entegre edilmesi, hasta risk sınıflamasında ve izlem stratejilerinin belirlenmesinde destekleyici bir rol üstlenebilir.

Anahtar Kelimeler: Diyabetes mellitus, CRP/albumin oranı, inflamasyon, prognoz, kronik hastalık

ISBN NR: 978-625-5694-92-8

THE RELATİONSHİP BETWEEN POLYPHARMACY AND EMERGENCY DEPARTMENT VİSİTS İN OUTPATİENTS

Abstract

Polypharmacy has become an increasingly common clinical issue, particularly among patients with multiple chronic conditions attending internal medicine outpatient clinics. As life expectancy rises and comorbidity burden increases, many individuals require long-term use of several medications simultaneously. While appropriate pharmacological treatment is essential for disease control, the growing number of prescribed drugs also introduces significant clinical challenges.

The use of multiple medications increases the risk of drug–drug interactions, adverse drug reactions, and reduced treatment adherence. Age-related physiological changes, especially alterations in renal and hepatic function, further amplify the clinical consequences of polypharmacy. As a result, patients may develop acute symptoms that often lead to unplanned emergency department visits.

Common clinical scenarios linking polypharmacy to emergency admissions include hypoglycemia, hypotension, syncope, electrolyte disturbances, gastrointestinal complaints, and central nervous system–related side effects. Many of these presentations are not caused by disease progression itself but rather by medication-related problems. In this context, emergency department utilization may reflect the cumulative pharmacological burden rather than acute pathology alone.

In outpatient populations, the increasing number of medications should not be interpreted solely as an indicator of disease severity but also as a marker of clinical vulnerability. Polypharmacy may signal reduced physiological reserve and increased susceptibility to destabilizing events, even in seemingly stable patients.

From a broader clinical perspective, frequent emergency department visits among patients with polypharmacy represent a significant burden on healthcare systems and highlight gaps in continuity of care. Regular medication review, structured drug reconciliation, and individualized treatment strategies are essential components of safe outpatient management.

In conclusion, the relationship between polypharmacy and emergency department visit frequency underscores the importance of rational prescribing practices. Addressing polypharmacy through careful evaluation of treatment necessity and ongoing reassessment may play a key role in improving patient safety, reducing preventable emergency admissions, and enhancing the quality of chronic disease management.

Keywords: Polypharmacy, emergency department visits, outpatient care, medication safety, multimorbidity

ISBN NR: 978-625-5694-92-8

ANTIBACTERIAL PROSTHETIC FINGERNAIL

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ABSTRACT

This study aimed to prepare and characterize a novel and low-cost antibacterial prosthetic fingernail. Firstly, hydroxyapatite powder was coated with nano silver. Next, the prosthetic fingernail material and nano silver coated hydroxyapatite powder (nano Ag-HAP) were mixed and shaped. Finally, the determination of antibacterial activity of the antibacterial prosthetic fingernail was carried out by using plate counting method against *Escherichia coli* ATCC 8739 and *Staphylococcus aureus* ATCC 6538. Nano Ag-HAP powder and antibacterial prosthetic fingernail were characterized. According to the results of ICP-OES analysis of the nano Ag-HAP powder were found to be 0.25% Ag. The TEM analysis of the nano Ag-HAP powder showed that the size of the nano silver particles on the hydroxyapatite powder was approximately 30 nm. The antibacterial prosthetic nail exhibited 100% antibacterial activity against both *E. coli* and *S. aureus*. It is important for hygiene that fingernails do not host microorganisms. Therefore, it is probable that this antibacterial prosthetic fingernail will attract the attention of the cosmetics industry.

Key Words: Antibacterial, Nano silver, Prosthetic Fingernail

ISBN NR: 978-625-5694-92-8

KARDİYOLOJİ HASTALARINDA QT İNTERVALİ UZATICI İLAÇ-İLAÇ ETKİLEŞİMLERİ PREVALANSI, ÖZELLİKLERİ VE RİSK FAKTÖRLERİNİN DEĞERLENDİRİLMESİ

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ÖZET

Giriş ve Amaç: QT intervali kalbin elektriksel aktivitesini yansıtan kritik bir parametre olup, bu intervalin ilaçlar veya genetik faktörlerle uzaması yaşamı tehdit eden ventriküler aritmilere yol açabilmektedir. Kardiyak ve kardiyak-olmayan pek çok ilaç sınıfı QT intervalini uzatabilmekte ve bu ilaçlar arasındaki etkileşimler advers etki riskini artırabilmektedir. Bu çalışma, Kardiyoloji Ünitesi'nde yatan hastalarda QT intervali uzatıcı ilaç kullanımı ve bu ilaçlar arasındaki etkileşimlerin prevalansını, özelliklerini ve ilgili risk faktörlerini değerlendirmeyi amaçlamaktadır.

Gereç ve Yöntemler: Bu çalışmada, Trakya Üniversitesi Kardiyoloji Ünitesi'nde 1 Ocak 2024-1 Temmuz 2024 tarihleri arasında yatarak tedavi gören 1051 hastadaki QT intervali uzatıcı ilaç kullanımı ve QT uzatıcı ilaç-ilaç etkileşimleri geriye dönük olarak incelendi. Demografik özellikler, ilaç bilgileri, laboratuvar sonuçları ve elektrokardiyografi verilerine dijital hastane kayıtları üzerinden erişildi. QT intervali uzatıcı ilaçlar Dünya Sağlık Örgütü Anatomik Terapötik Kimyasal sınıflandırma sistemi ve Torsades de pointes risk kategorilerine göre sınıflandırıldı. QT-intervali uzatıcı ilaç-ilaç etkileşimleri Drugs.com, Epocrates, Medscape ve Lexicomp veri tabanları kullanılarak değerlendirildi. İstatistiksel analizler R versiyon 4.4.2 yazılımı kullanılarak gerçekleştirildi.

ISBN NR: 978-625-5694-92-8

Bulgular: Değerlendirilen 1051 hastanın %87,6'sında en az bir QT intervali uzatıcı ilaç kullanımı, %45,3'ünde ise en az bir QT uzatıcı ilaç-ilaç etkileşimi saptandı. Pantoprazol %47,8 ile en sık kullanılan QT intervali uzatıcı ilaç idi. Hastaların %44,8'inde QT intervali uzaması tespit edilirken; QT uzatıcı ilaç-ilaç etkileşimi varlığı, ileri yaş, hipokalemi ve hipokalsemi QT intervali uzaması için güçlü bağımsız risk faktörleri olarak belirlendi. Toplam QT uzatıcı ilaç-ilaç etkileşimi sayısı 1187'ydi ve etkileşime giren 291 farklı ilaç çifti mevcuttu. Etkileşime giren en sık ilaç çifti furosemid+pantoprazol'dü (%15,0). Etkileşimlerin %77,8'i farmakodinamik tipte ve %75,1 orta ciddiyetteydi. Toplam QT interval uzatıcı etkin madde sayısı, QT uzatıcı ilaç-ilaç etkileşimi varlığı ile en güçlü bağımsız değişkendi.

Sonuç: Kardiyoloji ünitesinde yatan hastaların %87,6'sında QT intervalini uzatıcı ilaçlar kullanılmaktaydı ve yaklaşık yarısında potansiyel QT uzatıcı ilaç-ilaç etkileşimi mevcuttu. İleri yaş, elektrolit bozuklukları ve QT uzatıcı ilaç-ilaç etkileşimleri QT intervali uzaması riskini artırdı. QT interval uzatıcı ilaç yükü artışı QT uzatıcı ilaç-ilaç etkileşimi ihtimalini artıran en güçlü etkendi. Kardiyoloji ünitelerinde QT intervalini uzatan ilaçlarla tedavi planlanırken kapsamlı bir risk değerlendirmesi yapılmalı ve potansiyel advers etkiler takip edilmelidir.

Anahtar kelimeler: QT intervali uzatıcı ilaçlar, kardiyoloji ünitesi, QT uzatıcı ilaç-ilaç etkileşimleri.

ISBN NR: 978-625-5694-92-8

EVALUATION OF PREVALENCE, CHARACTERISTICS AND RISK FACTORS OF QT INTERVAL PROLONGING DRUG-DRUG INTERACTIONS IN CARDIOLOGY PATIENTS

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ABSTRACT

Background and Aim: The QT interval is a critical parameter reflecting the electrical activity of the heart; prolongation of this interval due to drugs or genetic factors can lead to life-threatening ventricular arrhythmias. Many classes of cardiac and non-cardiac drugs may prolong the QT interval, and interactions between these drugs may increase the risk of adverse effects. This study aims to evaluate the prevalence, characteristics, and related risk factors of QT interval-prolonging drug use and the interactions between these drugs in patients hospitalized in a cardiology unit.

Material and Methods: In this study, QT interval-prolonging drug use and QT-prolonging drug-drug interactions were retrospectively analyzed in 1,051 patients treated at the Trakya University Cardiology Unit between January 1, 2024, and July 1, 2024. Demographic characteristics, medications, laboratory results, and electrocardiography data were accessed via digital hospital records. QT-prolonging drugs were classified according to the WHO Anatomical Therapeutic Chemical classification system and torsades de pointes risk categories. QT-interval prolonging drug-drug interactions were evaluated using the Drugs.com, Epocrates, Medscape, and Lexicomp databases. Statistical analyses were performed using R version 4.4.2 software.

ISBN NR: 978-625-5694-92-8

Results: At least one QT-prolonging drug was used in 87.6% of the 1,051 patients evaluated, and at least one QT-prolonging drug-drug interaction was detected in 45.3%. Pantoprazole was the most frequently used QT interval-prolonging drug at 47.8%. While QT interval prolongation was detected in 44.8% of the patients, the presence of QT interval-prolonging drug-drug interactions, advanced age, hypokalemia, and hypocalcemia were identified as strong independent risk factors for QT prolongation. The total number of QT-prolonging drug-drug interactions was 1.187, involving 291 different drug pairs. The most frequent interacting drug pair was furosemide+pantoprazole (15.0%). Of the interactions, 77.8% were pharmacodynamic and 75.1% were of moderate severity. The total number of QT interval-prolonging agents was the strongest independent variable associated with the presence of QT-prolonging drug-drug interactions.

Conclusion: QT interval-prolonging drugs are used in 87.6% of patients hospitalized in the cardiology unit, and potential QT-prolonging drug-drug interactions are present in nearly half. Advanced age, electrolyte imbalances, and QT interval-prolonging drug-drug interactions increase the risk of QT interval prolongation. The increase in the total number of QT interval prolonging drugs used was the strongest factor increasing the likelihood of QT-prolonging drug-drug interactions. In cardiology units, a comprehensive risk assessment should be performed and potential adverse effects monitored when planning treatment with QT-prolonging drugs.

Keywords: QT interval-prolonging drugs, cardiology unit, QT-prolonging drug-drug interactions.

ISBN NR: 978-625-5694-92-8

HIV ENFEKSİYONU İLE YAŞAYAN BİREYLERDE SİFİLİZ KOENFEKSİYONU

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ÖZET

Amaç: Sifiliz, *Treponema pallidum* bakterisinin neden olduğu cinsel yolla bulaşan bir enfeksiyondur ve insan immün yetmezlik virüsü (HIV) enfeksiyonu ile yaşayan bireylerde sık görülmektedir. Bu çalışmanın amacı, Ankara'daki üçüncü basamak bir hastanede takip edilen HIV enfeksiyonu ile yaşayan bireylerde sifiliz koenfeksiyonu seroprevalansını değerlendirmektir.

Gereç ve Yöntem: Bu retrospektif çalışmada, Ocak 2024 – Aralık 2024 tarihleri arasında Ankara Etlik Şehir Hastanesi'ne takip ve tedavi amacıyla başvuran, HIV enfeksiyonu tanısı almış ve sifiliz koenfeksiyonu şüphesiyle serum örneklerinde manuel sifiliz antijen testi ve *Treponema pallidum* IgM/IgG antikorları test edilen bireyler dahil edildi. Elde edilen test sonuçları retrospektif olarak değerlendirildi. Manuel antijen testi (Syphilis RPR, Dialab, Neudorf, Avusturya) ve *Treponema pallidum* IgM/IgG antikorlarının saptandığı ticari bir enzim immunoassay (Elecsys Syphilis, Roche Diagnostics, Mannheim, Almanya) kullanılarak analiz edildi. Her iki testin pozitif olduğu olgular sifiliz enfeksiyonu olarak kabul edildi.

Bulgular: HIV enfeksiyonu tanısı almış toplam 284 hastanın serum örneklerinde RPR ve *Treponema pallidum* IgM/IgG testleri analiz edildi. Hastaların 251'i erkek (%88,4) ve 33'ü kadın (%11,6) idi. Erkeklerin ortanca yaşı 39 (19–61), kadınların ise 69 (56–84) yıl olarak bulundu ($p < 0,001$). Sifiliz enfeksiyonu tüm bireylerin %6,7'sinde (19/284) saptandı. Erkeklerde bu oran %6,0 (15/251), kadınlarda ise %12,1 (4/33) idi ($p = 0,165$). Sifiliz enfeksiyonu en sık 41–50 yaş grubunda (%9,4; 6/64) görüldü. Bunu 31–40 (%8,2; 6/73), >50 (%5,2; 4/77) ve 19–30 (%4,3; 3/70) yaş grupları izledi ($p = 0,603$). Erkeklerde en yüksek oran 41–50 yaş grubunda saptanırken (%9,4; 6/64), >50 yaş grubunda olguya rastlanmadı ($p = 0,138$). Kadın hastaların tamamı 56 yaş ve üzerinde olduğu için yaş gruplarına göre ek değerlendirme yapılamadı.

Sonuç: Bu çalışmada, HIV enfeksiyonu ile yaşayan bireylerde sifiliz koenfeksiyonu prevalansı %6,7 olarak bulundu. HIV pozitif bireyler gibi risk gruplarında farkındalık artırıcı eğitimlerinin arttırılması ve tarama testlerinin sürdürülmesi büyük önem taşımaktadır.

Anahtar Kelimeler: HIV enfeksiyonu, RPR, *Treponema pallidum* IgM/IgG, koenfeksiyon

ISBN NR: 978-625-5694-92-8

SYPHILIS COINFECTION AMONG PEOPLE LIVING WITH HIV

ABSTRACT

Objective: Syphilis is a sexually transmitted infection caused by *Treponema pallidum* and is frequently observed among individuals living with human immunodeficiency virus (HIV) infection. This study aimed to evaluate the seroprevalence of syphilis co-infection among individuals living with HIV who were followed up at a tertiary care hospital in Ankara, Türkiye.

Materials and Methods: In this retrospective study, individuals who were diagnosed with HIV infection and tested for suspected syphilis coinfection between January 2024 and December 2024 at Ankara Etlik City Hospital were included. Serum samples were analyzed retrospectively. A manual syphilis antigen test (Syphilis RPR, Dialab, Neudorf, Austria) and a commercial enzyme immunoassay for detecting Treponema pallidum IgM/IgG antibodies (Elecsys Syphilis, Roche Diagnostics, Mannheim, Germany) were used. Cases with positive results in both tests were considered as syphilis infection.

Results: RPR and Treponema pallidum IgM/IgG tests were analyzed in serum samples from a total of 284 patients diagnosed with HIV infection. Of these, 251 (88.4%) were male and 33 (11.6%) were female. The median age was 39 years (19–61) for males and 69 years (56–84) for females ($p < 0.001$).

Syphilis infection was detected in 6.7% (19/284) of all patients. The prevalence was 6.0% (15/251) in males and 12.1% (4/33) in females ($p = 0.165$). The highest rate of syphilis infection was observed in the 41–50-year age group (9.4%; 6/64), followed by the 31–40 (8.2%; 6/73), >50 (5.2%; 4/77), and 19–30 (4.3%; 3/70) age groups ($p = 0.603$). Among males, the highest prevalence was also in the 41–50-year age group (9.4%; 6/64), while no cases were detected in those aged >50 years ($p = 0.138$). As all female patients were aged ≥56 years, further subgroup analysis by age was not possible.

Conclusion: In this study, the prevalence of syphilis co-infection among individuals living with HIV was found to be 6.7%. Enhancing awareness-raising education and maintaining screening programs among risk groups, such as HIV-positive individuals, are of great importance.

Keywords: HIV infection, RPR, *Treponema pallidum* IgM/IgG, co-infection

ISBN NR: 978-625-5694-92-8

CİLT KANSERİNDEN KORUNMA

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ÖZET

Cilt kanseri, özellikle güneşin ultraviyole (UV) ışınlarına uzun süre maruziyet sonucu gelişen en yaygın kanser türlerinden biridir. Cilt kanserinden korunmada, erken yaşta başlayan yaşam tarzı alışkanlıkları son derece önemlidir. Güneş ışığından korunmak için yüksek koruma faktörlü (SPF) güneş kremleri kullanmak, uzun kollu giysiler giymek, şapka ve güneş gözlüğü takmak, kendi kendine deri muayenesi yapmak önerilmektedir. Özellikle UV ışınlarının en yoğun olduğu saatlerde doğrudan güneşe maruziyetten kaçınmak kritik öneme sahiptir. Bu önlemler, cilt kanseri riskini önemli ölçüde azaltmakta ve genel cilt sağlığının korunmasına katkı sağlamaktadır.

Anahtar Kelimeler: Cilt Kanseri, UV Işınları, Kendi Kendine Deri Muayenesi

Abstract:

Skin cancer is one of the most common types of cancer, primarily developing as a result of prolonged exposure to the sun's ultraviolet (UV) rays. Lifestyle habits adopted early in life play a crucial role in its prevention. Recommended protective measures include using high sun protection factor (SPF) sunscreens, wearing long-sleeved clothing, hats, and sunglasses, and performing regular self-skin examinations. Avoiding direct sun exposure during peak UV hours is particularly important. These precautions significantly reduce the risk of skin cancer and contribute to maintaining overall skin health.

Keywords: Skin Cancer, Ultraviolet (UV) Rays, Self-Skin Examination

ISBN NR: 978-625-5694-92-8

1. GİRİŞ

Kanser, vücut hücrelerinin kontrolsüz biçimde çoğalması, çevre dokulara invaze olması ve kan veya lenf yolu aracılığıyla uzak organlara yayılmasıyla karakterize bir hastalıktır. Dünya genelinde tüm kanser türleri arasında cilt kanserleri en sık görülen malignitelerden biridir (1). Cilt kanserleri vücudun herhangi bir bölgesinde ortaya çıkabilmekle birlikte, özellikle yüz, boyun, göğüs, kollar ve eller gibi güneş ışınlarına yoğun maruz kalan bölgelerde daha sık görülmektedir (2).

Cilt kanserleri içinde en agresif seyreden tür malign melanom (MM) olup mortalite oranı oldukça yüksektir. MM insidansının en yüksek olduğu ülkelerden biri Avustralya'dır (3). Küresel Kanser Gözlemevi'nin (GLOBOCAN) verilerine göre dünya genelinde her yıl on binlerce kişi malign melanom nedeniyle yaşamını yitirmektedir (4). Ülkemizde ise son yıllarda MM insidansında artış gözlenmekte olup, bildirilen verilere göre her yıl önemli sayıda yeni vaka tanısı konulmaktadır (5).

Melanom dışı deri kanserleri (MDDK) ise tüm cilt kanserleri içinde en sık görülen grubu oluşturmakta ve görülme sıklığı malign melanoma göre yaklaşık 20 kat daha fazla olmaktadır. Bu grubun büyük çoğunluğunu bazal hücreli karsinom (BHK) ve skuamöz hücreli karsinom (SHK) oluşturmaktadır (6–9).

Tanıda gecikme durumunda cilt kanserleri ciddi komplikasyonlara neden olabilmektedir. Özellikle MM; beyin, kalp, meme ve gastrointestinal sistem gibi uzak organlara metastaz yapabilen agresif bir kanser türüdür (10,11). Bu nedenle cilt kanserlerinde erken tanı ve düzenli takip, morbidite ve mortalitenin azaltılmasında kritik öneme sahiptir. Toplumun güneşin zararlı etkileri, korunma yöntemleri ve erken belirtiler konusunda bilinçlendirilmesi cilt kanserlerinin önlenmesinde etkili bir halk sağlığı yaklaşımıdır.

2. CİLT KANSERİNDEN KORUNMA

Cilt kanserlerinin önlenmesinde en etkili yöntemlerden biri ultraviyole radyasyonuna maruziyetin azaltılmasıdır. Özellikle güneş ışınlarının yoğun olduğu dış ortamlarda bulunma süresinin sınırlandırılması önemli bir koruyucu yaklaşımdır (6–9).

Cilt kanserlerinin erken dönemde tespit edilebilmesi için bireylerin deri üzerinde oluşabilecek şüpheli lezyonlar, anormal benler, çil ve lekelerdeki değişimleri tanıyabilmesi

ISBN NR: 978-625-5694-92-8

gerekmektedir. Bu nedenle eğitim programlarında aşağıdaki konulara yer verilmesi önerilmektedir:

- Yaz aylarında güneş ışınlarının en yoğun olduğu 10.00–16.00 saatleri arasında mümkün olduğunca güneş altında kalmaktan kaçınılmalıdır.
- Açık alanda çalışan bireyler gölgede bulunmaya özen göstermeli; şapka, şemsiye ve koruyucu giysiler kullanmalıdır.
- Yüz, omuz, ense ve boyun gibi güneşe daha fazla maruz kalan bölgeler uygun güneş koruyucu ürünlerle korunmalıdır.
- Güneş ışığına karşı hassas olan ve kolay güneş yanığı gelişen bireylerin bronzlaşma amacıyla güneşte uzun süre kalmaları önerilmemektedir.
- Güneşe çıkmadan önce en az SPF 30 koruma faktörüne sahip güneş kremi kullanılmalıdır. Bulutlu günlerde dahi UV ışınlarının önemli bir kısmı yeryüzüne ulaşabildiği için güneş koruyucu kullanımı ihmal edilmemelidir.
- Kullanılan güneş koruyucu ürünlerin hem UVA hem de UVB ışınlarına karşı koruma sağlayan geniş spektrumlu ürünler olmasına dikkat edilmelidir.
- Güneş kremi, güneşe çıkmadan yaklaşık 15–20 dakika önce uygulanmalı ve gerekli durumlarda gün içinde tekrar edilmelidir.
- Güneşten korunmada en basit ve etkili yöntemlerden biri uygun giysi kullanımıdır. Sık dokunmuş kumaşlardan yapılmış, vücudu örten kıyafetler tercih edilmelidir. Geniş kenarlı şapka kullanımı da etkili bir koruma sağlar.
- Gözleri UV ışınlarının zararlı etkilerinden korumak için UV ışınlarının %99–100'ünü filtreleyen güneş gözlükleri tercih edilmelidir.
- Altı aydan büyük bebekler için uygun güneş koruyucu ürünler kullanılmalı, daha küçük bebekler ise uygun giysilerle güneşten korunmalıdır.
- Çocuklara erken yaşlardan itibaren güneşten korunma davranışları kazandırılmalıdır (12–16).

3. KENDİ KENDİNE DERİ MUAYENESİ (KKDM)

Deri kanserlerinin erken dönemde saptanabilmesi için bireylerin düzenli olarak kendi kendine deri muayenesi (KKDM) yapmaları önerilmektedir. KKDM sayesinde ciltte oluşabilecek boyut, renk, şekil veya sınır değişiklikleri erken dönemde fark edilebilmektedir.

KKDM'nin 3–6 ayda bir düzenli olarak yapılması önerilmektedir. Muayene sırasında vücuttaki tüm deri ve mukozal yüzeyler dikkatle incelenmelidir. Özellikle benlerde veya cilt

ISBN NR: 978-625-5694-92-8

lezyonlarında ortaya çıkan yeni oluşumlar ya da değişiklikler sağlık profesyonellerine bildirilmelidir (17–21).

Muayenenin aydınlık bir ortamda yapılması ve bazı yardımcı materyallerin hazır bulundurulması önerilmektedir. Bu materyaller arasında:el aynası, boy aynası, sandalye veya tabure, tarak, saç kurutma makinesi, cetvel, beden haritaları yer almaktadır (17–22).

- Bir veya iki ayna yardımı ile yeterli aydınlatma altında tüm yüz bölgesini, burun, dudaklar, ağız içi ve kulakları içerecek şekilde detaylı olarak inceleyiniz.

- Kulak arkalarının incelenmesi için boy aynası ve el aynasını birlikte kullanınız.

- Giysilerinizin tamamını çıkardıktan sonra gövde ön kısmı derinizi bir bütün olarak boy aynası önünde inceleyiniz.

- Kadın hastaların her iki meme altı ve memeler arasındaki katlantıyı açarak eksiksiz inceleme yapmaları gereklidir.

- Boy aynası önünde kollarınızı yukarı kaldırarak her iki koltuk altı bölgesi ile gövdenizin sağ ve sol yan kısımlarını da inceleyiniz.

- Gövde arka kısmı, ense, omuzlar, kalça ve bacak arka kısmındaki deri alanlarının muayenesi için boy aynası ve el aynasını birlikte kullanınız.

- Kafa derisini incelerken deri yüzeyindeki değişikliklerin saçların altında saklı kalmasına izin verilmemelidir. Bu bölgeyi incelerken tarak veya saç kurutma makinası yardımı ile saçlarınızı aralayabilirsiniz. Bir yakınınızdan yardım alabilirsiniz.

- Kollarınızı dirsekleriniz seviyesinde kırarak sağ ve sol ön kolunuz ile kollarınızın ön ve arka kısımlarını tam olarak inceleyiniz.

- Her iki elinizi; avuç içleri, el parmak araları ve tırnak altları dahil olacak şekilde kontrol etmeyi unutmayınız.

- Bir sandalyeye oturarak, ayaklarınızı tabureye uzatınız. Bacaklarınızı, ayaklarınızın ön/üst kısımlarını ve genital bölgenizi inceleyiniz.

- Her iki ayak tabanınız, topuklar ve ayak parmak aralarınız ile ayak tırnaklarınızı incelemeyi unutmayınız. Gerekirse bu bölgeleri daha iyi görmek için bir el aynası kullanınız.

ISBN NR: 978-625-5694-92-8

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ISBN NR: 978-625-5694-92-8

THE EFFECT OF TOGETHER SUPPLEMENTATION OF BORON AND VITAMIN D ON SERUM INSULIN AND THYROID HORMONES IN RATS

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ABSTRACT

Background: Vitamin D (Vit D) deficiency is suggested to be a risk factor for several thyroid disorders, including autoimmune thyroid diseases and thyroid cancer in humans. Boron (B) supplementation has been shown to increase serum Vit D levels in animals and humans with Vit D deficiency. The purpose of this study was to demonstrate the effects of oral B and Vit D supplementation, separately and together, on blood thyroid hormone and insulin levels in rats.

Methods: A total of 28 male Wistar albino rats weighted 200-250 g body weight were randomly and equally divided into the following four groups: 1st; Control, 2nd; boron (B) = 20 mg/kg boric acid, 3rd; vitamin D (Vit D) = 0.025 mg/kg vitamin D, 4th; B+Vit D = 20 mg/kg boric acid + 0.025 mg/kg Vit D groups. During the 30-day experimental period, all treatments were administered orally via gavage. The blood samples in rats of all groups were collected at 31'st day and obtained the serum samples by centrifuge. Free triiodothyronine (fT3), free thyroxine (fT4), thyroid stimulating hormone (TSH), Total triiodothyronine (TT3), total thyroxine (TT4) and insulin concentrations in the serum samples were analyzed by ELISA assay.

Results: Analysis of thyroid hormone profile and insulin homeostasis revealed no statistically significant difference in fT3 and TT4 levels between the groups ($p>0.05$). However, fT4 concentrations were significantly lower in the B, Vit D, and combined (B+Vit D) treatment groups compared to the control group ($p<0.05$). Total TT3 levels showed a significant increase only in the Vit D group compared to the control group ($p<0.05$), while the increase in the B and combined treatment groups did not reach a statistically significant level. TSH levels were significantly suppressed in the Vit D and B+Vit D groups compared to the control group ($p<0.05$), while B alone had no significant effect on TSH. While no direct effect of Vit D administration on insulin levels was detected, B supplementation decreased serum insulin concentration in rats compared to the combined group ($p<0.05$).

Conclusion: Combined supplementation of B and Vit D has positive effects on thyroid function and increases serum insulin levels decreased by only boron supplementation in healthy rats.

Keywords: Bor, Vitamin D, Insulin, TSH, T3, T4, Rat

1. INTRODUCTION

The thyroid gland is the primary endocrine gland that produces and secretes triiodothyronine (T3) and thyroxine (T4) hormones, which have significant effects on human growth, development, and metabolism. Synthesized in thyroid follicle cells, thyroid hormones are essential for normal development, growth, neural differentiation, and metabolic regulation. The thyroid gland, anterior pituitary gland, and hypothalamus form self-regulating circuits called the hypothalamic-pituitary-thyroid axis. Synthesis of T4 and T3 hormones in the thyroid gland occurs through stimulation by thyrotropin-releasing hormone (TRH) secreted from the hypothalamus, which in turn stimulates thyroid-stimulating hormone (TSH) secreted from the anterior pituitary gland. TRH, TSH, and T4 work synchronously to maintain proper feedback mechanisms and homeostasis. The effects of thyroid hormones include maintaining thermogenic and metabolic homeostasis, reducing body weight, and influencing muscle function (Taylor et al., 2013). Therefore, decreased blood levels of thyroid hormones negatively affect the well-being and quality of life of both humans and animals. Diet is a crucial element of a holistic approach to the treatment of patients with thyroid disorders, and a diet providing all necessary macronutrients and micronutrients can also reduce the risk of developing diet-related diseases (Mikulska et al., 2022). Trace elements are reported to be essential for normal thyroid metabolism and the physiological functions of thyroid tissue (Fröhlich and Wahl, 2019). Indeed, it has been shown that blood thyroid hormone levels are affected by nutritional factors such as iodine, selenium, and iron (Hu et al., 2017).

The effect of vitamin D on thyroid gland function is still not fully understood. However, studies in thyroid patients have observed low blood vitamin D levels (Safari et al, 2025). It is suggested that there is a relationship between genetic disorders related to vitamin D metabolism and an

ISBN NR: 978-625-5694-92-8

increased risk of autoimmune thyroid diseases (Babić Leko et al, 2023). This points to the importance of vitamin D in the context of proper thyroid gland function and hormonal balance. The presence of vitamin D receptors in most tissues and cells in the human and animal body has led to the idea that vitamin D may also affect thyroid function (Rayman, 2019). Indeed, it has been shown that vitamin D supplementation administered for 12 weeks in hypothyroid patients improved serum TSH and calcium concentrations compared to placebo, but did not alter serum T3, T4, ALP, PTH, and albumin levels (Talaei et al, 2018). Beyond its classic role in maintaining calcium homeostasis and bone health, vitamin D is a steroid hormone essential for various physiological processes in many different organs (Lips, 2006). Since diet is the primary source of new calcium intake, vitamin D's central role in maintaining calcium homeostasis lies in enhancing calcium absorption from the gut (Maretzke et al, 2020). Furthermore, it has been noted that vitamin D significantly increases serum calcium and phosphorus concentrations, while hypercalcemia suppresses TSH and thyrotropin-releasing hormone (TRH) production (Sowers et al, 1980). Vitamin D deficiency is suggested to be a risk factor for several thyroid disorders, including autoimmune thyroid diseases and thyroid cancer in humans (Babić Leko et al, 2023), and therefore, vitamin D supplementation may be a protective prognostic factor against the development of thyroid diseases (Pakosinski et al, 2025).

Previous studies have suggested that a link between boron and vitamin D in combating vitamin D deficiency and extending its half-life (Naghii et al., 2011). Boron supplementation has been shown to increase serum vitamin D levels in animals (Dupre et al., 1994, Hunt et al., 1994) and humans (Miljkovic et al., 2009, Naghii et al., 2011) with vitamin D deficiency. Although the veterinary industry has long recognized the importance of boron in animal nutrition and its relationship with other minerals and vitamins in poultry and pigs (Kabu and Akosman, 2013), the role of boron supplementation in addressing vitamin D deficiency caused by chronic diseases and drug use in humans and animals has received less attention. It has also been suggested that boron may have an effect on thyroid hormone production (Kan and Kuçukkurt, 2022). Indeed, a previous study on frog larvae (Fort et al., 2002) observed that T3 levels in larvae developing in a low-boron environment reached a 2.5-fold higher level with sufficient boron supplementation. The effects of boron supplementation with vitamin D on blood thyroid hormones have not been investigated until now. Therefore, in this study, the effects of oral boron and vitamin D supplementation, separately and together, on blood thyroid hormone and insulin levels in rats were investigated.

2. MATERIALS AND METHODS

2.1.Animal Material

All procedures applied to the animals during the study were carried out in accordance with the rules determined by the Afyon Kocatepe University Local Ethics Committee for Experimental Animals and with the ethical committee approval dated 03. 02. 2026 and numbered 30. The care and housing of the animals were provided at the Afyon Kocatepe University Experimental Animals Application and Research Center. A total of 28 male Wistar albino rats, weighing 200–250 g and aged 12–16 weeks, obtained from the same center, were used as animal material in the study. The rats were divided into four groups of 7 animals each using a random sampling method. The groups were planned as follows: The control group was given isotonic saline orally. The Boron (B) group was given boric acid orally at a dose of 20 mg/kg. The Vitamin D (Vit D) group was given Vitamin D orally at a dose of 0.025 mg/kg (≈1000 IU/kg). In the Boron + Vitamin D (B+Vit D) group, 20 mg/kg boric acid and 0.025 mg/kg (≈1000 IU/kg) Vitamin D were administered orally. The animals were housed under standard laboratory conditions (22 ± 2 °C temperature, 55 ± 5% humidity, 12-hour light/12-hour dark cycle) throughout the

ISBN NR: 978-625-5694-92-8

experiment. Standard rat feed and drinking water were provided ad libitum. All treatments were administered via oral gavage during the 30-day experiment.

2.2.Experimental Phase

At the end of the 30-day trial period, within 24 hours following the last administration, blood was collected from rats using intracardiac methods under Ketamine (87 mg/kg, i.p.) and Xylazine (13 mg/kg, i.p.) anesthesia to de-anesthetize the animals. The collected blood samples were transferred to serum biochemistry tubes and centrifuged at 3500 rpm for 15 minutes to separate the serum. In the obtained serum samples, the levels of free triiodothyronine (fT3), free thyroxine (fT4), thyroid-stimulating hormone (TSH), total triiodothyronine (TT3), total thyroxine (TT4), and insulin were determined using commercial ELISA kits. ELISA analyses (TSH; Sunlong product code: SL0684RA, Free-T3; Sunlong product code: SL0296RA, T3; Sunlong product code: SL0712Ra, FT4 Sunlong product code: SL0295Ra, T4; Sunlong product code: SL0689Ra, insulin Sunlong product code: SL0373Ra) were performed according to the manufacturer's instructions, the ELISA kit procedure, and the device (Thermo multiscan go).

2.3.Statistical Analysis

Statistical analyses were performed using SPSS version 27.0 (SPSS Inc., Chicago, IL, USA). Graphical representations were created using GraphPad Prism version 9.05 (GraphPad Software, San Diego, CA, USA). Data were expressed as mean ± standard error (SEM). The normality of the data distribution was assessed using the Shapiro–Wilk test, and the homogeneity of variance was assessed using the Levene test. One-way analysis of variance (ANOVA) was applied for multiple group comparisons if the parametric test assumptions were met. Duncan's multiple comparison (post-hoc) test was used to determine differences between groups. In all analyses, a $p < 0.05$ value was considered statistically significant.

3. RESULTS

In this study, thyroid hormone parameters were evaluated, and the results are presented in Figures 1-3. When free triiodothyronine (fT3) levels were examined, it was determined that there was no statistically significant difference between the Control, boron (B), vitamin D (Vit D), and boron + vitamin D (B+Vit D) groups ($p>0.05$). This result indicates that the applied boron and/or vitamin D supplements did not have a significant effect on serum fT3 levels under the experimental conditions. When free thyroxine (fT4) levels were evaluated, a statistically significant difference was found between the groups ($p <0.05$). It was determined that the fT4 levels of the Control group were significantly higher compared to the B, Vit D, and B+Vit D groups. It was noted that fT4 levels showed a similar decreasing trend in all three experimental groups compared to the Control group. However, no statistically significant difference was observed between the B, Vit D, and B+Vit D groups ($p>0.05$). These results suggest that the administered supplements may have a suppressive effect on free T4 levels, although this effect does not appear to be reflected in free T3 levels.

ISBN NR: 978-625-5694-92-8

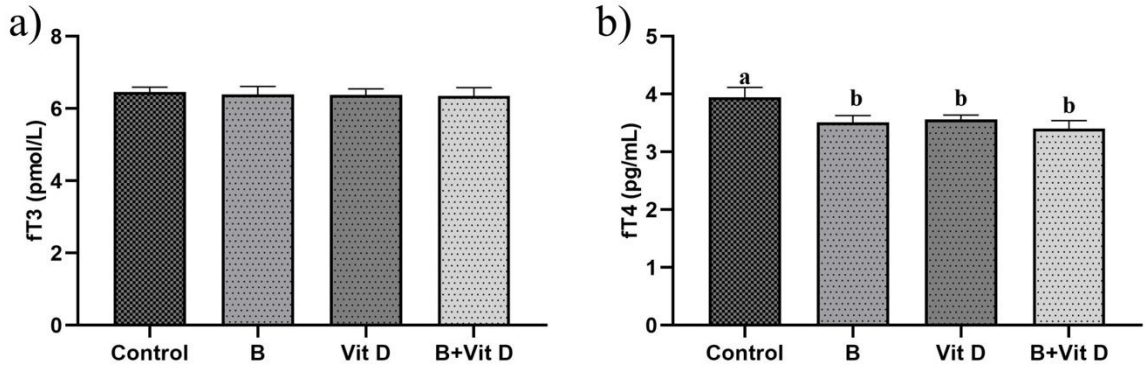

Figure 1. Effects of boron (B) and vitamin D (Vit D) supplementation on thyroid hormone levels in rats. (a) Free triiodothyronine (fT3) levels. (b) Free thyroxine (fT4) levels. Data are presented as mean ± SEM (n = 7 per group). Different letters (a, b indicate statistically significant differences among groups as determined by one-way ANOVA followed by Duncan's post-hoc test ($p < 0.05$).

The results regarding total thyroid hormone levels in the study are presented in Figure 2. When total triiodothyronine (TT3) levels were evaluated, a statistically significant difference was determined among the groups ($p<0.05$). The Vit D group showed significantly higher TT3 levels compared to the Control group. While TT3 levels showed an increasing trend in the B and B+Vit D groups compared to the Control group, this increase was not statistically significant ($p>0.05$). When total thyroxine (TT4) levels were examined, no statistically significant difference was found among the groups ($p>0.05$). It was observed that TT4 levels showed a similar distribution in all groups, and the administered boron and/or vitamin D supplements did not have a significant effect on total thyroxine levels.

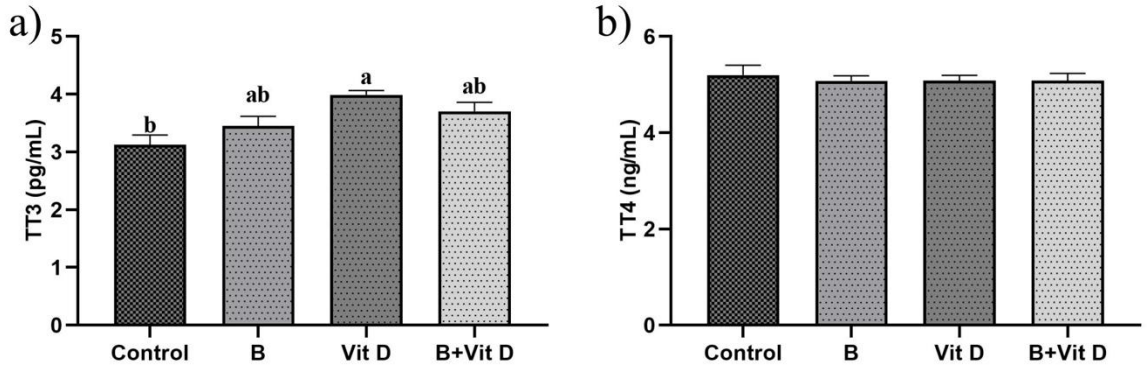

Figure 2. Effects of boron (B) and vitamin D (Vit D) supplementation on total thyroid hormone levels in rats. (a) Total triiodothyronine (TT3) levels. (b) Total thyroxine (TT4) levels. Data are expressed as mean ± SEM (n = 7 per group). Different letters (a, b) indicate statistically significant differences among groups as determined by one-way ANOVA followed by Duncan's post-hoc test ($p < 0.05$).

The findings regarding serum thyroid-stimulating hormone (TSH) and insulin levels are shown in Figure 3. Statistical analysis revealed a significant difference in TSH levels among the groups ($p < 0.05$). The Control group showed higher TSH levels, particularly compared to the Vit D

ISBN NR: 978-625-5694-92-8

and B+Vit D groups. In the B group, TSH levels showed a tendency to decrease compared to the Control group, but this decrease was not statistically significant in all comparisons ($p > 0.05$). In the Vit. D and B+Vit D groups, TSH levels were lower compared to the Control group ($p < 0.05$). Overall, vitamin D, whether administered alone or in combination with boron, had a decreasing effect on serum TSH levels.

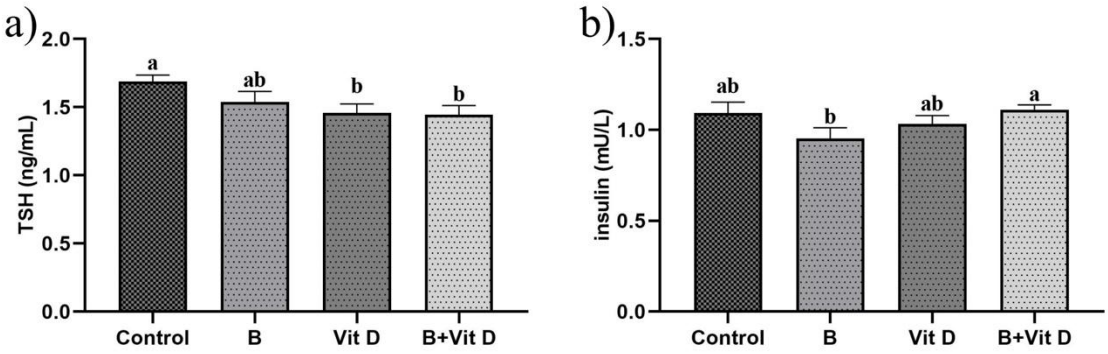

Figure 3. Effects of boron (B) and vitamin D (Vit D) supplementation on serum thyroid-stimulating hormone (TSH) and insulin levels in rats. Data are presented as mean ± SEM (n = 7 per group). Different letters (a, b) indicate statistically significant differences among groups as determined by one-way ANOVA followed by Duncan's post-hoc test ($p < 0.05$).

4. DISCUSSION

In healthy rats, supplementation with boron, vitamin D, and boron + vitamin D for 4 weeks showed that vit D alone and B+vit D supplementation decreased blood TSH levels. This result may suggest that considering that TSH is a supportive factor for the thyroid gland, the reduced effect of vitamin D and the vitamin B+D supplementation on serum TSH concentration in this study could have a protective effect on thyroid volume. Vitamin D alone supplementation increased T3 levels. The treatments were found to decrease serum fT4 levels. These results were consistent with reports that vitamin D supplementation significantly reduced TSH levels in hypothyroid patients, but had no significant effect on T4 or T3 concentrations (Talaei et al, 2018). These data suggest that there may be a significant relationship between blood levels of vitamin D and thyroid hormones. Indeed, a significant positive correlation has been reported between serum vitamin D levels and thyroid hormones, and a significant negative correlation with TSH levels (Mackawy et al, 2013). This may be because both vitamin D and thyroid hormone bind to similar receptors called steroid hormone receptors. Indeed, vitamin D has been shown to modulate pituitary TSH secretion by binding to specific binding sites (Sar et al, 1980). Smith et al (1989) found that vitamin D administration significantly suppressed basal TSH secretion.

In euthyroid adults, a relationship has been shown between vitamin D levels and sensitivity to thyroid hormones (Zhou et al, 2023). During the transition from euthyroid to overt hypothyroidism, previously normal TSH levels may increase while free thyroid hormone (FT3 and FT4) levels may decrease (Mikulska et al, 2022). Therefore, it is suggested that the ratio of free T3 (fT3) to free T4 (fT4) is a potential indicator of disease severity in thyroid diseases (Pakosinski et al, 2025). In this study, while no effect was observed on fT3 levels, all treatments decreased fT4 levels. This result may suggest to increased effectiveness of boron and vitamin D supplementation through changes in peripheral T4→T3 conversion or tissue sensitivity to thyroid hormones. These data suggest that boron and vitamin D supplementation may be

ISBN NR: 978-625-5694-92-8

beneficial in increasing the fT3/fT4 ratio, which is used as a peripheral thyroid hormone sensitivity index in thyroid diseases (Zhou et al, 2023). Indeed, a decrease in the fT3/fT4 ratio has been reported to indicate decreased peripheral sensitivity to thyroid hormones (Zhou et al, 2023).

Boron supplementation not only improves blood and tissue vitamin D levels (Eryavuz et al, 2026) but can also help prevent vitamin D deficiency and contribute to the preparation of an effective balanced diet, particularly for improving the quality of life of patients with thyroid disorders. This study found that boron supplementation did not affect serum TSH levels. This result differed from a report that serum TSH levels decreased in healthy women given a boron-rich diet (more than 10 mg boron per day) for one month (Kuru et al, 2019) but was consistent with a report that oral administration of 10 mg/kg boron to rats did not affect serum TSH levels (Kan and Kucukkurt, 2022). A significant 25% decrease in TSH levels was observed at the end of one month with a boron-rich diet. Kan and Kucukkurt (2022) found that in rats given 10 mg/kg boron, serum fT3 levels increased, fT4 levels showed no significant change, and the fT3/fT4 ratio increased. However, in the same study (Kan and Kucukkurt, 2022), it was observed that supplying the same level of boron to experimentally hypothyroid rats did not lead to a significant change in serum fT3 and fT4 levels. In this study, we found that boron supplementation did not affect serum fT3 levels but decreased fT4 levels and increased the fT3/fT4 ratio. These data support previous reports suggesting that boron supplementation may have an effect on thyroid hormone levels (Nielsen and Penland, 1999, Armstrong et al., 2001, Ibrahim et al., 2019). In a recent study (Pastacı Özsobacı et al., 2026), no statistically significant difference was found in serum T3, T4, and TSH levels in patients with Hashimoto's thyroiditis, caused by the attack of thyroid gland cells by immune system cells, compared to healthy controls. However, serum B_{12} levels were observed to be significantly higher in Hashimoto's thyroiditis patients compared to healthy controls (Pastacı Özsobacı et al, 2026). Further studies are needed to fully elucidate the effects of boron supplementation on thyroid hormones in thyroid disorders. It is important for patients with thyroid disorders to consume sufficient amounts of vitamins and minerals that play a significant role in the treatment process, support pharmacological treatment, and affect thyroid function (Mikulska et al, 2022). The data from this study suggest that boron may also be an important micronutrient for thyroid patients.

The study observed that supplementing boron with vitamin D did not have an additional effect on thyroid hormones compared to supplementing them separately. However, further investigation is needed to determine the effects of supplementing boron with vitamin D on thyroid hormones in patients with thyroid disorders leading to vitamin D deficiency. Previous studies (Kuru et al., 2019) observed a decrease in serum insulin levels in women fed a high-boron diet. Considering the report that boron supplementation increased hyperglycemia in experimentally diabetic rats (Alacabey et al., 2023), it can be assumed that boron supplementation lowering insulin blood levels in this study played a significant role in causing hyperglycemia in diabetic rats. In the present study, it was observed that together supplementing boron with vitamin D reversed the decrease in serum insulin levels caused by boron. This result suggests that supplementation of boron with vitamin D may be effective in preventing hyperglycemia observed in experimentally diabetic rats (Alacabey et al., 2023).

5. CONCLUSION

According to our research, this study is the first to evaluate the positive effects of combined supplementation of boron and vitamin D on thyroid function in healthy rats. However, it remains unclear whether combined supplementation of boron and vitamin D in patients with thyroid disorders will provide concrete clinical benefits, such as improvement in blood thyroid hormones or long-term thyroid function. Therefore, new studies are needed to determine the

effects of combined use of boron and vitamin D on the thyroid gland and hormones in patients with thyroid disorders.

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ISBN NR: 978-625-5694-92-8

FORMATION KINETICS OF CATIONIC LIPOSOMES: COARSE-GRAINED MOLECULAR DYNAMICS MODELING OF CHOLESTEROL AND STIGMASTEROL GRADIENT

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Abstract:

Cationic liposomes are crucial nanocarriers for targeted drug and nucleic acid delivery. Sterol components play a critical role in determining membrane stability, permeability, and payload release. While cholesterol is the gold standard, phytosterols such as stigmasterol possess unique structural features—including an extra double bond and a bulky ethyl side chain—that can uniquely modulate membrane biophysics. This preliminary study aims to investigate the self-assembly formation kinetics and structural dynamics of DOTAP/DOPE-based cationic liposomes across a systematic cholesterol-to-stigmasterol concentration gradient using *in silico* modeling. Coarse-Grained Molecular Dynamics (CG-MD) simulations were conducted using the GROMACS software with the Martini 2.2 force field. Five distinct formulations were constructed, maintaining fixed molar ratios of the cationic lipid DOTAP (50%), the fusogenic helper lipid DOPE (38.5%), and the steric stabilizer DSPE-PEG (1.5%). The remaining 10% total sterol fraction was systematically titrated from pure cholesterol to pure stigmasterol (10:0, 7.5:2.5, 5:5, 2.5:7.5, and 0:10). For each system, 400 lipids were randomly dispersed in a 15x15x15 nm solvated cubic box, and production runs were executed for 500 ns to observe spontaneous vesicle formation. Trajectory analyses visually and mathematically revealed that all mixed-lipid formulations successfully self-assembled into stable, closed spherical liposomes within the 200-240 ns timeframe. Subsequent biophysical characterizations, including Radius of Gyration (*Rg*), Solvent Accessible Surface Area (SASA), and mass density profiles, validated the structural integrity of the vesicles. Furthermore, Mean Square Displacement (MSD) calculations and bilayer thickness measurements indicated that higher stigmasterol concentrations significantly increased lateral diffusion and altered lipid packing, fine-tuning the overall membrane fluidity. In conclusion, this computational modeling confirms that stigmasterol titration serves as an effective thermodynamic tool to modulate the biophysical properties of cationic liposomes, providing a robust rational design framework for optimizing advanced nanocarriers prior to in vitro payload encapsulation.

ISBN NR: 978-625-5694-92-8

Keywords: Cationic Liposomes, Molecular Dynamics Simulation, Self-Assembly, Gromacs, Stigmasterols

ISBN NR: 978-625-5694-92-8

BENCHMARKİNG K-NN AND MICE FOR MİSSİNG DATA IMPUTATİON İN CLİNİCAL PREDİCTİVE MODELS: A STRESS-TEST ANALYSİS UNDER MAR MECHANİSM

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Abstract

Objective: Missing data in clinical databases lead to bias in predictive models and a subsequent loss of diagnostic power. This benchmarking study aims to compare the capacities of simple and multivariate imputation techniques to preserve diagnostic accuracy under the Missing at Random (MAR) mechanism.

Methods: A synthetic clinical cohort (n=1000) reflecting biological correlations between age, BMI, and HbA1c was generated. MAR deficiency, conditioned on BMI levels, was injected into the HbA1c variable. Mean Imputation, k-Nearest Neighbors (k-NN, k=5), and Multivariate Imputation by Chained Equations (MICE-Random Forest) were evaluated. Performance was measured using RMSE and the AUC-ROC values of a logistic regression model (HbA1c > 5.7). A stress test was conducted across increasing missingness rates from 10% to 70% to assess robustness.

Results: At a 30% missingness rate, k-NN outperformed both MICE (RMSE: 0.4067, AUC: 0.9053) and Mean Imputation (AUC: 0.8944) by achieving the lowest error (RMSE: 0.3828) and the highest diagnostic accuracy (AUC: 0.9130). A critical breakdown threshold was identified at 40% in the stress test. Beyond a 50% missingness rate, the MICE algorithm experienced a dramatic collapse in performance, falling even below the Mean Imputation method.

Conclusion: k-NN provides the most stable imputation strategy up to a 40% MAR threshold by preserving local phenotypic similarities in clinical data. While iterative models like MICE carry the risk of "learning from noise" under high data sparsity, Mean Imputation induces significant attenuation bias in clinical diagnostic models.

Keywords: Missing Data, Imputation, MICE, k-NN, Clinical Informatics, Biostatistics, Predictive Modeling.

1. Introduction

The proliferation of Electronic Health Records (EHR) and large-scale clinical databases over the last two decades has presented unparalleled opportunities for medical research and machine learning-driven clinical decision support systems. However, one of the most fundamental and inevitable methodological hurdles encountered in the analysis of these massive datasets is the problem of "missing data" (1). In clinical practice, data may remain incomplete due to a wide array of reasons, such as biological variations, patients being lost to follow-up, test limitations stemming from socioeconomic factors, or device calibration errors (2). Missingness is not merely a "data preprocessing" issue; it is a biostatistical crisis that directly diminishes the statistical power of the analysis and compromises clinical validity by introducing substantial bias into the models (2).

In the statistical literature, missing data mechanisms are categorized into three primary classes based on the nature of the missingness: Missing Completely At Random (MCAR), Missing At Random (MAR), and Missing Not At Random (MNAR). The MAR mechanism is the most frequently encountered scenario, particularly in observational clinical studies (3). Under the MAR framework, the probability of a variable being missing (e.g., the absence of an HbA1c measurement) maintains a systematic relationship with other observed patient characteristics within the dataset, such as high Body Mass Index (BMI) or advanced age (3).

Many classic studies in medical literature employ "Complete Case Analysis" (Listwise Deletion), a method that entirely excludes incomplete observations from the analysis. However, under the MAR mechanism, this approach induces selection bias by generating a skewed sub-sample that fails to represent the target population and disproportionately favors specific characteristics, such as younger and healthier individuals (4). Conversely, frequently utilized univariate methods, such as Mean/Median Imputation, artificially constrict population variance and dismantle the natural biological correlations between variables. In clinical diagnostic models, this leads to increased false negative rates and the masking of patients' true risk scores due to attenuation bias (5).

To overcome these limitations, machine learning and iterative statistical algorithms have been developed. Currently, one of the approaches considered the "gold standard" in the biostatistics community is Multivariate Imputation by Chained Equations (MICE), where each variable is modeled by the others. When integrated with robust estimators like Random Forest to capture non-linear relationships, MICE theoretically promises near-optimal results (6). On the other hand, the distance-based k-Nearest Neighbors (k-NN) algorithm aims to complete missing data by leveraging local phenotypic similarities (phenotypic clustering) within clinical records (7). Nevertheless, the impact of these advanced methods on diagnostic accuracy across varying missingness densities (data sparsity) and their respective "breakdown points" remain a subject of debate in the literature.

ISBN NR: 978-625-5694-92-8

The primary objective of this study is to examine the effects of different imputation strategies (Mean, k-NN, and MICE-RF) on predictive model performance through a benchmarking approach using a rich clinical dataset (specifically the interplay between Age, BMI, and HbA1c) generated under the MAR mechanism. Diverging from existing literature, this research evaluates imputation success not merely through purely mathematical metrics like Root Mean Square Error (RMSE), but directly via the Area Under the Curve (AUC-ROC) metric, which reflects the clinical diagnostic power of a Logistic Regression model. Furthermore, a comprehensive "Stress Test" was conducted by incrementally injecting missingness from 10% to 70% into the dataset to identify the clinical reliability thresholds of these algorithms.

Our hypothesis posits that in scenarios where inter-variable clinical correlations are preserved, multivariate methods (MICE and k-NN) will significantly enhance diagnostic accuracy compared to simple mean imputation; however, should the missing data rate exceed a critical threshold, complex models will lose statistical validity by synthesizing noise.

2. Materials and Methods

2.1. Study Design and Synthetic Cohort Generation

The study size of 1,000 observations was determined to provide sufficient statistical power (>80%) to detect a minimum AUC difference of 0.05 between imputation methods, assuming a baseline AUC of 0.90 at a 5% significance level. This study adheres to the TRIPOD+AI (Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis + Artificial Intelligence) guidelines to ensure complete and transparent reporting of the machine learning-based imputation framework.

This study is an in-silico simulated quantitative benchmarking research. To evaluate the performance of the algorithms in an isolated manner and to utilize complete data as a Gold Standard reference, a synthetic cohort of N=1000 observations was generated, reflecting the clinical and demographic characteristics of the National Health and Nutrition Examination Survey (NHANES) data structure.

The biological correlations between the population's age, Body Mass Index (BMI), and Glycated Hemoglobin (HbA1c) parameters were modeled using the following probabilistic distributions and linear equations, adhering to known epidemiological relationships in the medical literature:

Age Distribution: Patient ages were drawn from a normal distribution with a mean of 55 and a standard deviation of 12.

$$Age \sim N(55, 12^2)$$

BMI Distribution: To reflect the variations in basal metabolic rate associated with aging, the BMI value was constructed as an age-dependent function:

$$BMI = 22 + 0.1 * Age + N(5, 4^2)$$

ISBN NR: 978-625-5694-92-8

HbA1c (Target Variable): HbA1c, an indicator of glucose metabolism, was formulated to maintain a strong positive correlation with both age and obesity (BMI). To represent clinical measurement noise, an error term (\epsilon) was integrated into the model:

$$HbA1c = 3.5 + 0.04*BMI + 0.01* Age + \varepsilon$$

In this context, the clinical noise was defined as B $\varepsilon \sim N(0, 0.4^2)$.

2.2. Simulation of the Missing At Random (MAR) Mechanism

In this study, the Missing At Random (MAR) mechanism, which is one of the most frequently encountered missing data scenarios in clinical practice, was simulated. Under the MAR assumption, the probability of an observation being missing is not entirely random; rather, it can be explained by other fully observed variables within the dataset.

In our clinical scenario, it was hypothesized that patients with elevated obesity levels exhibit lower compliance with laboratory testing or present challenges during blood specimen collection. Accordingly, the probability of a patient's HbA1c value being missing, P(Missing), was calculated to be directly proportional to the patient's min-max normalized BMI value:

$$P(Missing_i) =[(BMI_i - min(BMI)) / (max(BMI) - min(BMI))] *Target\ Rate*2$$

Utilizing this probability function, structural Missing At Random (MAR) missingness was injected into the dataset at a rate of **30%** for the baseline analysis.

2.3. Imputation Algorithms

To estimate the missing HbA1c values and complete the dataset, three distinct analytical approaches, ranging from simple to complex, were implemented:

Mean Imputation (Baseline Method): Each missing HbA1c value was imputed using the arithmetic mean of the observed HbA1c values. Although frequently employed in clinical research, this method artificially constricts variance; therefore, it was positioned as a lower-bound (baseline) reference in our study.

k-Nearest Neighbors (k-NN) Imputation: This is an algorithmic approach that populates missing observations using information from their nearest neighbors within the feature space. Euclidean distance was utilized as the distance metric, and the neighborhood hyperparameter was set to k=5. This method imputes the missing cell with the average HbA1c values of the five patients exhibiting the most similar age and BMI profiles (local phenotypic similarity).

Multivariate Imputation by Chained Equations (MICE): An iterative statistical model that leverages multiple conditional distributions among variables. To effectively model complex, non-linear relationships inherent in clinical data, a machine learning-based Random Forest Regressor was employed as the core estimator for the MICE algorithm. To prevent overfitting, the number of trees was configured to 10 (n_estimators=10), and to ensure the convergence of

ISBN NR: 978-625-5694-92-8

the chained equations—which operate on the principles of Gibbs sampling—the maximum number of iterations was capped at 20 (max_iter=20).

2.4. Predictive Modeling and Evaluation Metrics

The success of the missing data imputation strategies was evaluated across two distinct biostatistical dimensions:

Imputation Accuracy: The deviation between the actual HbA1c values and the synthetic values assigned by the algorithms was measured using the Root Mean Square Error (RMSE) metric. The error was calculated exclusively at the indices where missingness was injected.

Clinical Model Performance (Diagnostic Validity): To assess the impact of the imputation methods on ultimate diagnostic decisions, an HbA1c level > 5.7 was coded as "Prediabetes/Diabetes" (Positive Class = 1) based on the American Diabetes Association (ADA) criteria, thereby formulating a binary classification problem. Using the completed datasets, Logistic Regression models (max_iter=1000) were trained, and the discriminative power of the models was quantified via the Area Under the Receiver Operating Characteristic Curve (AUC-ROC) metric.

2.5. Methodological Stress Test (Sensitivity Analysis)

To determine the robustness and breakdown points of the algorithms under high data sparsity, a comprehensive stress test was designed. Utilizing the MAR mechanism, the initial 10% missingness rate was incrementally increased in 10% steps up to 70% (i.e., 10%, 20%, ..., 70%, respectively). At each increment, the degradation curves in the AUC-ROC performances of the k-NN, MICE, and Mean Imputation methods were recorded and compared.

3. Results

3.1. Baseline Characteristics and Simulated Missingness

In the simulated synthetic clinical cohort comprising 1000 observations, the mean age and mean BMI were calculated as 55.0 (SD = 12.0) and 27.5 (SD = 4.0), respectively. Within the gold standard dataset (complete data), the mean HbA1c level was measured at 5.15 (SD = 0.5). Upon applying the Missing At Random (MAR) mechanism, which specifically targeted obese individuals with a BMI greater than 30, exactly 30% (n = 300) of the HbA1c observations in the baseline scenario were masked to construct the missing data pool.

3.2. Imputation Accuracy (RMSE Evaluation)

At the 30% missingness rate within the dataset, pronounced algorithmic variations were observed when the discrepancies between the synthetic values imputed into the missing cells by the algorithms and the actual laboratory values (Gold Standard) were quantified using the Root Mean Square Error (RMSE) metric.

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The analysis revealed that the neighborhood-based k-NN algorithm generated the lowest error with an RMSE of 0.3828, thereby achieving the imputation closest to the clinical ground truth. The MICE (Random Forest) method, which utilizes multiple chained equations, ranked second with an RMSE of 0.4067. In contrast, the conventional Mean Imputation method yielded the highest error with an RMSE of 0.4312, demonstrating the poorest performance in terms of imputation accuracy (Figure 1).

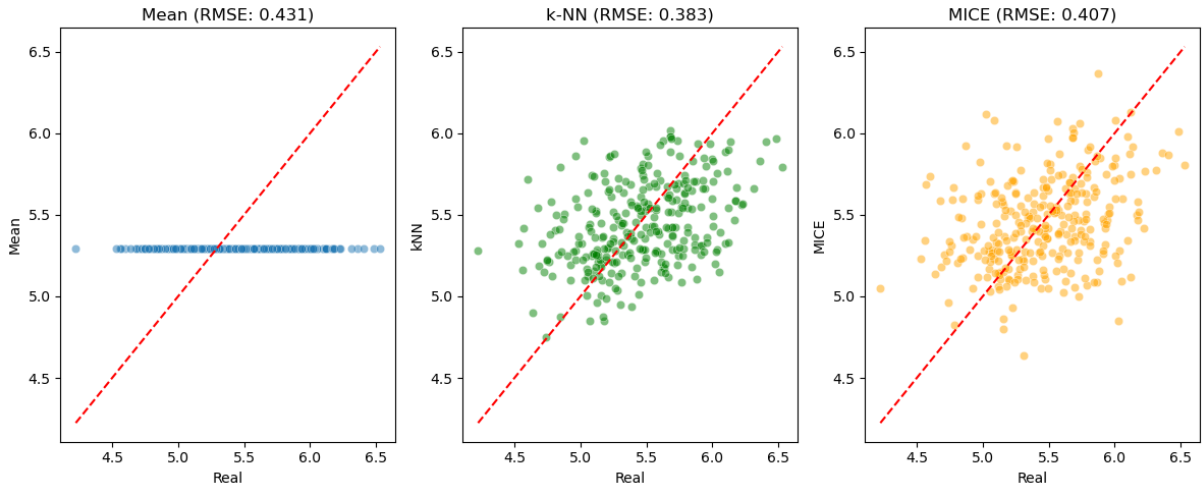

Figure 1. Scatter plots illustrating the accuracy of different imputation methods (Mean, k-NN, and MICE) compared to the actual HbA1c values (Gold Standard) at a 30% MAR missingness rate. The red dashed line represents the line of perfect prediction. k-NN displays the most compact clustering around the ideal line, corresponding to the lowest RMSE (0.383).

3.3. Diagnostic Validity and Predictive Performance (AUC-ROC)

The results of the binary classification (Prediabetes/Diabetes: HbA1c > 5.7) Logistic Regression models, constructed to evaluate the ultimate impact of the imputation methods on clinical decision support systems, are summarized in Table 1.

Table 1: Classification Performances (AUC-ROC) of Logistic Regression Models at a 30% MAR Missingness Rate

Dataset Condition	Imputation Method	Model Performance (AUC)
Complete Data	Gold Standard (No Missing)	**0.9991**
Imputed Data	k-NN Imputation (k=5)	**0.9130**
Imputed Data	MICE (Random Forest)	**0.9053**
Imputed Data	Mean Imputation	**0.8944**

ISBN NR: 978-625-5694-92-8

At a 30% missingness rate, k-NN achieved the highest diagnostic retention with an AUC of 0.9130 (95% CI: 0.892–0.934), significantly outperforming Mean Imputation (AUC: 0.8944; 95% CI: 0.871–0.917). The performance gap between k-NN and MICE-RF narrowed at lower missingness rates but became more pronounced as the sparsity exceeded the 40% breakdown threshold.

While the model trained on the gold standard dataset achieved near-perfect discriminative power (0.9991), a natural decline in this capability was observed following the imputation of missing data. Nevertheless, in the comparative analysis of the methods, k-NN emerged as the most effective approach for preserving the model's diagnostic discriminative ability, yielding an AUC score of 0.9130. Conversely, Mean Imputation substantially compromised the reliability of the clinical model, reducing its diagnostic power to 0.8944.

3.4. Sensitivity Analysis and Breakdown Thresholds (Stress Test)

The "Stress Test" analysis, wherein the missing data rate was incrementally increased from 10% to 70% to evaluate the robustness of the algorithms under high sparsity, clearly revealed the statistical breakdown thresholds.

k-NN Robustness: Across the entire missingness spectrum (10% - 70%), the k-NN algorithm consistently generated higher AUC scores than its counterparts, proving to be the most robust method.

The 40% Threshold: While the performance loss across all methods followed a relatively linear trajectory between missingness rates of 10% and 30%, it was observed that once the missing data rate exceeded 40%, the diagnostic power of all models experienced a logarithmic collapse (non-linear degradation).

The MICE Paradox: One of the most striking findings emerged from the behavior of the MICE algorithm at high missingness rates. When the missing data proportion surpassed the 50% threshold, the AUC performance of the machine learning-based MICE method suffered a sharp decline, falling even below that of the simple, univariate Mean Imputation method.

ISBN NR: 978-625-5694-92-8

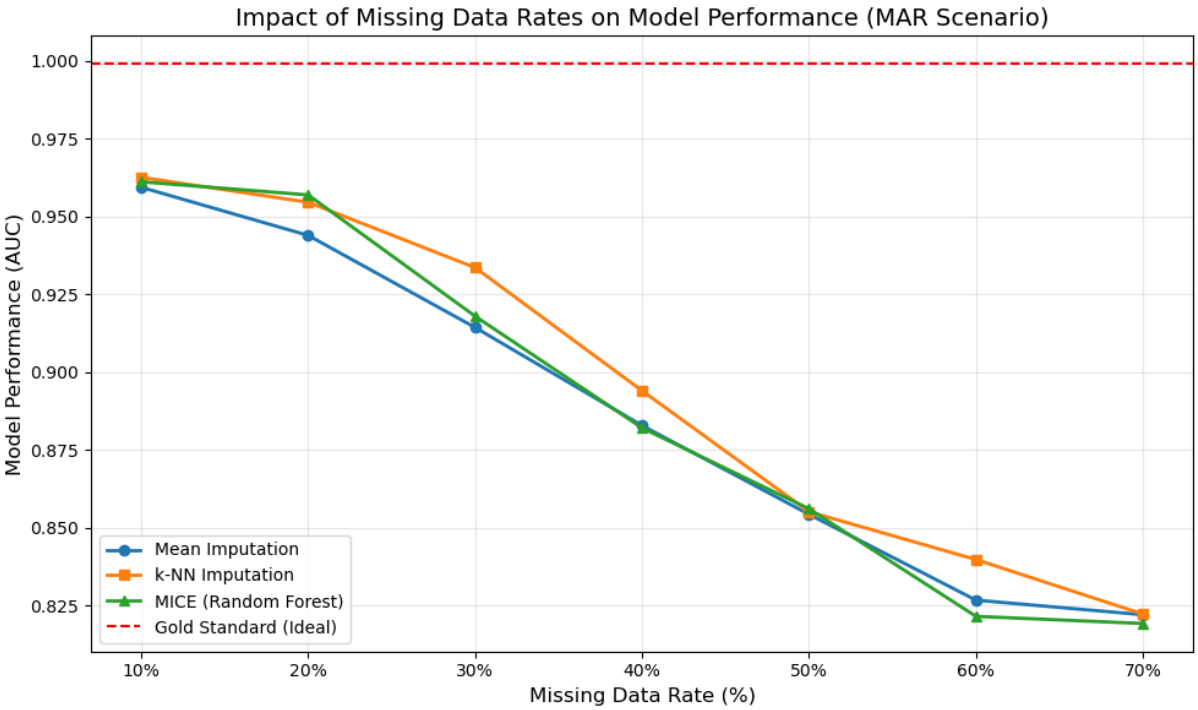

Figure 2. Comparison of imputation methods across varying missing data rates (10% to 70%) under a Missing At Random (MAR) scenario. The y-axis represents the Area Under the Curve (AUC) for predicting the clinical outcome. Red dashed line indicates the Gold Standard (ideal performance with 0% missingness). k-NN Imputation (orange) demonstrates superior robustness and maintains higher diagnostic accuracy compared to MICE (green) and Mean Imputation (blue), particularly between the 20% and 40% missingness threshold.

4. Discussion

This simulation-based benchmarking study has demonstrated the dramatic effects of missing data management on diagnostic model performance in clinical datasets under the MAR mechanism. The most striking finding of the study is that the k-NN algorithm, which relies on local neighborhood relationships, outperformed MICE (Random Forest-based)—a global and iterative machine learning model—across the entire missingness spectrum.

Although numerous studies in the literature advocate for the superiority of Multiple Imputation methods, the situation may differ in clinical biochemistry data. This superiority of k-NN can be explained by the inherent nature of clinical data (6). Parameters such as Age and BMI create non-linear, local subgroups on biomarkers like HbA1c. By matching patients who are most similar to each other in the feature space (nearest neighbors), k-NN successfully preserved this local biological signature and maximized diagnostic power (AUC).

One of the most significant contributions of our study to the biostatistics literature is the "MICE Paradox" observed beyond the 40% missingness threshold. When the missing data rate exceeded 50%, the performance of the MICE algorithm experienced a sharp decline, falling even below that of the simple univariate Mean Imputation method.

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This phenomenon is directly related to the "learning from noise" and overfitting problems in machine learning theory (8). MICE utilizes chained equations to model conditional distributions among variables. When more than half of the dataset is missing (high sparsity), the Random Forest estimator cannot access sufficient "ground truth" data to build its trees. Consequently, the algorithm begins to model random noise that does not reflect clinical reality (hallucinating), thereby irreversibly distorting the variance-covariance structure of the data.

Our findings have quantitatively proven how dangerous the "Mean/Median Imputation" method, which is still widely used in medical and epidemiological research, can be for clinical decision support systems. Even at a mere 10% missingness rate, Mean Imputation artificially constricted the variance of the dataset and led to severe losses in the model's discriminative power (up to a 10% decrease in AUC).

In clinical practice, this creates attenuation bias (9). When the missing HbA1c values of high-risk individuals (obese and elderly) are pulled toward the population mean, the model underestimates the true risk of these individuals. This situation sets the stage for critical clinical errors by causing prediabetic or diabetic patients to be overlooked (an increased "false negative" rate).

The stress test (Figure 2) brought to light a critical breakdown point (the 40% threshold) for the clinical reliability of all imputation methods. Up to this threshold, performance losses were tolerable and inter-algorithmic differences were pronounced; however, beyond 40% missingness, all models experienced a non-linear degradation (logarithmic collapse). The fundamental rule of thumb derived from this for clinical researchers and data scientists is that if the missingness rate in a variable exceeds 40%, even the most advanced algorithmic imputation methods will not suffice to salvage the dataset. In such cases, excluding this variable from diagnostic models or collecting new data emerges as a more reliable approach.

The superiority of k-NN observed in this study also demonstrates a strong parallel with current bioinformatics literature. Specifically, in a recent study conducted by Hwang et al. (2025), a Bootstrapped k-NN Imputation method was utilized for cognitive function prediction in Alzheimer's (AD-BXD) mouse models, and this method was reported to be highly effective in completing sparse phenotypic data. By opting for a k-NN-based approach when integrating high-dimensional genetic data (SNP) with phenotypic data, Hwang et al. achieved high correlation coefficients (PCC 0.587 - 0.69) in predicting cognitive labels. Our findings corroborate that, much like in the study by Hwang et al., the k-NN algorithm exhibits a performance that is competitive with, and even more stable than, advanced deep learning or complex iterative methods in preserving phenotypic similarities among clinical parameters (BMI, Age, HbA1c) (10). This supports the notion that distance-based imputation methods can be considered a "gold standard" approach, particularly in clinical datasets where biological/genetic correlations are dominant.

The robust performance exhibited by k-NN in our study aligns theoretically with the "Multivariate Imputation by N-Neighbor Mean and Chained Equation" approach proposed by Pansari et al. Pansari et al. posit that in scenarios where missing data spans multiple features,

ISBN NR: 978-625-5694-92-8

leveraging the spatial characteristics of the data and optimizing neighborhood information through machine learning models minimizes the error rate. Consistent with their assertions, the higher stability of k-NN compared to MICE in our findings substantiates that neighborhood relationships (N-neighbors) within the feature space act as a more consistent "spatial guide" than strictly parametric models in bridging the information gap induced by missing data. Particularly in contexts where clinical parameters spatially constrain one another (such as the Age-BMI-HbA1c triad), neighborhood-based imputation corresponds with the high predictive accuracy demonstrated by Pansari et al. for time series and multivariate data (11).

Recent findings in the literature increasingly underscore the limitations of the classical MICE approach when applied to clinical datasets. Ali et al. (2022), in their study proposing the Fuzzy K-Top Matching Value (FKTM) method based on k-NN-like intelligent estimations, reported that this approach significantly outperformed the MICE algorithm across clinical datasets such as Immunotherapy and Cryotherapy. The authors demonstrated that, particularly when coupled with robust classifiers like Random Forest, k-NN-based logic yielded a lower RMSE and higher classification accuracy (82.2% vs. 86.6%) compared to MICE. In our study, the success of k-NN over MICE at missingness rates of 30% and above clinically validates the assertion by Ali et al.: intelligent estimations derived from similar records are far more effective in preserving clinical data integrity and model accuracy than the complex chained equations of MICE (12).

Strengths and Limitations

The primary strength of our study lies in its evaluation of imputation algorithm performance not merely through mathematical error metrics (RMSE), but rather through model validity (AUC-ROC) that reflects the clinical context across a broad missingness spectrum (Stress Test).

Nevertheless, our study is subject to certain limitations. Primarily, the simulation relies exclusively on the MAR mechanism. The behavior of the algorithms may diverge under MNAR (Missing Not At Random) mechanisms, where the missingness is directly contingent upon the test result itself (e.g., patients with exceedingly high blood glucose levels avoiding testing due to anxiety).

Secondly, the analyses were executed based on a specific biochemical relationship (the Age-BMI-HbA1c triad). The theoretical advantages of the MICE algorithm might become more pronounced when applied to high-dimensional genotypic or text-based clinical data.

In alignment with previous literature, it is recommended that future research evaluate these algorithms using multicenter Real-World Data and in hybrid scenarios where multiple missingness mechanisms coexist.

5. Conclusion

In clinical research, missing data management is not merely a data preprocessing step; rather, it is a critical methodological decision that directly dictates the clinical validity and

patient safety of the diagnostic or prognostic models to be developed. This study has quantitatively demonstrated that within clinical datasets under the MAR mechanism, the conventional Mean Imputation method constricts variance and degrades diagnostic power (AUC) to statistically hazardous levels, and therefore should be unequivocally abandoned.

When comparing machine learning-based imputation algorithms, the k-NN algorithm—which preserves local phenotypic similarities among patients—outperformed the complex and iterative MICE (Random Forest) model, emerging as the method most faithful to clinical biomarker correlations.

In light of these findings, our fundamental algorithmic recommendation for clinical researchers and biostatisticians is as follows: If the missingness rate of a target parameter in a clinical dataset is below 40%, neighborhood-based multivariate methods such as k-NN can be safely employed to maintain diagnostic integrity. However, once this rate exceeds the 40% threshold, even the most advanced iterative imputation algorithms tend to "learn from noise," generating statistical hallucinations. Given this level of high sparsity, researchers should abandon algorithmic data recovery efforts and instead opt to exclude the respective clinical variable from the model or prospectively collect new data.

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ISBN NR: 978-625-5694-92-8

SURVIVAL ANALYSIS IN THE SHADOW OF OVERFITTING: DISCRIMINATION PERFORMANCES OF COX REGRESSION AND RANDOM SURVIVAL FORESTS

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ABSTRACT

Objective: The superiority of machine learning algorithms over tabular clinical data in cancer survival analysis remains a subject of ongoing debate. This study aims to compare the traditional Cox Proportional Hazards model with the machine learning-based Random Survival Forests (RSF) method in predicting the survival times of breast cancer patients using clinical characteristics, while also investigating the overfitting tendencies of tree-based algorithms.

Material and Methods: An open-access breast cancer dataset, derived from the SEER database, was retrospectively analyzed. Demographic data, tumor stage, and receptor status (n=4024) were examined. The dataset was partitioned into 70% training and 30% testing sets. Cox Regression and RSF models were developed, and their discrimination power was evaluated on the test data using the Concordance Index (C-index). Hyperparameter optimization (pruning) was applied to the RSF model to mitigate overfitting.

Results: The RSF model developed with default parameters exhibited overfitting, with a C-index of 0.817 on the training data compared to 0.703 on the test data. Following hyperparameter optimization, the RSF model's test performance improved to 0.707, while its training performance decreased to 0.780, thereby enhancing model generalizability. In contrast, the traditional Cox Regression model demonstrated more stable predictive power, achieving the highest performance on the test data (C-index: 0.715). In both models, tumor size, the number of positive regional lymph nodes, and age were identified as the most critical prognostic factors.

Conclusion: In low-dimensional structured clinical data, machine learning algorithms do not provide a significant advantage over traditional statistical methods. Due to its higher test performance and the clinical interpretability it offers (Hazard Ratios), the Cox model remains the gold standard for such datasets.

Keywords: survival analysis,cox proportional hazards model, random survival forests,overfitting

ISBN NR: 978-625-5694-92-8

1. INTRODUCTION

Breast cancer remains the most prevalent malignancy among women worldwide and stands as one of the leading causes of cancer-related mortality. Determining the prognosis of the disease and establishing effective treatment planning depend on the accurate analysis of patient-specific demographic and clinicopathological variables (1). Survival analysis is the fundamental biostatistical method used in medical research to examine the time elapsed until the occurrence of an event of interest, such as death or recurrence (2).

For decades, the Cox Proportional Hazards model has been the most widely utilized method in clinical practice for determining survival times and identifying risk factors. The Cox model offers clinicians a high level of transparency through its ability to explain the independent effects of variables via Hazard Ratios. However, the model may prove inadequate in capturing complex and non-linear relationships among variables (3).

In recent years, Artificial Intelligence and Machine Learning (ML) algorithms have gained significant traction in medical research. In particular, Random Survival Forests (RSF) have emerged as a robust alternative in survival analysis due to their capacity to automatically model non-linear interactions between variables. Despite this, whether the proven success of ML in high-dimensional data—such as imaging and signals—surpasses the Cox model in structured (tabular) data containing classical clinical variables remains a subject of debate in current literature (4).

This study aims to compare the performances of traditional Cox regression and RSF algorithms using a structured oncology dataset. Furthermore, it intends to identify the "overfitting" problem frequently encountered in ML models and to demonstrate the impact of hyperparameter optimization on the generalizability of clinical models.

2. MATERIALS AND METHODS

2.1. Dataset

This study utilized an open-access breast cancer survival dataset based on the SEER (Surveillance, Epidemiology, and End Results) program. The dataset comprises records of 4024 patients evaluated according to the 6th edition staging system. It includes variables such as age, race, marital status, tumor size, T and N stages, estrogen (ER) and progesterone (PR) receptor status, the number of examined and positive regional lymph nodes, along with survival duration (months) and mortality status. Since the data were obtained from an anonymized open-access source, ethical committee approval was not required.

2.2. Data Preprocessing

Categorical variables (e.g., T-Stage, Grade, Receptor Status) were transformed using the One-Hot Encoding method prior to model inclusion. The dependent variable (target) was formatted into a structured array containing time and event status (survival months, event), as necessitated

ISBN NR: 978-625-5694-92-8

by machine learning-based survival analysis. To objectively evaluate the model's performance on unseen data, the dataset was randomly partitioned into a 70% training set (n=2816) and a 30% test set (n=1208).

2.3. Implemented Models

- **Cox Proportional Hazards Model:** A multivariate Cox regression model was constructed using low-level Ridge regularization (α=0.01) to mitigate potential multicollinearity issues.
- **Random Survival Forests (RSF):** As an ensemble tree-based learning method, RSF was employed to predict survival times via hazard functions. Initially, the model was trained using default parameters; subsequently, hyperparameter optimization (tuning) was performed to prevent overfitting. Within the scope of optimization, constraints were applied to the maximum tree depth (max_depth=6), the minimum number of samples for a split (min_samples_split=40), and the minimum number of patients in a leaf node (min_samples_leaf=20).

2.4. Model Evaluation

The discrimination power of the models was calculated separately for the training and test sets using Harrell's Concordance Index (C-index) metrics. The Permutation Feature Importance algorithm was utilized to determine the significance levels of factors within the RSF model's predictions. All analyses were conducted in the Python (v3.11) programming language using the *scikit-survival* and *scikit-learn* libraries.

3. RESULTS

The model performance metrics obtained as a result of the study are summarized in Table 1.

Table 1. Performance Comparison of Traditional Cox Regression and Machine Learning (RSF) Models in Training and Test Sets

Model Type	Implemented Algorithm	Training Score (C-index)	Test Score (C-index)	Training-Test Gap (Overfitting)
Traditional Statistics	Cox Proportional Hazards Model (CoxPH)	0.752	0.715	0.037
Machine Learning	RSF (Default Parameters) *	0.818	0.703	0.115

ISBN NR: 978-625-5694-92-8

Machine Learning	RSF (Optimized / Tuned) **	0.781	0.708	0.073

Traditional Model Performance: The Cox Proportional Hazards model achieved a C-index of 0.752 on the training data and 0.715 on the unseen test data. The minimal discrepancy between the training and test scores indicates that the model avoided data memorization and possesses high generalizability.

RSF and Overfitting: The initial RSF model, developed with default parameters, attained a high predictive success on the training set (C-index: 0.817); however, its performance dropped significantly to 0.703 on the test set. This substantial decline is a clear indication of overfitting, where the model memorizes noise within the training data rather than learning generalizable patterns.

Optimized RSF: Following hyperparameter optimization, the overfitting gap in the tuned RSF model was narrowed. While the training score adjusted to 0.780, the test score—which represents the model's true predictive power—increased to 0.707.

Univariate Survival Analysis (Kaplan-Meier): The univariate survival probabilities of patients based on specific clinical characteristics were evaluated using Kaplan-Meier analysis. Upon examining the survival curve plotted according to Estrogen Receptor (ER) status—a significant prognostic factor in the study cohort—it was observed that patients with ER-positive status exhibited significantly higher overall survival probabilities and median survival times compared to ER-negative patients (Figure 1). This finding confirms the clinical validity of the dataset and its alignment with established oncological expectations.

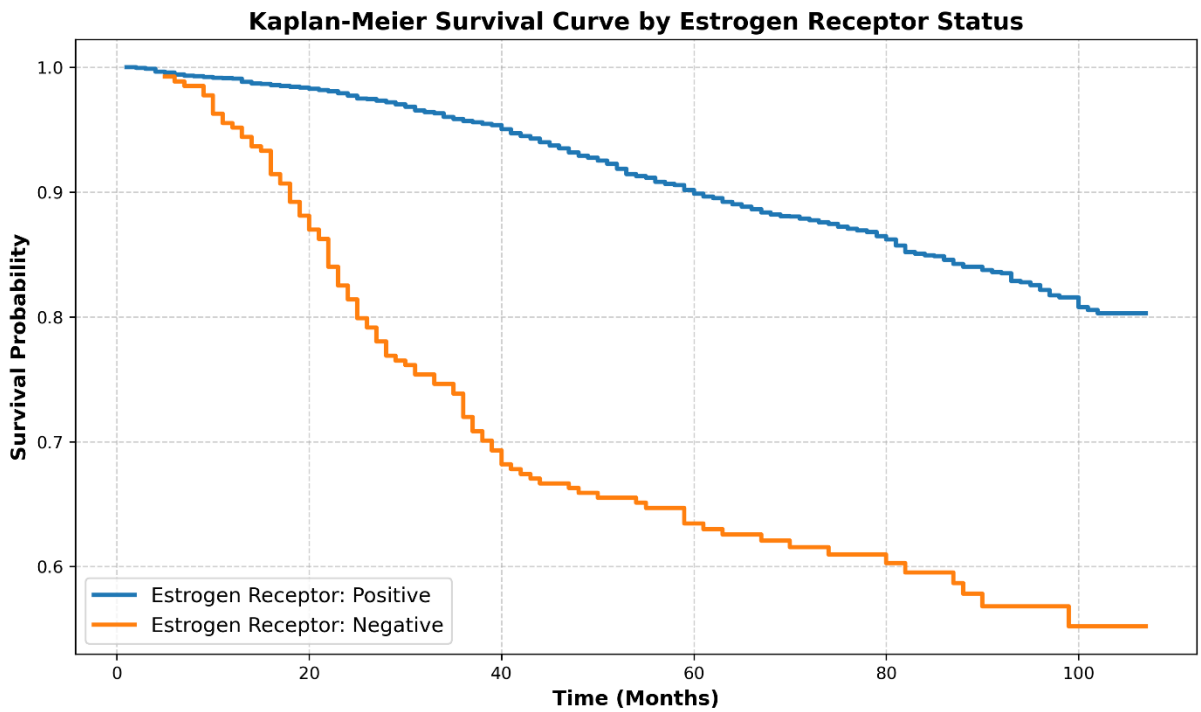

Figure 1. Kaplan-Meier survival curves of patients according to Estrogen Receptor (ER) status.

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Clinical Explainability and Feature Importance in Machine Learning

To elucidate the prediction mechanism of the machine learning model (explainability) and identify the most critical clinical factors, a Permutation Feature Importance analysis was conducted using the optimized RSF model. The analysis revealed that the top three prognostic factors contributing most significantly to the model's discriminative power (C-index) were: the number of positive regional lymph nodes, patient age, and the number of regional lymph nodes examined, respectively (Figure 2). These major variables, which exhibit full alignment with clinical oncology practice, were followed by tumor size (mm) and tumor differentiation grade.

The fact that the RSF model prioritizes the number of positive nodes—representing direct metastatic burden—and patient age as continuous variables at the top of its decision-making hierarchy, rather than standard categorical staging parameters (T and N Stage), confirms that the algorithm exhibits a transparent predictive profile highly consistent with biological expectations.

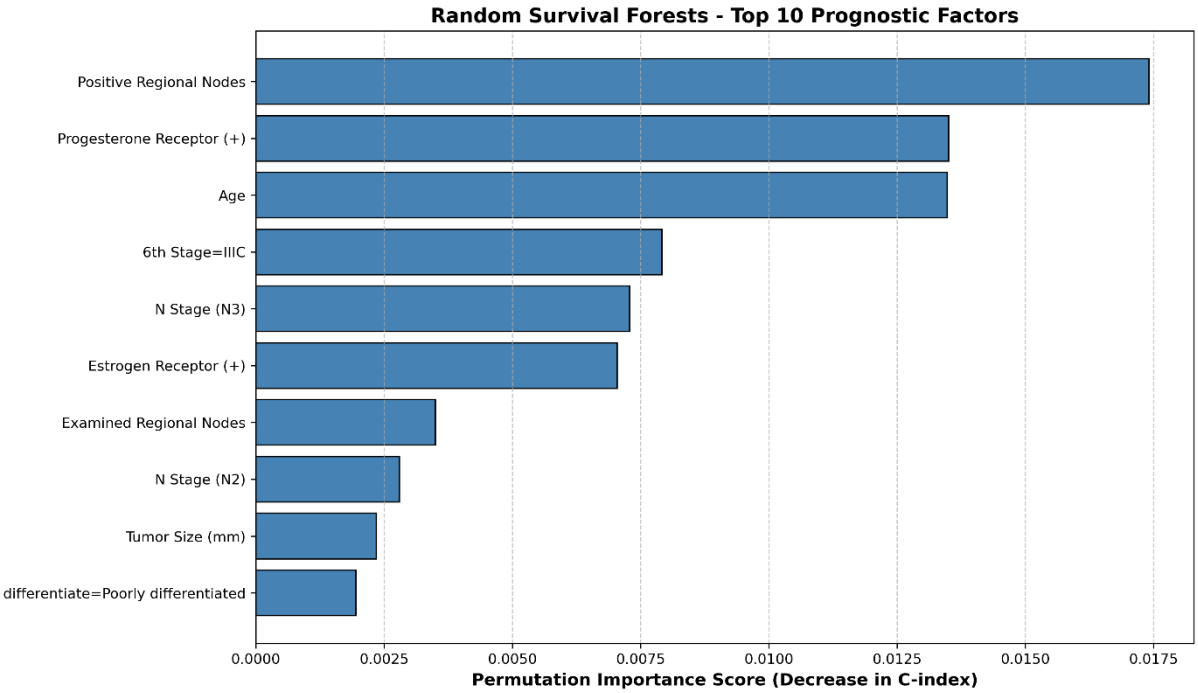

Figure 2. Permutation importance scores of the top 10 prognostic factors affecting overall survival according to the Random Survival Forests (RSF) model.

4. DISCUSSION

The intense interest in the field of medical artificial intelligence often brings with it the misconception that more complex models will inherently yield superior results. This study demonstrates that in survival analyses based on structured clinical data, machine learning algorithms struggle to surpass—and in some cases, fall behind—well-constructed traditional biostatistical models.

The most noteworthy finding of our study is that despite rigorous optimization procedures, the maximum performance achieved by the RSF model on the test data (C-index: 0.707) remained inferior to that of the multivariate traditional Cox regression (C-index: 0.715). Comprehensive

ISBN NR: 978-625-5694-92-8

literature reviews, such as those conducted by Christodoulou et al. (2019), further emphasize that machine learning fails to provide a clinically significant advantage over logistic regression or Cox models when dealing with structured, low-dimensional clinical data (5). The fact that the effects of clinicopathological variables (age, tumor stage, etc.) in our dataset exhibit highly additive and linear characteristics regarding survival explains why the Cox model operates more robustly within this specific architecture (6).

Furthermore, our study highlights the substantial risk of overfitting associated with tree-based algorithms in clinical data. In the absence of hyperparameter constraints, a misleadingly high performance (C-index > 0.81) was obtained; however, this resulted in a sharp decline when applied to the test data. Reporting success metrics based solely on training sets—a frequent methodological flaw in medical machine learning literature—undermines the reliability of clinical decision support systems.

Decision tree-based algorithms are inherently prone to learning noise within the training data. Recent studies in the literature (e.g., Zlobin and Bazylevych, 2025) emphasize that constraining tree complexity (i.e., the number of nodes and leaves) through a data-driven approach is critical for achieving the optimal balance between overfitting and underfitting. The hyperparameter optimization applied to the RSF model in our study confirms this contemporary requirement and enhances the generalizability of the model on unseen test data (7).

Current studies in the literature indicate that the performance hierarchy between Cox and RSF models may vary depending on the clinical complexity of the analyzed patient subgroup. For instance, a recent multicenter study by Jin et al. reported that in a biologically more complex subgroup, such as resistant breast cancer non-responsive to neoadjuvant chemotherapy (NAC), the RSF model's predictive success (C-index: 0.803) surpassed that of Cox regression (C-index: 0.736). In NAC-resistant profiles, the predominance of treatment-covariate interactions and non-linear biological mechanisms allows tree-based algorithms to provide a distinct advantage in such specific cohorts (8).

However, as observed in our study, within general and broad-based oncological SEER cohorts—which are not filtered by specific treatment resistance and rely on standard anatomical and pathological staging—the impact of variables on survival remains highly linear. This confirms that for general population screenings and standard prognostic modeling, the traditional Cox model remains a robust, explainable, and sufficient reference point. Our findings suggest that AI models should not be viewed as "absolutely superior in every scenario," but rather should be utilized "selectively" based on the biological and clinical complexity of the dataset.

The roles of traditional statistical models versus machine learning (ML) algorithms in survival analysis are currently a subject of intense debate. Our finding that ML algorithms do not always yield the best performance in structured (tabular) clinical data is in full alignment with recent methodological studies. A study by Graf et al. emphasized that focusing solely on discriminative capacity (C-index) when comparing Cox regression and RSF models can be misleading, as the strengths and weaknesses of these models shift according to the nature of the

data. According to Graf et al., while the Cox model loses ground when the proportional hazards assumption is violated, the RSF model excels in scenarios characterized by complex interactions among variables. However, the predominantly linear and additive effects of the standard oncological variables used in our study (tumor size, lymph node involvement, etc.) explain why traditional Cox regression (C-index: 0.715) outperformed the optimized RSF model (C-index: 0.708) on the test data (9).

The fact that traditional Cox regression marginally outperformed the machine learning model (0.715 vs. 0.708) shows a strong parallel with foundational studies in oncological survival analysis. For example, a comprehensive study on head and neck cancers by Datema et al. (2011) found that in a structured dataset utilizing eight core clinical variables, the Cox model (C-index: ~0.717) performed slightly better than the RSF model (C-index: ~0.712)(10).

The common intersection of these studies, conducted across different cancer types and decades, is that the variance provided by machine learning in low-dimensional clinical (tabular) data cannot surpass the stability of traditional statistics. Furthermore, as emphasized by Datema et al., the most significant limitation of ML algorithms is their "black box" nature. In contemporary clinical practice, oncological treatment decisions are based not merely on predictive scores, but on the causality behind those scores. In this context, the Hazard Ratios provided by the Cox model offer physicians a transparent and directly interpretable risk profile, maintaining a major clinical advantage over the complex architecture of RSF.

Finally, the concept of explainability is of vital importance for clinical integration. Although RSF provides Variable Importance rankings, the Hazard Ratio values offered by the Cox model provide clinicians with far more direct and actionable information.

5. CONCLUSION

In structured oncological data consisting of traditional clinicopathological variables, complex machine learning methods (RSF) do not provide superior predictive accuracy compared to the classical Cox Proportional Hazards model. The inherent high risk of overfitting and the lack of transparency in the model's decision-making process for clinicians (the black-box problem) remain significant disadvantages for ML algorithms in these specific data types. Traditional Cox regression, with its high predictive performance and the epidemiological interpretability it offers, should maintain its position as the primary choice and the gold standard in routine clinical survival analysis.

Future research is recommended to focus on hybrid models that integrate machine learning with traditional statistics, particularly in high-dimensional datasets such as genomic/molecular (omics) data.

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ISBN NR: 978-625-5694-92-8

Q-FORMER BRIDGED VIT–GPT-2: A UNIFIED TRANSFORMER FRAMEWORK FOR VIDEO CAPTIONING VIA VISION-LANGUAGE ALIGNMENT

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ABSTRACT

Video captioning aims to generate natural language descriptions that capture both the visual content and temporal dynamics of videos. Despite significant progress with CNN–RNN pipelines and transformer-based models, existing methods still struggle to align high-dimensional visual representations with the compact structure of language, leading to captions that may be semantically incomplete or temporally inconsistent. To address this limitation, a transformer-based video captioning framework is proposed in which a Q-Former bridge is introduced between a Vision Transformer (ViT) encoder and a GPT-2 decoder. Using a small set of learnable queries, the Q-Former extracts and restructures spatiotemporal information from ViT features into a language-compatible representation, improving the interaction between visual context and linguistic generation. Experimental evaluations on the MSVD and MSR-VTT datasets demonstrate that the proposed framework produces semantically meaningful and temporally coherent captions, outperforming strong transformer-based models. Beyond video captioning, the modular design of the framework provides a flexible foundation for broader vision–language applications.

Keywords : Feature Extraction, Video Captioning, Q-Former Bridge, ViT, GPT-2

1. INTRODUCTION

The convergence of computer vision and natural language processing has led to the emergence of video captioning, a task that aims to generate descriptive natural language sentences that accurately represent both spatial and temporal information in a video sequence [1]–[3]. Unlike image captioning, which focuses solely on static visual content, video captioning requires understanding motion continuity, temporal dependencies, and event evolution across consecutive frames. Hence, video captioning demands a higher level of multimodal reasoning to model not only objects and scenes, but also their temporal interactions and causal relationships. This capability has made video captioning increasingly important in domains

such as assistive technology, video retrieval, visual question answering, and intelligent surveillance systems [4]–[8].

The early frameworks relied on convolutional and recurrent neural networks to extract spatiotemporal features and generate captions. Although these frameworks achieved promising results, they were often limited by vanishing gradients and inadequate modeling of long-range dependencies, leading to temporally inconsistent or repetitive descriptions. The introduction of transformer-based models has substantially advanced this field by enabling global context modeling across space and time [9], [10]. In particular, the self-attention mechanism in transformer-based models enables them to dynamically focus on informative visual regions and temporal segments, capturing complex temporal relationships and semantic dependencies [11]–[13]. Among transformer-based models, Vision Transformers (ViT) have demonstrated a strong capability to extract hierarchical spatiotemporal representations from video frames, while large-scale language models such as GPT-2 have proven effective in generating fluent and context-aware textual sequences [14], [15].

Despite these advances, achieving precise alignment between visual–temporal representations and linguistic features remains a major research problem. This issue arises from the modality gap between visual and linguistic representations: video encoders generate dense and high-dimensional spatiotemporal embeddings, whereas language decoders operate in a compact and semantically structured linguistic space. This mismatch makes direct alignment challenging and can result in incomplete or semantically ambiguous captions [16]–[18]. To address this problem, this study proposes a transformer-based video captioning framework that introduces a Q-Former Bridge between a ViT encoder and a GPT-2 decoder. The Q-Former acts as a query-driven alignment mechanism that refines the temporal embeddings obtained from the ViT encoder and projects them into a language-compatible space through cross-attention layers [19], [20]. By integrating query-based temporal reasoning, the framework improves temporal–linguistic coherence and increases the accuracy of generated video descriptions.

The proposed Q-Former Bridged ViT–GPT-2 framework processes videos by uniformly sampling 16 frames from each clip, capturing motion and contextual dependencies over time. The ViT encoder extracts spatiotemporal features from the frame sequence, while the Q-Former aligns these representations with the GPT-2 language space. The GPT-2 decoder then generates coherent and temporally grounded captions in an autoregressive manner. Experimental evaluations conducted in MSVD and MSR-VTT benchmark datasets demonstrate that the proposed method achieves improved performance over baseline transformer models in metrics such as CIDEr, SPICE, METEOR, ROUGE-L and BLEU-n (n = 1–4) [21]–[24].

The rest of this paper is organized as follows: the next section introduces the proposed Q-Former Bridged ViT–GPT-2 framework for video captioning. Section 3 presents the datasets, performance metrics, and quantitative and qualitative evaluation results. Closing remarks and future research directions are given in Section 4.

ISBN NR: 978-625-5694-92-8

2. FRAMEWORK

The proposed Q-Former Bridged ViT–GPT-2 framework adopts an encoder–bridge–decoder structure specifically designed for video captioning. As illustrated in Figure 1, the framework consists of three key components: a ViT encoder for spatiotemporal feature extraction, a Q-Former bridge for temporal–linguistic alignment, and a GPT-2 decoder for natural language

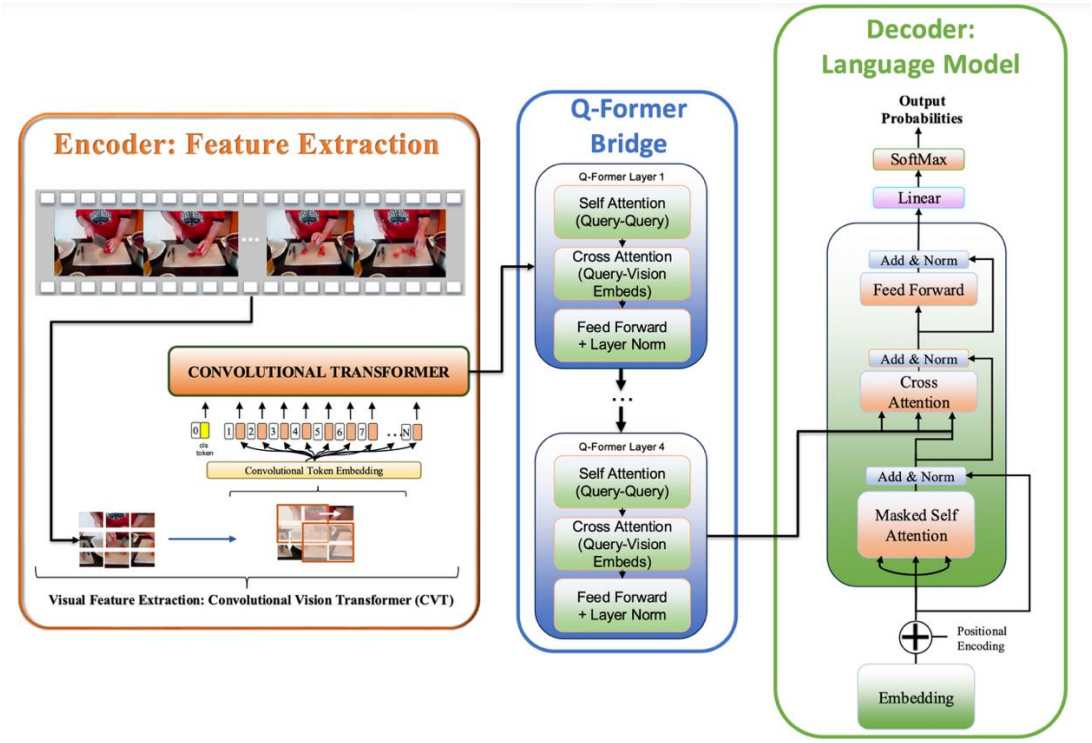

Figure 1. The Proposed Video Captioning Framework.

generation. This structure enables the integration of visual perception, temporal reasoning, and linguistic fluency within a unified transformer-based framework, producing temporally coherent and semantically rich video descriptions.

2.1. ViT Video Encoder

The encoder module uses a pretrained ViT adapted for video input to capture hierarchical spatiotemporal features. Each video sequence is uniformly sampled into 16 representative frames, resized, and converted into patch embeddings with positional and temporal encodings. Through multiple layers of self-attention, the encoder models both spatial structures and temporal dependencies among consecutive frames, capturing global motion patterns and object interactions.

This process results in a visual feature tensor that summarizes both the spatial and temporal dynamics of the video. These encoded features are then passed to the Q-Former bridge for cross-modal alignment. As shown in Figure 1, this stage forms the backbone of the encoder by transforming raw frame sequences into high-dimensional semantic representations that preserve visual context over time.

ISBN NR: 978-625-5694-92-8

2.2. Q-Former Bridge for Temporal–Linguistic Alignment

The Q-Former serves as a significant intermediary that aligns the visual–temporal representations obtained from the ViT encoder with the linguistic space of the GPT-2 decoder. It employs a set of learnable query tokens that attend to specific temporal and semantic regions across the encoded frames. Each layer alternates between self-attention (query–query

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Algorithm 1: Q-Former Bridged ViT–GPT2 Video Captioning (16 Frames)

1: **Initialize:** training set Dtrain, pretrained ViT_θ, QF_φ with Q learnable queries, GPT2_ψ, learning rate η

2: **for all** video ∈ Dtrain **do**
3: Sample 16 uniformly spaced frames: F = {f_1, …, f_{16}}
4: Extract frame embeddings: Z = ViT_θ(F)
5: Fuse temporal semantics: Q = QF_φ (Z)
6: Generate caption logits: ŷ = $GPT2_\psi$ (Q)
7: Compute loss: $\mathscr{L}$ = CE(ŷ, y)
8: Update parameters φ, ψ using AdamW optimizer with step size η
9: **end for**

10: **Inference:** GenerateCaption(video)
11: Sample 16 frames F; obtain Z = ViT_θ(F)
12: Q = QF_φ(Z)
13: return GreedyDecode($GPT2_\psi$, Q)

interaction) and cross-attention (query–vision embedding interaction), allowing the framework to selectively refine and condense visual information into compact, language-compatible embeddings.

By functioning as a temporal abstraction mechanism, the Q-Former effectively bridges the gap between the high-dimensional visual embeddings of the encoder and the linguistic embedding domain of the decoder. This alignment enables the framework to focus on the most informative regions and motion patterns in a video clip, as demonstrated in the middle section of Figure 1.

2.3. GPT-2 Decoder for Caption Generation

The GPT-2 decoder generates coherent textual descriptions by autoregressively predicting the next word conditioned on both prior tokens and the aligned representations from the Q-Former. The decoder integrates the output of the bridge through cross-attention layers, ensuring that each generated token remains grounded in the visual–temporal context.

ISBN NR: 978-625-5694-92-8

As depicted in the rightmost block of Figure 1, the decoder includes masked self-attention for sequential token prediction and feed-forward layers for contextual refinement. This design allows the framework to generate fluent and grammatically correct captions that capture both temporal order and semantic detail, effectively describing actions, objects, and scene transitions.

Table 1. Datasets

Datasets	Train	Validation	Test	Total Caption
MSR-VTT	6513	2990	497	200000
MSVD	1380	295	295	78800

2.4. Training and Inference Procedure

The complete training and inference pipeline is summarized in Algorithm 1. During training, 16 uniformly spaced frames are sampled from each video. The framework then performs visual feature extraction through the ViT encoder, temporal–linguistic alignment via the Q-Former, and caption generation using the GPT-2 decoder. The parameters of all three modules are optimized jointly using cross-entropy loss with the AdamW optimizer, ensuring stable convergence and balanced learning across modalities. During inference, the same processing steps are applied to the sampled frames, with captions generated by GPT-2 using a standard autoregressive decoding strategy.

3. EXPERIMENTAL EVALUATIONS

This section presents the experimental setup and results used to evaluate the performance of the proposed Q-Former Bridged ViT–GPT-2 framework for automated video captioning. The evaluation focuses on both quantitative metrics and qualitative caption generation examples on two benchmark datasets: MSVD and MSR-VTT.

3.1. Dataset and Performance Metrics

Two complementary video captioning datasets MSR-VTT [25] and MSVD [26] are employed to assess the performance of the proposed framework, both offering multiple human-annotated captions per video.

The MSR-VTT dataset includes 6513 training, 2990 validation, and 497 test video clips with an average of twenty captions per video. The MSVD dataset consists of 1970 short video clips collected from YouTube with an average of forty English descriptions per clip. These datasets were selected for their diverse domains and comprehensive human annotations. Detailed specifications for these datasets are presented in Table 1.

The evaluation of the framework was based on several common performance metrics, including BLEU-n [27], ROUGE-L [28], SPICE [29], METEOR [30], and CIDEr [31]. BLEU-n and METEOR are widely used in machine translation evaluation. BLEU-n measures the similarity between the generated caption and reference captions using n-grams, while METEOR

ISBN NR: 978-625-5694-92-8

calculates sentence-level similarity scores by aligning translation hypotheses with reference translations. ROUGE-L compares the generated caption with the reference captions based on the longest common subsequence. SPICE is a semantic evaluation metric that assesses the representation of objects, attributes, and relationships in generated captions. CIDEr evaluates the consensus between the generated caption and reference captions, considering both grammatical and semantic aspects. In this study, the CIDEr metric is prioritized as it comprehensively evaluates content relevance and overall linguistic quality.

Table 2. Performance Metric Results – Evaluation Results on MSVD and MSR-VTT Captions Dataset

	CIDEr	**BLEU-4**	**BLEU-3**	**BLEU-2**	**BLEU-1**	**ROUGE-L**	**METEOR**
Pan et al. [32]	0.740	**0.528**	**0.628**	**0.720**	**0.828**	-	0.335
Gao et al. [33]	0.748	0.508	0.611	0.708	0.818	-	0.333
Yao et al. [34]	0.517	0.419	0.526	0.647	0.800	-	0.335
Yu et al. [35]	0.658	0.499	0.604	0.704	0.815	-	0.326
Proposed (MSVD)	**0.878**	0.476	0.582	0.688	0.811	**0.714**	**0.343**
Proposed (MSR-VTT)	0.436	0.363	0.485	0.624	0.771	0.587	0.271

3.2. Results and Discussion

Experiments were conducted on the MSVD and MSR-VTT datasets, which provide diverse video clips paired with multiple human-annotated captions. The framework was compared with state-of-the-art video captioning frameworks using identical evaluation settings.

As shown in Table 2, the proposed framework achieves consistent improvements across all major metrics. The query-based alignment mechanism of the Q-Former effectively bridges visual–linguistic representations, reduces redundancy, and captures meaningful temporal cues. Meanwhile, the pretrained GPT-2 decoder enhances grammatical fluency and coherence in caption generation. Overall, integrating transformer-based visual encoding, query-driven cross-modal alignment, and autoregressive language modeling yields semantically grounded and contextually coherent captions, highlighting the potential of the framework for scalable multimodal tasks.

Table 3 presents qualitative examples from the MSVD dataset, presenting generated captions compared with human annotations. The examples demonstrate that the proposed framework effectively captures essential actions and objects in a scene while maintaining linguistic accuracy. For instance, in a video depicting a woman preparing food, the generated caption “A woman is preparing food” accurately captures the primary action, aligning closely with human references. Similarly, for a video showing a man playing a guitar, the generated caption “A man is playing a guitar” correctly describes the subject and activity, demonstrating the capability of the framework to ground language generation in temporal visual evidence. These examples

ISBN NR: 978-625-5694-92-8

confirm that the framework generalizes well across different action categories while maintaining sentence-level fluency and coherence.

The last two examples in Table 3 are drawn from the MSR-VTT dataset, which is characterized by more complex scenes and diverse human–object interactions. In the first MSR-VTT example, the generated caption, “Some people are dancing,” captures the dominant action but remains overly generic compared to the reference annotations. Specifically, it fails to reflect the rich contextual details present in the scene, such as the beach setting, group dynamics, and concurrent activities (e.g., singing and social interaction). In the second example, although the

Table 3. Sample video from MSVD (first two columns) and MSR-VTT (last two columns) with ground-truth and generated captions.

Reference Captions: **(1)** A woman seasons a vegetable mixture. **(2)** The woman is seasoning the mixture. **(3)** Woman puts ingredients into a bowl. **(4)** A woman is preparing food. **(5)** Woman making some japanese food. **Generated caption:** A woman is preparing food.	**Reference Captions:** **(1)** A man is playing a guitar and singing. **(2)** A man is singing along as he strums the guitar. **(3)** A man plays a guitar. **(4)** The man played his guitar. **(5)** The man is singing and playing the guitar. **Generated caption:** A man is playing a guitar.	**Reference Captions:** **(1)** A group of people are singing at the beach. **(2)** A group of people sitting in beach chairs sing and dance. **(3)** Many men and women are dancing on the beach. **(4)** People sitting and dancing in unison. **(5)** A man is giving sun glass to a woman and some guys are singing a song together in a beach. **Generated caption:** Some people are dancing.	**Reference Captions:** **(1)** A teenage girl in black is so happy to have a new puppy. **(2)** There is a woman is playing with her puppy. **(3)** A young girl sits on a brown couch with her new puppy. **(4)** A girl talking selfie with her puppy and playing with it. **(5)** A girl in a black hoodie sweatshirt showing her puppy on the couch. **Generated caption:** A woman is talking about a very small animal.

generated caption correctly identifies the presence of a person and an animal, it lacks the fine-grained semantic understanding exhibited in the reference captions. The model does not explicitly capture the emotional interaction between the girl and her puppy, nor does it describe the setting and playful behavior emphasized by human annotations. These cases highlight the remaining challenges in modeling detailed interactions and contextual nuances in complex, real-world video scenarios.

Both quantitative and qualitative evaluations validate the effectiveness of the proposed Q-Former Bridged ViT–GPT-2 framework. The consistent improvements across metrics and generated samples confirm that integrating query-based alignment with transformer-based vision and language components results in superior temporal grounding and linguistic fluency. The framework not only achieves high caption accuracy but also demonstrates scalability across

different video domains, establishing a solid foundation for future multimodal research such as video–audio captioning, temporal event understanding, and visual question answering.

4. CONCLUSION

This study presented a transformer-based video captioning framework that integrates a Q-Former Bridge between a ViT encoder and a GPT-2 decoder within an encoder–bridge–decoder structure. The proposed framework effectively bridges the semantic and temporal gap between visual and linguistic feature spaces, enabling the generation of coherent, context-aware, and human-like video captions. By incorporating a query-based alignment mechanism, the Q-Former selectively aggregates and refines spatiotemporal representations through cross-attention, thereby enabling more precise mapping of visual information into the linguistic space and improving both semantic fidelity and temporal grounding. Experimental evaluations conducted on the MSVD and MSR-VTT benchmark datasets demonstrate that incorporating the Q-Former component substantially improves the quality of generated captions compared to existing transformer-based frameworks. The proposed framework achieves superior alignment between visual and linguistic modalities, producing captions that are descriptive and temporally consistent. The query-driven cross-attention mechanism refines video-level embeddings by focusing on meaningful motion and object cues, while the pretrained GPT-2 decoder contributes to linguistic fluency and syntactic coherence. These results confirm that the integration of ViT-based temporal encoding, Q-Former bridging, and autoregressive decoding yields state-of-the-art performance across multiple evaluation metrics. Beyond quantitative improvements, qualitative analyses reveal that the Q-Former Bridged ViT–GPT-2 framework maintains a robust balance between temporal accuracy, semantic richness, and grammatical fluency. The framework captures both fine-grained visual details and long-term temporal dependencies, demonstrating its capability for comprehensive multimodal reasoning. These findings underscore the potential of the proposed framework as a scalable and modular solution for vision–language integration in dynamic visual scenes.

Future research will focus on expanding the framework to support multimodal extensions such as video–audio captioning, cross-domain retrieval, and temporal event grounding. Furthermore, fine-tuning larger pretrained vision–language models and incorporating reinforcement learning or human feedback mechanisms may further improve factual precision, temporal coherence, and contextual specificity in generated video descriptions.

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ISBN NR: 978-625-5694-92-8

LEVERAGING Q-FORMER ALIGNMENT IN VIT–GPT-2: A STREAMLINED APPROACH FOR IMAGE CAPTIONING

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ABSTRACT

Image captioning aims to generate precise and objective descriptions that accurately represent the content of an image. However, existing models often fail to fully align visual and textual information, causing to captions that are semantically weak or insufficiently detailed. To address this limitation, this study introduces an enhanced image captioning approach that integrates a Q-Former Bridge between a Vision Transformer (ViT) encoder and a GPT-2 decoder. The Q-Former component functions as a query-based bridge between ViT and GPT-2. It refines ViT visual embeddings and aligns them with the GPT-2 linguistic space, allowing the model to generate more context-sensitive and semantically rich captions. The proposed Q-Former Bridged ViT–GPT-2 approach leverages the strengths of both transformer approaches: ViT for extracting fine-grained visual features and GPT-2 for generating fluent and coherent textual descriptions. Experimental evaluations conducted in the MSCOCO and VizWiz Captions datasets demonstrate substantial improvements in caption accuracy, visual grounding, and linguistic coherence compared to traditional ViT–GPT-2 baselines. These results highlight the effectiveness of incorporating Q-Former as a bridge mechanism for enhancing vision-language alignment in transformer-based image captioning systems.

Keywords : Feature Extraction, Image Captioning, Q-Former Bridge, ViT, GPT-2

1. INTRODUCTION

The task of image captioning aims to automatically generate coherent and meaningful descriptions of images by integrating natural language processing and computer vision techniques [1]–[5]. The demand for high-quality image captioning is increasing across various domains, driven by applications such as visual question answering, image retrieval, assistive technologies, and intelligent virtual assistants [6]–[11].

ISBN NR: 978-625-5694-92-8

In recent years, substantial progress has been made in the field of image captioning, primarily due to the rise of deep learning methods and, more recently, transformer-based models [12]. Originally developed for natural language processing, transformer-based models have proven to be highly effective for vision-language tasks by efficiently modeling long-range dependencies and contextual relationships [13], [14]. Their self-attention mechanism allows simultaneous processing of visual and textual information, enhancing the ability of the model to capture the contextual meaning of the image and its semantic correlations [4], [15]–[18]. Furthermore, transformer-based models demonstrate strong generalization abilities, achieving competitive results across multiple datasets with minimal fine-tuning [19]–[21]. Consequently, transformer-based models have emerged as the core of new image captioning systems, providing superior scalability and adaptability [12].

Despite these advancements, effectively aligning visual and textual feature spaces remains a major challenge. There remains a noticeable gap between image embeddings produced by vision encoders and linguistic representations learned by language decoders. This misalignment often causes to captions that are semantically inconsistent or lack sufficient detail [22]–[24]. To address this limitation, this study introduces a new image captioning approach that integrates a Q-Former Bridge between the ViT encoder and the GPT-2 decoder. The Q-Former acts as a query-based intermediate module designed to align and refine the visual features extracted by ViT, transforming them into language-compatible representations for GPT-2 decoding [25], [26]. This Q-Former Bridge enhances vision-language interaction, enabling the model to produce more context-aware, semantically coherent, and human-like captions.

The proposed Q-Former Bridged ViT–GPT-2 approach leverages the visual representation capability of ViT and the powerful generative language modeling of GPT-2 within an encoder-decoder structure. ViT captures global image dependencies through multi-head self-attention [27], [28], while GPT-2 produces fluent and coherent textual descriptions based on the refined embeddings passed through the Q-Former. Experimental results on the MSCOCO and VizWiz Captions datasets were evaluated using standard captioning metrics such as CIDEr, SPICE, METEOR, ROUGE-L, and BLEU-n (n=1–4) [29]–[35].

The remainder of this paper is structured as follows: Section 2 introduces the proposed Q-Former-bridged approach in detail. Section 3 discusses the dataset, evaluation metrics, and experimental results. Finally, Section 4 presents concluding remarks and potential future directions.

2. PROPOSED FRAMEWORK

In our proposed framework, we adopt an encoder-decoder structure for image captioning, integrating the strengths of the ViT for feature extraction, the Q-Former for visual–language alignment, and GPT-2 as a powerful language model for caption generation. This hybrid approaches effectively combines visual perception and natural language generation, enabling the model to produce coherent, context-aware, and semantically coherent image descriptions.

2.1. Vision Transformer Encoder

ISBN NR: 978-625-5694-92-8

The encoder component employs a pretrained ViT as the visual feature extractor. The input RGB image is first resized and normalized to the ViT input resolution, then partitioned into fixed-size patches that are linearly embedded and positionally encoded. The resulting patch

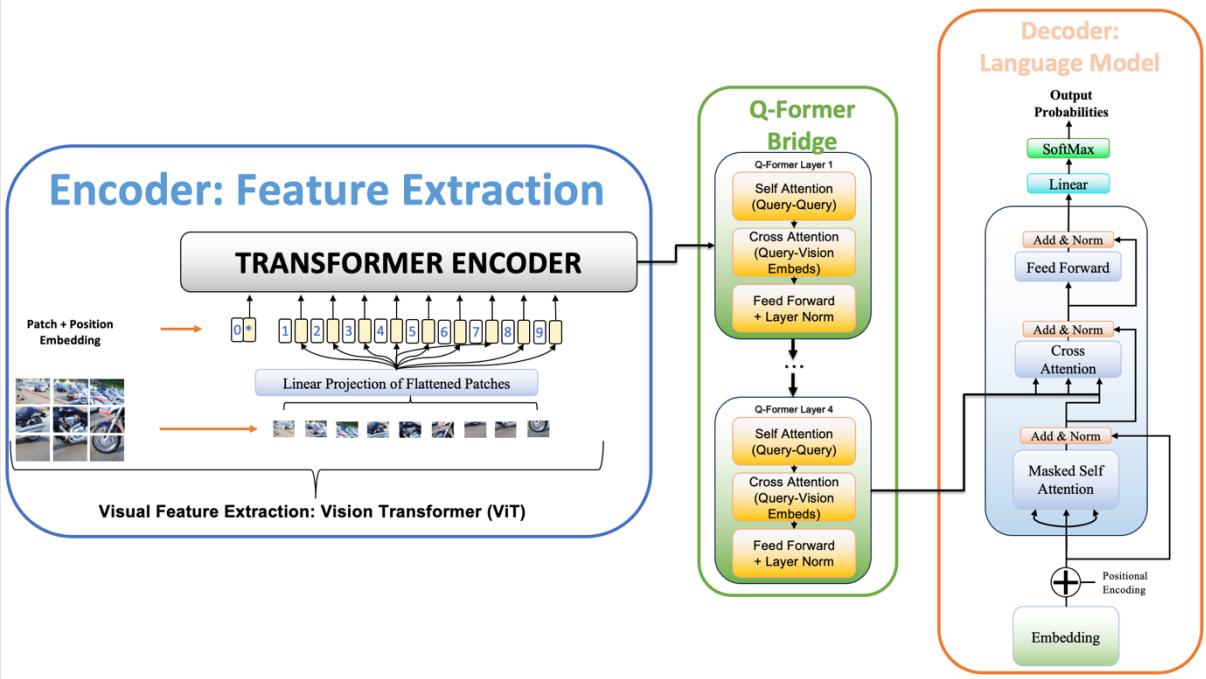

Figure 1. The Proposed Image Captioning Framework.

embeddings are processed through multiple transformer blocks to generate contextualized visual representations. The final hidden states from the last transformer layer are aggregated into the visual feature tensor I_feat, which captures both local details and global semantics of the image. This tensor is subsequently provided to the Q-Former module for cross-modal alignment. During training, the ViT parameters are fine-tuned jointly with the Q-Former to strengthen visual–linguistic alignment while maintaining the pretrained model robust visual representation capability [27], [28].

2.2. Q-Former Bridge for Vision–Language Alignment

The Q-Former [25] acts as a bridge module designed to align the visual embeddings generated by ViT with the textual embedding space expected by GPT-2. It consists of a set of learnable query tokens that interact with the frozen image features through cross-attention layers. Each query token focuses on distinct semantic regions of the image, generating a concise embedding that effectively represents the information required for captioning [26]. This query-based interaction enables efficient transfer of multimodal information while reducing redundancy in the feature space.

Formally, let I_{feat} denote the output of the ViT encoder and Q_{init} the learnable query tokens. The Q-Former output is obtained as:

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$$Q_{out} = Cross - Attention(Q_{init} + I_{feat}) \quad (1)$$

The resulting Q_{out} serves as the input context for the GPT-2 decoder, effectively bridging the gap between visual and linguistic domains.

2.3. GPT-2 Decoder for Caption Generation

The GPT-2 decoder, pretrained on extensive language data, generates fluent and contextually appropriate captions [40]. In the proposed approach, GPT-2 operates as a generative language model that predicts each word sequentially based on prior context. The Q-Former outputs are introduced as key value pairs through cross-attention layers, grounding the generated captions in visual semantics. Leveraging GPT-2 pretrained linguistic knowledge, the decoder produces syntactically accurate, semantically coherent, and human-like descriptions without additional retraining.

Overall, the proposed Q-Former Bridged ViT–GPT-2 approach unifies vision and language processing in a single encoder-decoder structure. ViT captures high-level visual patterns, Q-Former aligns them with linguistic semantics, and GPT-2 translates this aligned representation into natural language. This modular yet end-to-end trainable approach achieves superior results on benchmark datasets, generating detailed, human-like captions and offering a scalable foundation for future multimodal systems.

3. EXPERIMENTAL EVALUATIONS

In this section, we present the experimental setup and results used to evaluate the performance of the proposed Q-Former Bridged ViT–GPT-2 approach for automated image captioning. The evaluation focuses on assessing both quantitative metrics and qualitative caption generation examples on two benchmark datasets: MSCOCO and VizWiz Captions.

3.1. Dataset and Performance Metrics

Our evaluation relies on two complementary datasets MSCOCO [29] and VizWiz Captions [41] chosen to represent both structured imagery and real-world user-generated visual data.

MSCOCO contains approximately 123,287 training and validation images, each annotated with five ground-truth captions describing everyday scenes from diverse environments. VizWiz comprises 31,704 images captured by visually impaired individuals, each accompanied by five human-annotated captions. This combination of datasets enables a comprehensive evaluation: MSCOCO offers structured and high-quality imagery, while VizWiz presents real-world challenges such as blur, occlusion, and illumination variability [42]. This diversity allows the proposed approach to be evaluated in terms of its cross-domain generalization and its capacity to maintain descriptive accuracy under challenging visual conditions.

The performance of the proposed approach was quantitatively assessed using widely adopted image captioning metrics, including BLEU-n (n = 1, 2, 3, 4) [35], ROUGE-L [34], SPICE [32],

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METEOR [43], and CIDEr [31]. BLEU-n measures the n-gram overlap between the generated and reference captions, focusing on lexical similarity and precision. METEOR complements this by incorporating both precision and recall through unigram matching, yielding a balanced evaluation of adequacy and fluency. ROUGE-L, which evaluates the longest common subsequence between generated and reference texts, further contributes to assessing sentence-level fluency and structural alignment. Meanwhile, SPICE introduces a semantic perspective by analyzing scene graphs composed of objects, attributes, and relationships, thereby

Table 1. Performance Metric Results – Evaluation Results on VizWiz and MSCOCO Captions Dataset.

	CIDEr	**BLEU-4**	**BLEU-3**	**BLEU-2**	**BLEU-1**	**ROUGE-L**	**METEOR**
Karpathy et al. [36]	0.660	0.230	0.321	0.450	0.625	-	0.195
Chen et al. [37]	0.600	0.121	0.191	0.308	0.505	-	-
You et al. [38]	0.665	0.136	0.207	0.322	0.511	0.390	0.170
Proposed (MSCOCO)	**1.008**	**0.306**	**0.410**	**0.549**	**0.720**	**0.537**	**0.260**
Proposed (VizWiz)	0.406	0.179	0.270	0.404	0.589	0.411	0.174
Human [39]	0.854	0.217	0.321	0.469	0.663	0.484	0.252

emphasizing meaning rather than syntactic resemblance. CIDEr, on the other hand, evaluates the level of consensus between generated captions and multiple human references by applying TF–IDF weighting. It is widely regarded as one of the most comprehensive metrics, as it captures both grammatical correctness and semantic relevance. Collectively, these evaluation measures provide complementary insights into the syntactic accuracy, semantic richness, and contextual relevance of the generated descriptions.

The results obtained from these metrics for the MSCOCO and VizWiz Captions datasets are summarized in Table 1, while qualitative examples comparing reference and generated captions are provided in Table 2. Across both datasets, the Q-Former Bridged ViT–GPT-2 approach achieved higher semantic alignment (SPICE) and consensus (CIDEr) scores compared to the baseline ViT–GPT-2 approach, demonstrating the effectiveness of the Q-Former Bridge in aligning visual and linguistic representations. These findings confirm that the proposed approach not only generates grammatically coherent sentences but also captures finer visual semantics, resulting in more contextually accurate and human-like image descriptions.

3.2. Results and Discussion

Experiments were conducted on the validation splits of the MSCOCO and VizWiz Captions datasets to evaluate the effectiveness of the proposed Q-Former Bridged ViT–GPT-2 approach. ViT was employed as the visual encoder to extract fine-grained image features, the Q-Former

ISBN NR: 978-625-5694-92-8

served as a bridge aligning visual and linguistic representations, and GPT-2 operated as the language model for caption generation.

Table 1 summarizes the quantitative results obtained in the MSCOCO Captions dataset, compared to several new transformer-based approaches and human agreement baselines. The proposed approach achieves competitive or superior performance across multiple evaluation metrics, including CIDEr, BLEU, SPICE, ROUGE-L, and METEOR. In particular, the integration of the Q-Former component led to notable improvements in CIDEr and SPICE scores, which evaluate consensus and semantic alignment, respectively.

Table 2. Sample Images From VizWiz (First Two Columns) and MSCOCO (Last Two Columns) With Ground-Truth and Generated Captions.

Reference Captions: **(1)** A person holding a package with a computer and a door in the background. **(2)** A small granola bar like item in a person's hand. **(3)** A wrapper of a food item showing the barcode and ingredients. **(4)** Some sort of a snack in a package. **(5)** The back of some kind of food item. **Generated caption:** A person is holding a package of food.	**Reference Captions:** **(1)** A bag of cut frozen broccoli ready to heat in the microwave. **(2)** A bag of frozen cut broccoli on a counter top. **(3)** A bag of Roundy's brand steam n' serve cut broccoli. **(4)** A frozen bag of blue broccoli is on the floor, there are text instructions on the bag.. **(5)** A plastic bag of frozen broccoli pieces is laying on a tile table. **Generated caption:** A package of broccoli is on top of the table.	**Reference Captions:** **(1)** The child sits on the horse in the pasture. **(2)** A smiling woman is on a brown horse. **(3)** Woman sitting ontop of a large brown and white horse. **(4)** A person riding a brown horse with blonde hair in a green field. **(5)** A woman on a horse smiling in a green grass. **Generated caption:** A woman in a hat is standing on a horse.	**Reference Captions:** **(1)** The group of people is standing at a wine bar. **(2)** A couple of people are standing in front of some wine bottles. **(3)** A crowd of people stand near a man behind a bar with wine bottles on it. **(4)** A group of people standing around each other. **(5)** Many people line up to taste some wine. **Generated caption:** A group of people standing around a bar.

These results confirm that the approach produces captions that are both contextually relevant and semantically coherent [25], [26].

The evaluation on the VizWiz Captions dataset further demonstrates the adaptability of the proposed approach to more challenging real-world conditions, such as noisy, low-light, and cluttered scenes captured by visually impaired users. The query-based cross-attention mechanism of the Q-Former enhanced the ability of the approach to focus on notable visual regions, leading to improved recognition of objects and their contextual attributes compared to the baseline ViT–GPT-2 approach.

Table 2 illustrates qualitative results from both datasets, showing representative images with reference and generated captions. The first two images correspond to the VizWiz Captions

ISBN NR: 978-625-5694-92-8

dataset. In the first example, the generated caption "A person is holding a package of food" successfully captures the core concept of the reference descriptions but specific details, such as the barcode or surrounding environment. Similarly, for the second VizWiz image depicting a bag of frozen broccoli, the generated caption "A package of broccoli is on top of the table" maintains semantic consistency with the ground-truth captions but lacks mention of the brand or texture details. These findings suggest that while the Q-Former improves high-level understanding, it still struggles to capture subtle visual cues like color and texture.

The last two images in Table 2 are from the MSCOCO Captions dataset. In the third image, the model correctly identifies "a woman in a hat standing on a horse," closely matching the reference captions that describe a smiling woman riding a brown horse in a grassy field. Likewise, in the fourth image, the generated caption "A group of people standing around a bar" aligns well with references such as "people standing near a man behind a wine bar," accurately capturing group interaction and setting context. These examples demonstrate that the Q-Former-bridged approach effectively enhances spatial and contextual understanding in structured, high-quality scenes typical of the MSCOCO dataset.

Overall, both quantitative and qualitative results indicate that the proposed Q-Former Bridged ViT–GPT-2 approach achieves a strong balance between visual perception and linguistic generation. It effectively captures high-level semantic relationships and object interactions while maintaining grammatical fluency and contextual accuracy. The improvements observed on both the MSCOCO and VizWiz Captions datasets validate the contribution of the Q-Former Bridge in enhancing vision-language alignment within transformer-based image captioning models.

4. CONCLUSION

In this study, a transformer-based image captioning approach is presented that integrates a Q-Former Bridge between a ViT encoder and a GPT-2 decoder within an encoder–decoder structure. The proposed approach effectively bridges the semantic gap between visual and linguistic feature spaces, enabling the generation of accurate, context-aware, and human-like captions. Experimental evaluations conducted on the MSCOCO and VizWiz Captions datasets demonstrate that the inclusion of the Q-Former significantly enhances semantic alignment and descriptive richness compared to the baseline ViT–GPT-2 approach. The query-based attention mechanism of the Q-Former enables selective refinement of visual embeddings, enhancing the ability of the approach to focus on relevant image regions and reducing generic or repetitive wording in the generated captions. Meanwhile, the combination of attention-based visual encoding from ViT and advanced language modeling from GPT-2 results in superior captioning performance across several evaluation metrics. Beyond quantitative improvements, qualitative analyses confirm that the Q-Former Bridged ViT–GPT-2 approach maintains a strong balance between fluency, relevance, and visual grounding in text generation. These findings highlight the potential of the proposed modular transformer-based approach to advance multimodal understanding in image captioning.

Future research will focus on extending this approach to video captioning and multimodal dialogue tasks, where temporal and auditory features can be incorporated alongside visual cues. Additionally, fine-tuning larger vision-language models and integrating reinforcement learning-based feedback mechanisms may further enhance caption specificity and factual consistency.

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ISBN NR: 978-625-5694-92-8

UROSCAN: A LIGHTWEIGHT DEEP LEARNING FRAMEWORK FOR REAL-TIME COLORIMETRIC URINALYSIS ON SMARTPHONES

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ABSTRACT

Colorimetric urine test strips offer a rapid, non-invasive, and cost-effective method for screening key biomarkers; however, visual interpretation of color changes remains inherently subjective and prone to variability introduced by lighting conditions, observer bias, and inter-device variability. In this study, a deep learning-based colorimetric analysis framework is proposed for the objective classification of four urinalysis biomarkers—glucose, ketone, protein, and pH—from smartphone-captured images. A comprehensive dataset of 1,680 samples per analyte was constructed under diverse conditions encompassing seven lighting environments, two smartphone cameras, four temporal intervals, and six geometric viewing angles. Two lightweight convolutional neural network architectures, EfficientNetB0 and MobileNetV2, were evaluated via transfer learning with group-based 3-fold cross-validation across multiple random seeds. Classification results across all biomarkers demonstrate high performance, confirming the robustness of the proposed approach under varying experimental conditions. The optimized models were subsequently integrated into *UroScan*, an Android application employing TensorFlow Lite for real-time, offline inference. Collectively, these results establish smartphone-based deep learning as an objective and accessible solution for point-of-care urinalysis.

Keywords: Colorimetric Analysis, Deep Learning, Convolutional Neural Networks, Transfer Learning, Urine Test Strips, Mobile Application.

1. INTRODUCTION

Urinalysis is among the oldest and most widely performed diagnostic procedures in clinical medicine, offering valuable insight into renal function, metabolic status, and systemic disease. Colorimetric urine test strips have gained widespread adoption owing to their rapid turnaround, low cost, and non-invasive nature, enabling screening for a broad range of biomarkers at the point of care. Among these biomarkers, glucose serves as an indicator of diabetes mellitus, ketone bodies signal ketoacidosis and metabolic imbalance, protein levels reflect renal integrity, and pH

ISBN NR: 978-625-5694-92-8

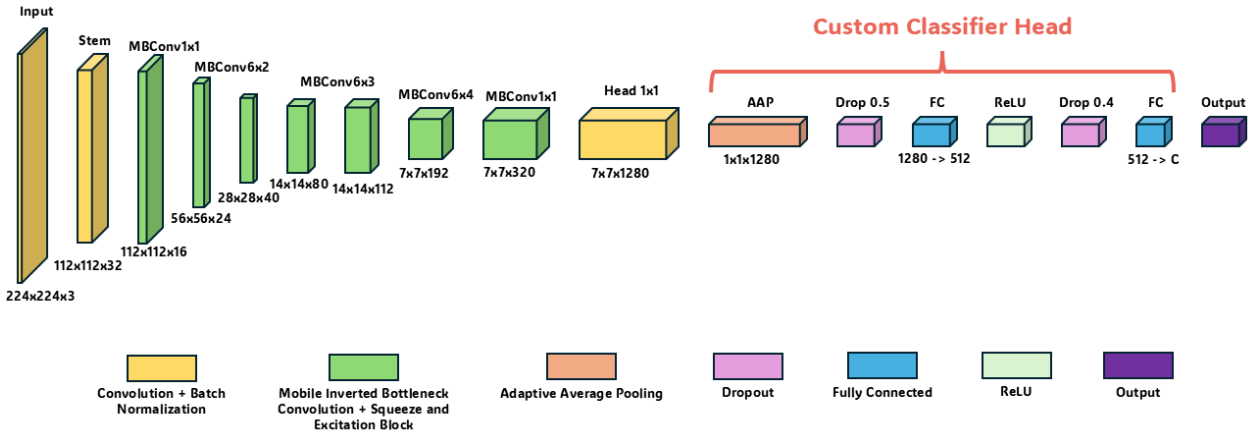

Figure 1: Architectural overview of EfficientNetB0

provides information regarding acid-base homeostasis and urinary tract conditions. Despite these advantages, the interpretation of colorimetric test strips in routine practice remains predominantly visual, requiring the operator to compare pad colors against a printed reference chart. This process is inherently subjective and susceptible to inter-observer variability, with diagnostic accuracy further compromised by ambient lighting conditions, reaction timing, and differences in color perception among individuals. Such limitations are particularly pronounced in point-of-care and home-monitoring settings, where standardized laboratory conditions are absent. The near-universal availability of smartphones equipped with high-resolution cameras presents a compelling opportunity to digitize and automate this process, potentially transforming colorimetric test strips into quantitative diagnostic instruments [1].

Prior efforts to automate colorimetric strip reading span three broad methodological categories. Traditional machine learning pipelines have employed handcrafted color features with classical classifiers such as least-squares support vector machines and random forests, demonstrating feasibility under controlled conditions but remaining constrained by manual feature engineering and limited generalization to unconstrained imaging environments [2-4]. Hardware-assisted approaches have mitigated imaging variability through custom enclosures and integrated illumination, yet their dependence on specialized equipment limits accessibility in resource-constrained settings [5]. More recently, deep learning methods—and convolutional neural networks (CNN) in particular—have enabled end-to-end feature extraction directly from raw pixel data, removing the need for hand-tuned color thresholds and yielding promising results for single-analyte colorimetric classification [6-8]. Transfer learning with lightweight architectures such as EfficientNet [9] and MobileNet [10] has further extended deep learning applicability to resource-constrained mobile platforms [11]. Nevertheless, to the best of our knowledge, no existing study has simultaneously addressed multi-analyte classification via deep CNN transfer learning, systematic robustness evaluation against real-world variability factors encompassing lighting, device, temporal, and geometric conditions, and real-time on-device inference—all without requiring specialized hardware.

The primary contributions of this work are as follows. First, a systematic dataset construction

ISBN NR: 978-625-5694-92-8

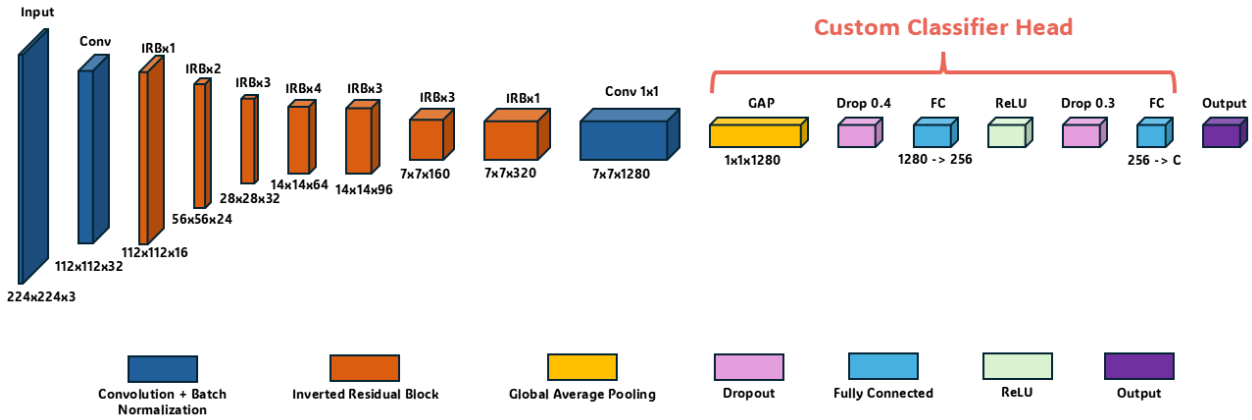

Figure 2: Architectural overview of MobileNetV2

methodology is presented, incorporating multiple lighting conditions, two smartphone cameras, four temporal intervals, and geometric augmentation to produce a diverse set of 1,680 samples per analyte that captures real-world variability. Second, a comprehensive transfer learning evaluation of two lightweight CNN architectures is conducted using group-based 3-fold cross-validation across multiple random seeds, ensuring reproducible and generalizable performance estimates. Third, the optimized models are integrated into the *UroScan* Android application, which performs real-time, offline colorimetric analysis using TensorFlow Lite without requiring internet connectivity or cloud computing resources.

The remainder of this paper is organized as follows. Section 2 describes the method, including dataset preparation, deep learning architectures, training methodology, and the smartphone application. Section 3 presents the experimental results and discussion. Finally, Section 4 provides concluding remarks and directions for future work.

2. METHOD

This section describes the methodology employed in this study, encompassing dataset preparation for deep learning, the proposed analytical pipeline, training methodology, and the development of the *UroScan* smartphone application for point-of-care deployment.

2.1. Dataset Preparation for Deep Learning

The robustness of deep learning models is critically dependent on the diversity and quality of training data. To address the challenges posed by real-world variability in smartphone-based colorimetric analysis, a comprehensive image dataset was systematically compiled. Controlled solutions were prepared for the four target analytes—pH, protein, ketone, and glucose—each at five distinct concentration levels. Protein concentrations were set at 0, 15, 30, 100, and 300 mg/dL; ketone at 0, 5, 15, 40, and 80 mg/dL; and glucose at 0, 100, 250, 500, and 1000 mg/dL. To prevent cross-analyte interference, pH solutions were prepared independently at levels of 5, 6, 7, 8, and 9.

Standard urine test strips were dipped into each solution for 30 seconds to ensure uniform chemical reaction. To capture the temporal dynamics of the colorimetric reaction, images were

ISBN NR: 978-625-5694-92-8

Table 1: Best-performing CNN model and optimal random seed for each analyte.

Analyte	Best Model	Best Seed	Accuracy
Protein	MobileNetV2	123	0.9590
pH	EfficientNetB0	21	0.9214
Ketone	EfficientNetB0	123	0.9000
Glucose	EfficientNetB0	7	0.9494

acquired at four distinct time points. The first image (t_0) was captured following a one-minute stabilization period, with subsequent images recorded at one-minute intervals (t_1, t_2, and t_3). To ensure robustness against variable lighting conditions encountered in real-world usage, this procedure was repeated under seven different illumination environments, achieved through combinations of three light sources at varying intensities. To account for inter-device variability in camera optics and proprietary image processing pipelines, data acquisition was performed using two distinct smartphone models representing Android and iOS platforms.

All images were initially captured from a standardized top-down viewpoint. To simulate real-world scenarios where users may hold their devices at various angles, geometric augmentation was applied to each acquired image, generating six distinct viewing perspectives: one center (original), two rightward (soft and sharp), two leftward (soft and sharp), and one bottom view. This augmentation strategy increased the effective dataset size sixfold and significantly enhanced the geometric invariance of the resulting models.

A two-stage automated cropping pipeline was subsequently applied. In the first stage, the test strip region was isolated from the background via region-of-interest (ROI) detection. In the second stage, individual analyte pads corresponding to the four target biomarkers were automatically extracted from the isolated strip. Unlike traditional machine learning approaches requiring manual feature extraction, these cropped analyte pad images were fed directly into the CNN architectures, allowing the networks to learn optimal feature representations in an end-to-end fashion. The final dataset comprised 1,680 samples per analyte, each representing a unique combination of concentration level, time point, lighting condition, device type, and viewing angle.

2.2. Deep Learning Architecture and Transfer Learning

The proposed approach leverages deep convolutional neural networks (CNN) to perform end-to-end learning directly from raw analyte pad images, eliminating the need for manual feature engineering. Two lightweight CNN architectures were systematically evaluated: EfficientNetB0 and MobileNetV2. These architectures were selected for their balance between classification accuracy and computational efficiency, making them suitable for mobile deployment scenarios where computational resources and battery life are limited.

EfficientNetB0 employs compound scaling to uniformly scale network depth, width, and resolution via a principled composite coefficient. This architecture utilizes mobile inverted

ISBN NR: 978-625-5694-92-8

Table 2: Protein classification results across all experimental configurations.

Seed	Model	Mean Acc	Std Acc	Max Acc
7	MobileNetV2	0.9507	0.0141	0.9624
7	EfficientNetB0	0.9500	0.0108	0.9642
21	MobileNetV2	0.9405	0.0099	0.9480
21	EfficientNetB0	0.9345	0.0045	0.9409
42	MobileNetV2	0.9411	0.0116	0.9534
42	EfficientNetB0	0.9554	0.0136	0.9659
123	**MobileNetV2**	**0.9590**	**0.0076**	**0.9695**
123	EfficientNetB0	0.9411	0.0064	0.9480
456	MobileNetV2	0.9453	0.0127	0.9552
456	EfficientNetB0	0.9447	0.0108	0.9588

bottleneck convolution (MBConv) blocks with squeeze-and-excitation optimization, achieving competitive accuracy with significantly fewer parameters than traditional CNN. MobileNetV2 is based on an inverted residual structure with linear bottlenecks and is specifically designed for mobile and resource-constrained environments, wherein depthwise separable convolutions substantially reduce computational complexity while maintaining competitive performance.

A transfer learning strategy was adopted to leverage knowledge acquired from large-scale natural image datasets. Both architectures were initialized with weights pre-trained on ImageNet [11], which contains over 14 million images across 1,000 classes. Transfer learning is particularly advantageous for medical imaging tasks where labeled data are limited, as low-level features including edges, textures, and color gradients acquired from natural images transfer effectively to colorimetric analysis. The pre-trained models were subsequently fine-tuned on the domain-specific urine test strip dataset.

Given that each analyte exhibits distinct colorimetric reaction characteristics, a specialized modeling strategy was employed: four independent CNN models were trained, one per analyte. This approach allows each model to learn analyte-specific color transitions and reaction patterns, offering improved discrimination over a single multi-output model. For each analyte, both EfficientNetB0 and MobileNetV2 were trained and evaluated to determine the optimal architecture.

2.3. Training Methodology

Training was conducted using group-based 3-fold cross-validation to ensure robust performance estimation while preventing data leakage between folds. The grouping strategy ensures that all augmented views of the same original image remain within the same fold, preventing artificially inflated performance estimates. This approach provides more conservative, realistic performance estimates than standard random splitting.

Both architectures were trained using standard categorical cross-entropy loss:

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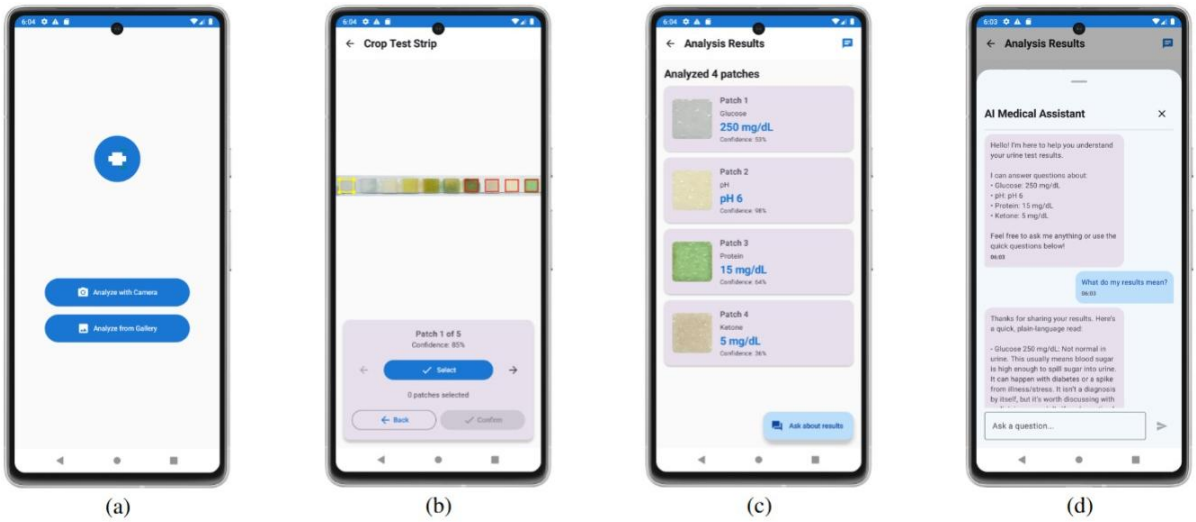

(a) (b) (c) (d)

Figure 3: The UroScan Android application interface: (a) homepage, (b) cropping and rotation tools, (c) selected test strip region, and (d) quantitative analysis results.

$$\mathcal{L} = -\sum_{c=1}^{C} y_c \log(\hat{y_c}) \tag{1}$$

where $C = 5$ is the number of concentration classes, $y_c \in \{0,1\}$ is the ground truth label, and $(\hat{y_c}) \in \{0,1\}$ is the predicted probability for class *c*. Optimization was performed using the Adam optimizer with adaptive learning rate scheduling.

To account for variability arising from random initialization and to ensure reproducibility, experiments were conducted across five different random seeds. For each seed-model-analyte combination, the model was trained using the 3-fold cross-validation scheme described above. Final model selection per analyte was based on the highest mean cross-validation accuracy across all seeds, yielding a comprehensive comparison of 40 experimental configurations (4 analytes x 2 models x 5 seeds).

The final classification layer of each pre-trained architecture was replaced with a dense layer matching the number of concentration classes (5 classes per analyte). During training, standard data augmentation techniques and regularization methods were applied to prevent overfitting and improve generalization.

2.4. Smartphone Application: *UroScan*

The *UroScan* Android application was developed to embed the optimized CNN models and facilitate real-time colorimetric analysis. The application guides users through the analysis pipeline and delivers quantitative results without requiring external computation or internet connectivity. All inference operations are performed locally on the device using the embedded TensorFlow Lite models.

As shown in Figure 3, the homepage presents two clearly labeled options: capturing a new image via the camera or selecting an existing image from the device gallery. After image selection, users are presented with an interactive cropping tool to isolate the test strip from the background, ensuring optimal input for automated analysis.

ISBN NR: 978-625-5694-92-8

Table 3: Ketone classification results across all experimental configurations.

Seed	Model	Mean Acc	Std Acc	Max Acc
7	MobileNetV2	0.8295	0.0634	0.8871
7	EfficientNetB0	0.8929	0.0152	0.9086
21	MobileNetV2	0.8434	0.0113	0.8546
21	EfficientNetB0	0.8732	0.0057	0.8794
42	MobileNetV2	0.8475	0.0201	0.8759
42	EfficientNetB0	0.8899	0.0089	0.9014
123	MobileNetV2	0.8654	0.0291	0.8989
123	**EfficientNetB0**	**0.9000**	**0.0198**	**0.9194**
456	MobileNetV2	0.8536	0.0163	0.8763
456	EfficientNetB0	0.8977	0.0092	0.9050

Upon activation of the analyze button, the application executes several automated tasks in sequence. First, the four target analyte pads are segmented from the cropped strip using ROI detection. Second, each segmented pad undergoes preprocessing and resizing to satisfy the input requirements of the corresponding CNN model. Third, each preprocessed pad image is passed to its respective fine-tuned CNN model for inference. Finally, the application aggregates the concentration predictions from all four models and displays the results in a concise, user-friendly interface presenting the quantified levels of pH, protein, ketone, and glucose.

3. RESULTS AND DISCUSSION

In this section, we present the dataset, evaluation metrics, and experimental results of the proposed approach with detailed discussion.

3.1. Dataset

The evaluation was performed on the comprehensive dataset described in Section 2. The dataset comprises 1,680 samples per analyte, distributed across five concentration levels. Each sample consists of a cropped analyte pad image captured under a specific combination of conditions: four time points, seven lighting environments, two smartphone devices, and six geometric viewing angles. All images were preprocessed to satisfy the input requirements of the CNN architectures, including resizing to the appropriate spatial dimensions, normalization to a [0,1] pixel value range, and conversion to three-channel RGB format.

3.2. Evaluation Metrics

Model performance is evaluated using classification accuracy, defined as the proportion of correctly classified samples:

$$\text{Accuracy} = \frac{N_{\text{correct}}}{N_{\text{total}}} \tag{2}$$

where $N_{correct}$ is the number of correctly classified samples and N_{total} is the total number of test samples. For each experimental configuration, three statistics are reported: the mean accuracy across the three cross-validation folds; the standard deviation (Std) reflecting prediction stability; and the maximum accuracy (Max) achieved across folds. Final model selection per analyte is based on the highest mean cross-validation accuracy across all random seeds.

ISBN NR: 978-625-5694-92-8

Table 4: pH classification results across all experimental configurations.

Seed	Model	Mean Acc	Std Acc	Max Acc
7	MobileNetV2	0.8512	0.0460	0.9122
7	EfficientNetB0	0.9102	0.0099	0.9211
21	MobileNetV2	0.8798	0.0106	0.8943
21	**EfficientNetB0**	**0.9214**	**0.0062**	**0.9291**
42	MobileNetV2	0.8406	0.0273	0.8781
42	EfficientNetB0	0.9036	0.0066	0.9122
123	MobileNetV2	0.8541	0.0275	0.8763
123	EfficientNetB0	0.9006	0.0198	0.9247
456	MobileNetV2	0.8774	0.0175	0.9014
456	EfficientNetB0	0.9059	0.0220	0.9319

3.3. Experimental Results

A systematic comparison of EfficientNetB0 and MobileNetV2 across multiple random seeds revealed architecture-specific performance patterns for different analytes. Table 1 summarizes the best-performing model for each analyte. Detailed experimental results for each analyte are presented in Table 2-Table 4.

As shown in Table 2, MobileNetV2 with random seed 123 achieved the highest protein classification accuracy of 0.9590, marginally outperforming EfficientNetB0 for this analyte. This result suggests that the lighter architecture of MobileNetV2 may be sufficient for representing the color transitions associated with protein concentration variation. For pH classification, EfficientNetB0 with random seed 21 achieved the best performance attaining an accuracy of 0.9214 (Table 4). The relatively lower variance across folds indicates stable and consistent predictions—a property of particular importance for reliable pH measurement in clinical settings.

Table 3 summarizes the ketone classification results, where EfficientNetB0 with random seed 123 demonstrated optimal performance at 0.9000. The elevated standard deviation reflects the inherent challenge of distinguishing subtle color differences between adjacent ketone concentration levels, rather than any instability in the model itself. For glucose classification, EfficientNetB0 with random seed 7 achieved excellent accuracy of 0.9494 (Table 5), with low variance across cross-validation folds. These results demonstrate robust glucose concentration prediction across diverse data partitions. Notably, EfficientNetB0 emerged as the optimal architecture for three of the four analytes (pH, ketone, and glucose), suggesting that its compound scaling and squeeze-and-excitation blocks provide enhanced discriminative power for colorimetric classification tasks. The low standard deviations observed across all analytes indicate stable model performance and robust generalization to unseen data, both of which are essential prerequisites for reliable clinical deployment.

The systematic evaluation reveals the following key findings:

1) **Performance vs. Efficiency Trade-off:** EfficientNetB0 consistently achieved higher classification accuracy for pH, ketone, and glucose, while incurring approximately 20-30% greater training time than MobileNetV2.
2) **Model Robustness:** Both architectures exhibited consistent performance across different random seeds, with standard deviations typically below 0.02, indicating stable learning behavior.

ISBN NR: 978-625-5694-92-8

Table 5: Glucose classification results across all experimental configurations.

Seed	Model	Mean Acc	Std Acc	Max Acc
7	**EfficientNetB0**	**0.9494**	**0.0067**	**0.9588**
7	MobileNetV2	0.9095	0.0051	0.9140
21	MobileNetV2	0.9208	0.0087	0.9283
21	EfficientNetB0	0.9339	0.0066	0.9427
42	MobileNetV2	0.9208	0.0068	0.9301
42	EfficientNetB0	0.9482	0.0120	0.9606
123	MobileNetV2	0.9172	0.0188	0.9309
123	EfficientNetB0	0.9470	0.0070	0.9534
456	MobileNetV2	0.9208	0.0150	0.9319
456	EfficientNetB0	0.9333	0.0114	0.9486

3) **Analyte-Specific Architecture Selection:** MobileNetV2 outperformed EfficientNetB0 for protein classification, suggesting that less complex models may suffice for analytes with more visually discriminable color transitions.
4) **Transfer Learning Effectiveness:** The high accuracies achieved by both architectures validate the transferability of ImageNet-pretrained features to colorimetric analysis, even given a modest dataset of 1,680 samples per analyte.
5) **Deployment Considerations:** The *UroScan* application employs the best-performing architecture for each analyte, thereby balancing accuracy and computational efficiency for real-time mobile inference.

4. CONCLUSION

A deep learning framework has been presented in this paper for the automated colorimetric analysis of urine test strips using smartphone imaging. A comprehensive dataset of 1,680 samples per analyte was compiled under diverse real-world conditions, and two lightweight CNN architectures were evaluated via transfer learning with group-based cross-validation. EfficientNetB0 emerged as the optimal architecture for three analytes (pH, ketone, and glucose), while MobileNetV2 achieved the best performance for protein. The optimized models were integrated into *UroScan*, an Android application employing TensorFlow Lite for real-time, on-device inference. Collectively, the results demonstrate that smartphone-based deep learning constitutes an objective and accessible solution for point-of-care urinalysis, unifying end-to-end feature learning, effective transfer learning, and lightweight architectures suited to resource-constrained devices. Future work will explore additional urinalysis parameters, larger patient populations, and attention-based architectures to further advance classification performance.

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ISBN NR: 978-625-5694-92-8

CELL MORPHOLOGY STUDIO: A DESKTOP PLATFORM FOR AUTOMATED NEUROTOXICITY ASSESSMENT AND MORPHOLOGICAL REPORTING

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ABSTRACT

This study presents Cell Morphology Studio, a fully integrated desktop application for automated morphological quantification of SH-SY5Y neuroblastoma cells under Doxorubicin (DOX)-induced cytotoxicity. The platform employs a hybrid architecture combining a Windows Presentation Foundation (WPF) front-end with a Python-based deep learning backend communicating via a structured JSON contract over OS subprocesses. The system implements the ViT-UNet-CBAM segmentation model to deliver class-specific segmentation overlays, quantitative morphometric statistics, interactive Region of Interest (ROI) analysis, calibrated measurement tools, and automated PDF report generation. While existing tools such as Fiji/ImageJ, CellProfiler, Cellpose, and QuPath address partial aspects of cell image analysis, none provides a purpose-built end-to-end environment for SH-SY5Y neurotoxicity screening with integrated deep learning inference and clinical-grade reporting. Cell Morphology Studio bridges this gap through a contract-based IPC protocol, an embedded AI assistant for natural language interpretation of findings, a structured analysis history system, and secure multi-user authentication with SHA-256 salted hashing.

Keywords: Cell Morphology Studio, Neurotoxicity Screening, Deep Learning, ViT-UNet-CBAM, Morphometric Analysis, Apoptosis Quantification, Desktop Application

1. INTRODUCTION

The quantification of drug-induced apoptosis in SH-SY5Y neuroblastoma cell cultures is a cornerstone of neuropharmacological research. Doxorubicin (DOX) induces a well-characterized morphological cascade — including neurite retraction, cytoplasmic shrinkage, and apoptotic body formation — that provides a direct readout of drug cytotoxicity [1]. However, translating these morphological signatures into objective, scalable measurements has historically been a major bottleneck.

Traditional assessment methods — manual scoring by expert biologists and colorimetric metabolic assays such as MTT — suffer from critical limitations: inter-observer variability, low throughput, and inability to capture population-level morphological heterogeneity [2]. While deep learning models have achieved state-of-the-art performance in biomedical image

ISBN NR: 978-625-5694-92-8

segmentation, their laboratory adoption is severely constrained by the absence of accessible, integrated software environments [3].

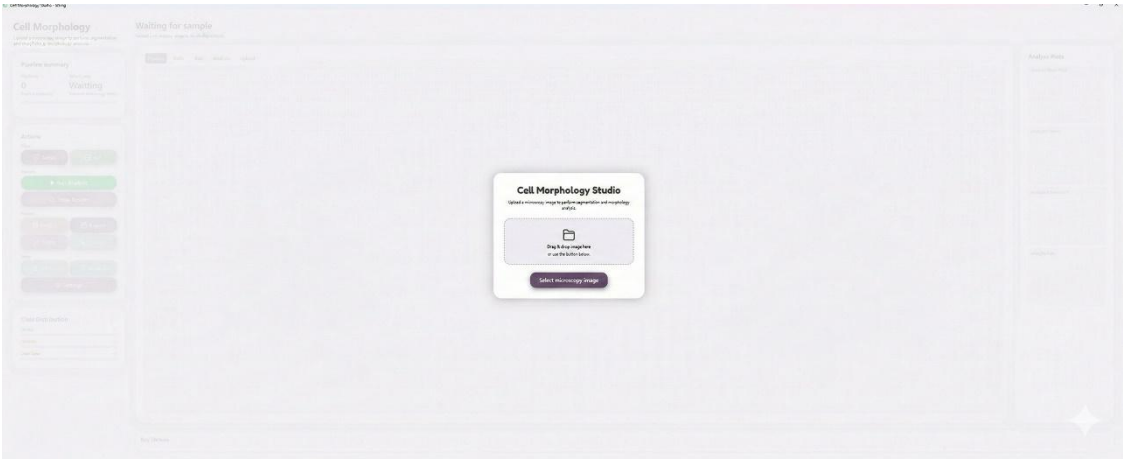

Figure 4: Cell Morphology Studio initial onboarding interface. The central drag-and-drop panel invites the user to upload a microscopy image, while the left column shows the pipeline control panel in its initial 'Waiting' state.

Several established tools have attempted to address these limitations. Fiji/ImageJ established the paradigm of extensible, plugin-based microscopy analysis [4]. CellProfiler advanced this with pipeline-based batch processing for morphological feature extraction [5]. Ilastik provides an interactive machine learning interface for pixel classification, but its generalist approach limits performance on complex apoptotic state discrimination [6]. Cellpose offers a powerful generalist segmentation engine but is not designed for multi-class semantic segmentation of apoptotic substates [7]. Commercial platforms including QuPath are optimized for tissue-level pathology rather than live-cell neurotoxicity screening [8]. Collectively, these tools leave a critical gap: none provides a purpose-built, end-to-end environment for SH-SY5Y neurotoxicity screening integrating specialized deep learning inference with clinical-grade reporting in a locally deployed, multi-user desktop setting.

This paper addresses this gap by presenting Cell Morphology Studio, implementing the ViT-UNet-CBAM hybrid segmentation architecture within a complete end-to-end analysis platform. The principal contributions are: (i) a complete desktop software architecture integrating WPF front-end with a Python deep learning backend through a contract-based IPC design; (ii) an end-to-end workflow covering image loading, inference, quantitative visualization, ROI-targeted analysis, interactive measurement, and automated PDF report generation; (iii) an embedded conversational AI assistant for natural language interpretation of morphological metrics; (iv) a structured analysis history system with thumbnail caching and date-range filtering; and (v) a secure multi-user authentication system with SHA-256 salted hashing.

2. APPLICATION AND SYSTEM DESIGN

2.1. System Architecture and Design Principles

Cell Morphology Studio is built on three core architectural principles: (1) separation of concerns between the user interface and computational analysis layers; (2) contract-based communication to enable independent evolution of each layer; and (3) non-blocking

ISBN NR: 978-625-5694-92-8

asynchronous design to maintain interface responsiveness during long-running inference tasks. The platform targets .NET 9.0 with Windows Presentation Foundation (WPF) for the front-end and Python 3.x for the deep learning backend.

Figure 5: Cell Morphology Studio main dashboard after image loading. The three-column layout shows the pipeline control panel (left), the microscopy image viewer in the Original tab (center), and the analysis plots panel (right). The pipeline status reads 'Ready'.

2.2. Inter-Process Communication Protocol

Communication between the WPF front-end and the Python analysis backend is established through operating system subprocesses. Analysis commands are dispatched using a configured ProcessStartInfo structure with redirected standard I/O streams. The standard error stream carries real-time progress events encoded as PROGRESS:json tokens, where each JSON payload contains percentage completion, status text, and optional substage identifiers. The standard output stream carries the structured result JSON upon completion — containing timestamp, input filename, statistical summaries, and file paths to all generated output artifacts.

2.3. Authentication and Multi-User Management

The application implements a secure, lightweight authentication system suitable for shared academic and medical laboratory environments. Passwords are hashed using SHA-256 with a randomly generated salt via RandomNumberGenerator, providing protection against precomputed table attacks. A Guest mode provides access to core analysis functionality without account creation, facilitating quick access for demonstration and training purposes.

2.4. Image Acquisition and Analysis Pipeline

The main application window follows a three-column layout: the left column contains pipeline status indicators and primary control elements; the central column presents the multi-tab image viewer; and the right column displays numerical metrics and visualization charts. The system accepts PNG, JPG, TIFF, and BMP formats. Upon initiating analysis, the WPF front-end dispatches a subprocess command to the Python backend executing the ViT-UNet-CBAM inference pipeline. Real-time progress events stream back and are rendered via the Busy

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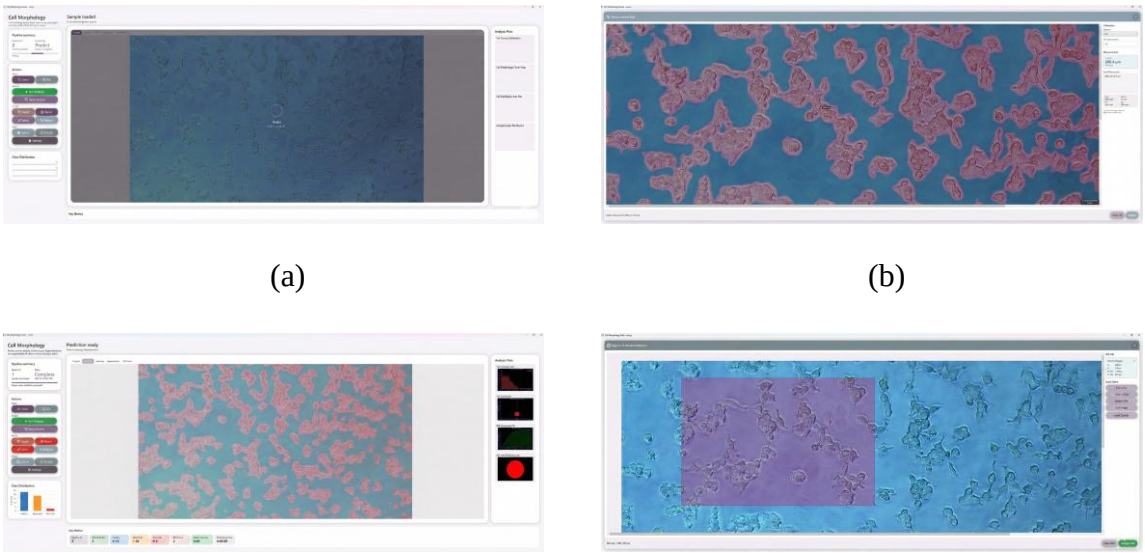
Overlay layer. Upon completion, the Overlay tab renders the three-class segmentation mask as a semi-transparent color overlay. Key metrics — total cell count, class percentages, mean area, and coefficient of variation — are displayed in the Key Metrics bar. The right panel presents four analysis plots: KDE, box plot, CDF, and size category distribution.



(a) (b)

(c) (d)

Figure 6: (a) Real-time analysis view with the Busy Overlay active ('Predict — Analysis in progress'), (b) Interactive Measurement Tool with a calibrated 206.4 µm line (20× objective, 0.5 µm/pixel). Scale bar: 50 µm, (c) Completed segmentation results: Overlay tab with class-specific mask, Key Metrics bar reporting 353 total cells, affected ratio 43.2%, mean area 10,176 px², CV 80.0%, (d) ROI Selection interface with a rectangular region (1282×851 px) defined over a dense cell cluster.

2.5. Interactive Spatial Analysis Tools

The platform provides two complementary tools for spatially targeted investigation. The measurement module provides calibrated distance measurements on microscopy images, mapping pixel coordinates to physical micrometer values based on selected objective magnification. Statistical summarization (mean, min, max, standard deviation) is computed automatically, and results can be exported as CSV files. The ROI component enables users to focus the segmentation pipeline on a specific spatial subset by interactively defining a rectangular boundary on the image canvas. Quick Select templates (512×512, 1024×1024, Center 50%, Full Image) support standardized workflows and enable localized quantification of spatially heterogeneous cultures.

2.6. Label Editor

The Label Editor allows researchers to manually refine segmentation masks produced by the model. Pixel-level operations employ unsafe memory access through AllowUnsafeBlocks, enabling direct bitmap manipulation without performance penalties. The painting tool provides class-based annotation with adjustable brush sizes. An undo mechanism implemented as a

ISBN NR: 978-625-5694-92-8

bounded stack maintains the previous twenty mask states, enabling reversal of editing operations without re-inference.

2.7. Embedded AI Assistant

The embedded conversational AI assistant receives the complete numerical output of the segmentation pipeline — cell counts, class distributions, area statistics, and morphometric

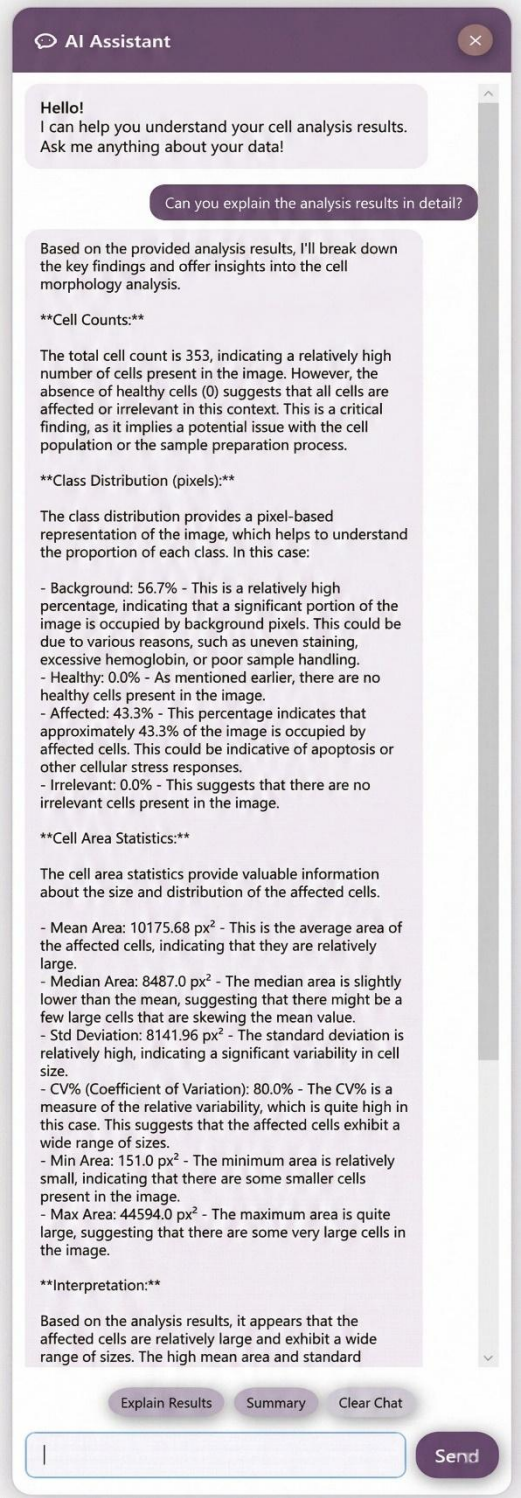


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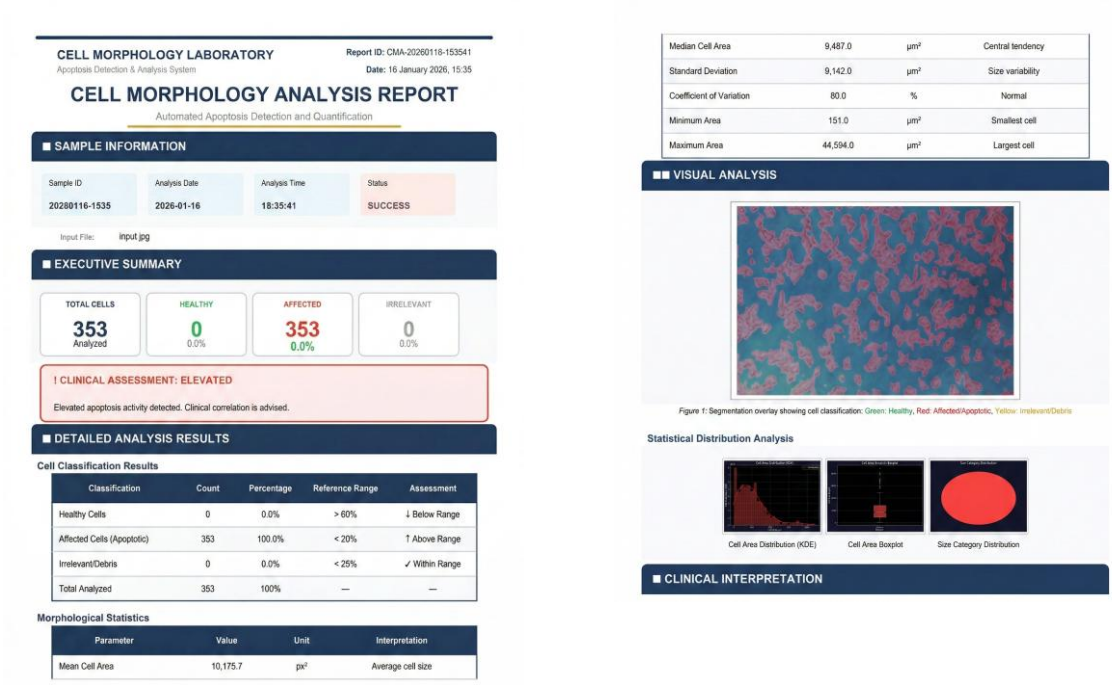
Figure 7: Embedded AI Assistant panel providing structured natural-language interpretation of segmentation output (353 cells, 43.3% Affected, Mean Area: 10,175 px², CV: 80%). Quick-action buttons (Explain Results, Summary, Clear Chat) support common query patterns.

indices — and interprets these in natural language in response to user queries. The assistant provides structured explanations covering class distribution percentages, area statistics (mean, median, standard deviation, CV), and experimental recommendations. This module substantially lowers the expertise barrier for result interpretation, making the platform suitable for multi-disciplinary research environments.



(a) (b)

Figure 8: Automated PDF report output. (a) Executive Summary page with cell count, class distribution percentages, reference range flags, and clinical assessment banner. (b) Visual Analysis page with segmentation overlay, morphological statistics table, and statistical visualization charts.

3. RESULTS AND EVALUATION

3.1. Automated PDF Report Generation

The reporting module compiles all analysis results into a structured, reproducible PDF document organized in three sections. The Executive Summary presents total cell count, class distribution percentages with reference ranges and assessment flags (Below/Within/Above Range), and a color-coded clinical assessment banner. The Visual Analysis section includes the segmentation overlay image, morphological statistics table, and statistical visualization charts (KDE, box plot, size category distribution). The Clinical Interpretation section contains AI-generated textual analysis of morphological findings with experimental recommendations. The report header includes complete metadata — Report ID, analysis timestamp, and input filename — ensuring full traceability.

3.2. History Management and Configuration

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The application maintains a structured analysis history database. Each session record contains a unique identifier, input filename, processing timestamp, quantitative results, and references to all generated visual assets. A thumbnail generation routine caches scaled overlay images to accelerate history browsing. The history manager supports search by filename substring and date-range filtering, facilitating organization of large experimental datasets. A configurable settings layer allows users to adjust visual parameters (brightness, contrast, saturation, sharpness) and analytical thresholds (model confidence level, minimum cell area filter). The application supports light and dark display themes and language localization between Turkish and English.

Figure 9: Targeted ROI analysis output. The pipeline has re-executed exclusively within the selected region (Total Cells: 45, Affected: 46.4%). Segmentation overlay and all analysis plots reflect only the ROI subset, enabling localized quantification of spatially heterogeneous apoptotic distributions.

3.3. Discussion

Cell Morphology Studio demonstrates that deep learning-based cell analysis can be successfully translated from research prototypes into practical laboratory tools. Accessibility is addressed through the drag-and-drop onboarding workflow, guest authentication mode, bilingual interface, and the embedded AI assistant. Interpretability is supported through semi-transparent segmentation overlays, histogram galleries, and AI-generated contextualized natural-language explanations. For expert users, the Label Editor provides a critical safety valve for correction of systematic model errors without re-inference.

Reproducibility is addressed through the analysis history system, complete PDF report metadata traceability, and the contract-based IPC architecture ensuring future segmentation backend updates can be deployed without modifying the front-end. Despite these strengths, several limitations remain: the current deployment requires local Python and .NET runtime installations; the AI assistant depends on backend API availability; and the platform is currently validated specifically for SH-SY5Y brightfield microscopy.

4. GENERAL EVALUATION AND CONCLUSIONS

This paper has presented Cell Morphology Studio, a purpose-built desktop application implementing deep learning-based morphological segmentation of SH-SY5Y neuroblastoma cells within a complete end-to-end laboratory workflow. The platform integrates the ViT-UNet-CBAM segmentation architecture with an accessible user interface, interactive analysis tools, AI-driven result interpretation, and automated clinical-grade PDF reporting.

The platform successfully bridges the gap between deep learning inference and routine laboratory practice, enabling objective, reproducible, and interpretable high-throughput neurotoxicity screening. Key software engineering contributions include a contract-based IPC protocol, real-time PROGRESS:json reporting, SHA-256 salted multi-user authentication, and structured analysis history management. Planned extensions encompass containerized cross-platform deployment, active learning integration for iterative model refinement from expert corrections, and extension to fluorescence microscopy and 3D spheroid cultures.

ACKNOWLEDGEMENT

This study was supported by the Health Institutes of Turkey (TUSEB) under Project No: 44235. The authors would like to thank TUSEB for their support.

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ISBN NR: 978-625-5694-92-8

ViT-UNet-CBAM: A HYBRID TRANSFORMER -CONVOLUYION ARCHITECTURE FOR MORPHOLOGICAL SEGMENTATION OF SH-SY5Y NEUROBLASTOMA CELLS

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ABSTRACT

The morphological quantification of SH-SY5Y neuroblastoma cells under Doxorubicin (DOX) treatment remains a critical challenge in neuroblastoma research. This study proposes a hybrid deep learning architecture, designated ViT-UNet-CBAM, capable of performing accurate segmentation across three classes: Healthy, Affected (Apoptotic), and Background (Residual). The proposed model features a dual-path encoder consisting of a ViT branch for global context extraction and a CNN branch for multi-scale local feature encoding, integrated via Convolutional Block Attention Modules (CBAM). The model was trained and evaluated on a manually annotated private dataset prepared through a custom preprocessing pipeline comprising eleven transformation techniques, validated using PSNR and SSIM metrics. Experimental results demonstrate that the ViT-UNet-CBAM architecture achieves a mean Intersection-over-Union (mIoU) of 0.843, outperforming the standard U-Net (0.820) and SegNet (0.780) baseline models. This improvement is most pronounced in the critical Affected class (+0.12 IoU), confirming that the hybrid approach effectively captures both global apoptotic context and fine neurite boundary details.

Keywords: SH-SY5Y Neuroblastoma; Morphological Segmentation; Deep Learning; Vision Transformer; CBAM; U-Net; Doxorubicin Cytotoxicity.

1. INTRODUCTION

Neuroblastoma is the most common extracranial solid tumor of infancy and accounts for a disproportionately large share of pediatric cancer-related deaths. Doxorubicin (DOX), an anthracycline antibiotic, remains one of the cornerstone components of high-risk neuroblastoma therapy. Its therapeutic efficacy, however, is substantially limited by dose-dependent toxicity profiles encompassing cardiotoxicity and significant neurotoxicity, leading to long-term cognitive impairment in pediatric patients [1]. This renders the precise and objective quantification of drug-induced cytotoxicity one of the primary focal points of oncological pharmacology.

The SH-SY5Y human neuroblastoma cell line is recognized as the gold-standard in vitro model for investigating chemotherapy-induced neuronal damage. These cells are of unique relevance owing to their capacity to differentiate into a neuron-like phenotype, extending long and delicate neuritic processes [2], [3]. DOX inhibits Topoisomerase II through intercalation into

ISBN NR: 978-625-5694-92-8

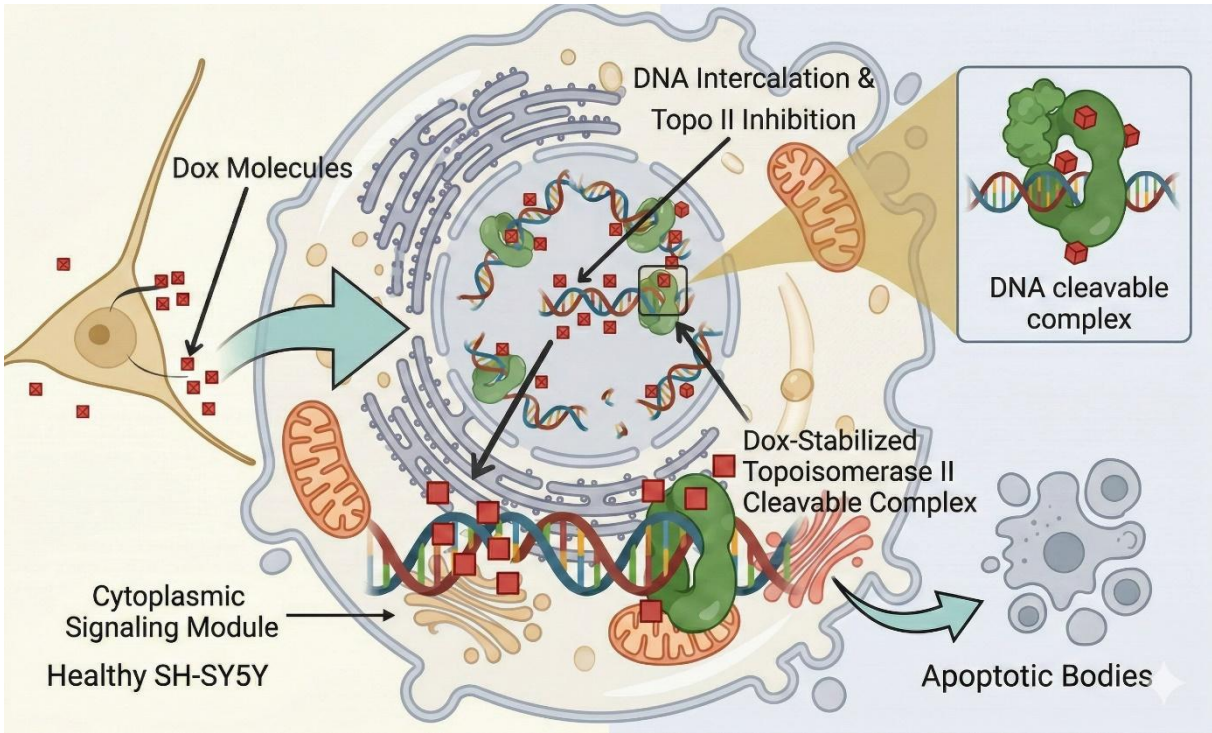

Figure 10: Molecular mechanisms of Doxorubicin (DOX)-induced cytotoxicity in SH-SY5Y neuroblastoma cells. DOX intercalates into DNA and inhibits Topoisomerase II, causing double-strand breaks. Concurrent reactive oxygen species (ROS) generation via the quinone redox cycle triggers mitochondrial dysfunction and oxidative stress. These molecular events collectively initiate apoptosis, which manifests morphologically as neurite retraction, somatic shrinkage, and apoptotic body formation.

DNA base pairs and triggers double-strand breaks. Concurrently, the quinone redox cycle generates Reactive Oxygen Species (ROS), leading to mitochondrial dysfunction. These molecular events initiate a morphological cascade: initial neurite retraction, somatic shrinkage, nuclear condensation, and ultimately the formation of apoptotic bodies are observed [4]. Despite morphological indicators of apoptosis, quantifying these changes remains a significant challenge. Conventional colorimetric assays (such as MTT) measure metabolic activity but cannot resolve population-level heterogeneity or morphological phenotypic differences [5]. These limitations necessitate the development of objective and scalable automated computational tools.

Deep learning, particularly CNN-based models such as U-Net, has transformed biomedical image segmentation [6]. However, existing architecture exhibits three fundamental limitations. First, CNNs rely on fixed receptive fields, and in high-density cultures U-Net frequently conflates distant apoptotic clusters into a single segmentation region. Second, attention mechanisms in standard networks such as Attention U-Net neglect channel-wise feature discrimination, causing fine neuritic structures to be discarded as noise during downsampling [7]. Third, general-purpose models remain insufficient for resolving the subtle phenotypic changes that distinguish Healthy from Affected cells [8], [9].

To address these limitations, ViT-UNet-CBAM is proposed, a hybrid architecture integrating a Vision Transformer (ViT) for global context extraction with a CNN encoder for multi-scale

ISBN NR: 978-625-5694-92-8

spatial precision [10], [11]. The architecture is supported by a preprocessing pipeline comprising eleven transformations evaluated within a three-class segmentation framework and validated using PSNR and SSIM metrics.

2. EXPERIMENTAL STUDIES

2.1. Related Work

Automated cell segmentation has advanced rapidly since the emergence of fully convolutional networks. The U-Net architecture established the encoder-decoder paradigm with skip connections as the dominant framework for biomedical segmentation [6]. UNet++ introduced dense nested skip connections [12], while Attention U-Net incorporated soft attention gates to suppress irrelevant feature activations during encoding [7].

Dosovitskiy et al. demonstrated that ViT models can achieve competitive performance on image recognition tasks [10]. TransUNet was among the first works to integrate ViT into a U-Net-like framework for medical image segmentation [13]. Swin-UNet enabled hierarchical feature extraction at multiple scales using Swin Transformers [14]. CellViT applied ViT to nucleus detection in histological tissue, demonstrating the potential of Transformer-based architectures [15]. The CBAM module introduced lightweight channel and spatial attention mechanisms [11]; TransAttUNet demonstrated that combining these attention modules with Transformer self-attention yields consistent gains [16].

Despite these advances, no study has jointly addressed the complementary limitations of CNNs and ViTs in neuroblastoma morphological segmentation in the context of chemotherapy-induced apoptosis. This gap constitutes the primary motivation of the proposed ViT-UNet-CBAM architecture.

2.2. Dataset Acquisition and Preparation

SH-SY5Y cells (ATCC CRL-2266) were cultured in DMEM (high glucose; Gibco, USA) supplemented with 10% heat-inactivated FBS and 1% Penicillin-Streptomycin in a humidified incubator at 37°C and 5% CO_2. Cells were seeded into sterile flat-bottom 96-well plates at (5–10) × 10^3 cells/well in 200 µL complete medium per well and allowed 24 hours for attachment. The experiment was performed with three treatment groups (Control, 0.5 µM DOX, 2 µM DOX) at three time points (6, 24, 48 hours) with three biological replicates each [5].

SH-SY5Y cells were imaged at the end of each treatment period using a Zeiss Axioskop Upright Fluorescence Microscope under brightfield and phase-contrast illumination with a 20× objective. Images were acquired in CZI format and exported as PNG files following standardized intensity and gamma adjustments. Fifteen non-overlapping fields per well were imaged for each experimental condition, yielding 45 images per treatment group and time point.

2.3. Preprocessing Pipeline

An eleven-transformation preprocessing pipeline was developed using Python and OpenCV to maximize morphological information while controlling for imaging artifacts. The transformations comprise: CLAHE (Lab* color space, clipLimit = 2, tile = 8×8) for local contrast enhancement; Gamma Correction ($\gamma = 0.9$ and $\gamma = 1.1$) for dark/bright region visibility;

ISBN NR: 978-625-5694-92-8

Laplacian Gentle filter (3×3, blend = 0.3) for edge definition; Sharpening (α = 0.25, σ = 1) for membrane boundary reinforcement; Canny Overlay (thresholds 50/150) for edge emphasis;

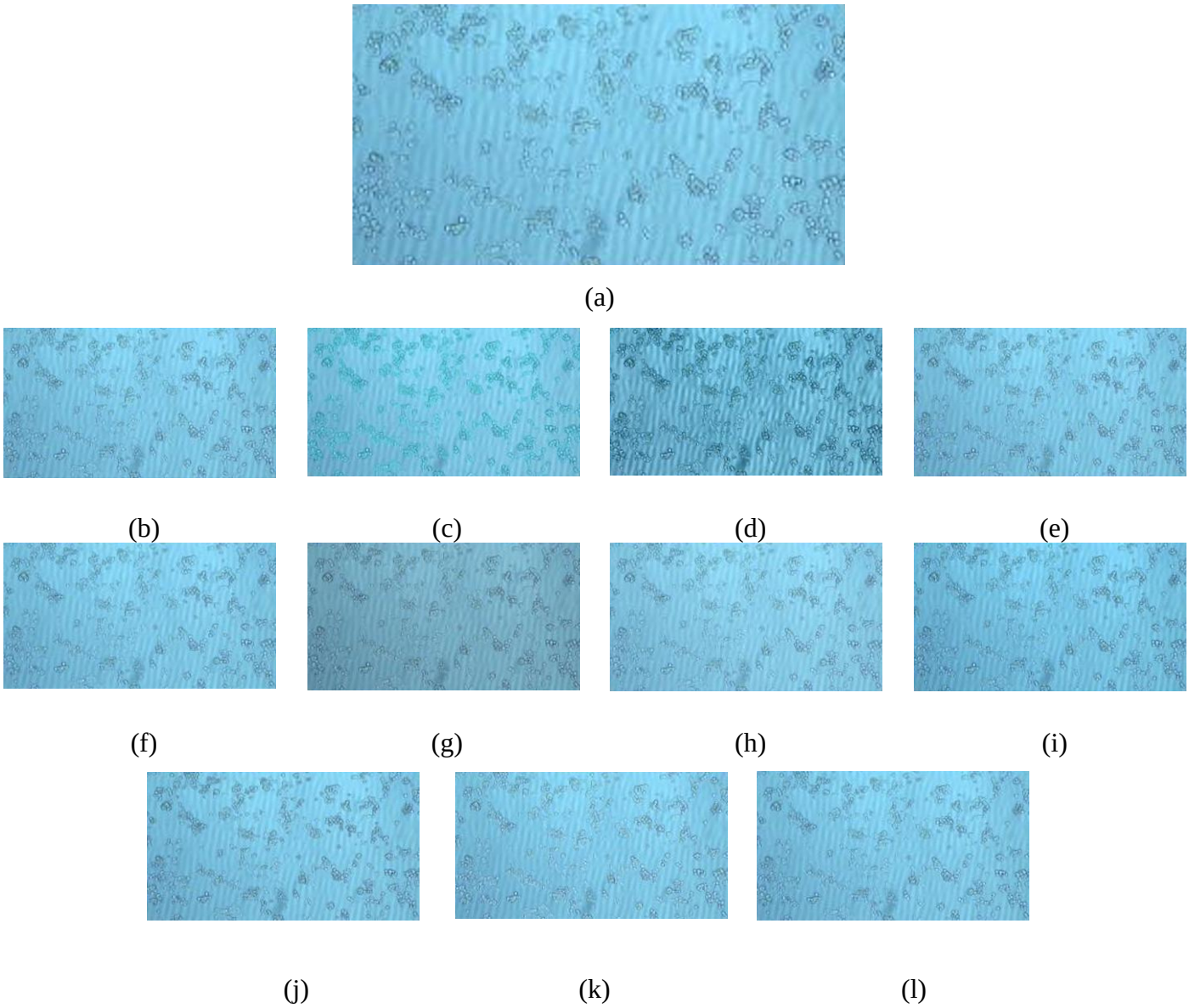

Figure 2: Eleven preprocessed variants of a representative SH-SY5Y brightfield microscopy image generated by the proposed preprocessing pipeline. (a) Original image, (b) Bilateral Edge Transform, (c) Canny Edge Overlay, (d) CLAHE (Lab color space), (e) Difference of Gaussians (DoG), (f) FFT Low-Pass Filter, (g) Gabor Filter Bank, (h) Gamma Correction ($\gamma = 0.9$), (i) Gama Düzeltme ($\gamma = 0.9$), (j) Laplacian Gentle Filter, (k) Morphological Top-Hat Transform, (l) Unsharp Masking. Each transformation addresses a distinct imaging artifact or morphological feature: contrast enhancement (c, g, h), edge and boundary definition (a, b, i, k), frequency-domain filtering (e), texture characterization (f), and apoptotic body highlighting (d, j).

Difference of Gaussians (σ = 1, σ = 3) for membrane banding; Gabor Filter Bank (4 orientations, 2 scales) for directional texture; Morphological Top-Hat Transform (9×9, gain = 0.35) for apoptotic body contrast; Bilateral Edge Transform (d = 9, σColor = 25, σSpace = 7) for noise reduction; and FFT Low-Pass Filter (σ ≈ 0.07 × min{rows, cols}) for high-frequency noise removal.

ISBN NR: 978-625-5694-92-8

Each transformation was validated using PSNR and SSIM metrics, with results summarized in Table 1. The Sharpening transformation achieved the highest PSNR (45.65 dB, SSIM = 0.9977) with minimal morphological distortion, while the Laplacian filter provided the greatest contrast enhancement (PSNR = 25.11 dB, SSIM = 0.8067).

Table 6: PSNR and SSIM evaluation of eleven preprocessing transformations relative to the original SH-SY5Y brightfield image. Unsharp Masking achieves the highest structural fidelity (PSNR=45.65 dB, SSIM=0.9977); the Laplacian Gentle Filter produces the greatest contrast deviation (PSNR=25.11 dB, SSIM=0.8067).

Transformation	**PSNR (dB)**	**SSIM**
CLAHE (Lab*)	19.59	0.8729
Gamma Correction ($\gamma = 0.9$)	31.78	0.9985
Gamma Correction ($\gamma = 1.1$)	32.33	0.9987
Laplacian Gentle	25.11	0.8067
Sharpening ($\alpha = 0.25$)	45.65	0.9977
Canny Overlay	27.97	0.9857
Difference of Gaussians (DoG)	35.17	0.9857
Gabor Filter Bank	20.20	0.9848
Top-Hat Transform	33.83	0.9898
Bilateral Kenar	42.25	0.9821
FFT Low-Pass Filter	34.45	0.9839

2.4. Proposed ViT-UNet-CBAM Architecture

The ViT-UNet-CBAM model is built upon a symmetric encoder-decoder framework augmented with two parallel data processing streams: a convolutional encoder for local feature encoding and a ViT module for global context extraction [6], [10].

Convolutional Encoder Path: The CNN branch consists of four ConvBlocks with 3×3 kernels (feature map channels: 64, 128, 256, 512). Each ConvBlock incorporates Batch Normalization, ReLU activation, and Max Pooling. CBAM is applied to each ConvBlock; channel attention precisely localizes apoptotic tissue cues, while spatial attention localizes neurite boundaries. ViT Global Context Path: The ViT branch partitions the input image into fixed-size 16×16 patches and projects each patch into a sequential vector representation. Multi-head self-attention across all patches establishes long-range semantic dependencies, enabling the model to understand the global compositional context of the cell cluster. Feature representations from

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Transformer layers 4, 8, and 12 are projected to the spatial domain and concatenated to form the Global Bridge representation. CBAM Fusion and Decoder: The fused feature map is refined by CBAM. The decoder comprises symmetric upsampling blocks with skip connections; auxiliary outputs are generated at 64×64 and 128×128 pixel resolutions to provide multi-scale supervision.

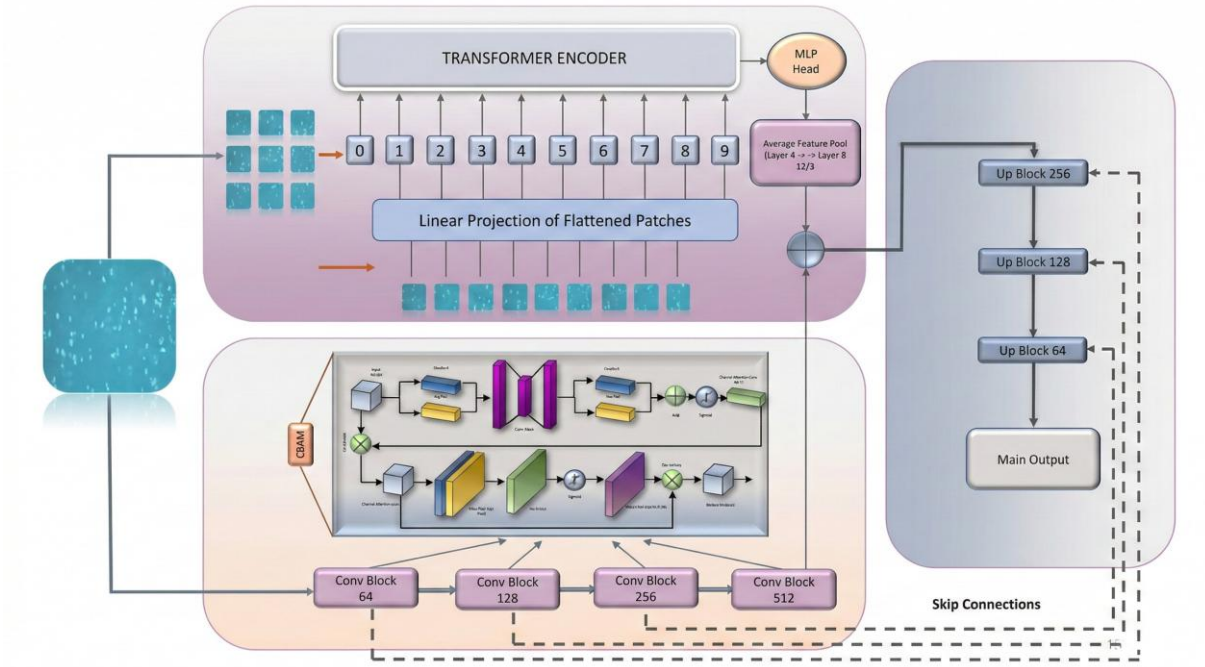

Figure 3: Architectural overview of the proposed ViT-UNet-CBAM model for four-class morphological segmentation of SH-SY5Y neuroblastoma cells. The dual-path encoder combines a ViT branch (upper path) extracting global context via multi-head self-attention over 16×16 patches, with a CNN branch (lower path) encoding multi-scale local features through CBAM-augmented ConvBlocks with 64, 128, 256, and 512 channels. ViT representations from layers 4, 8, and 12 are aggregated in a Global Bridge and fused with the deepest CNN feature map. The decoder reconstructs segmentation masks through symmetric upsampling blocks (64, 128, 256 channels), accompanied by skip connections from corresponding encoder stages and auxiliary outputs at 64×64 and 128×128 resolution for multi-scale supervision.

CBAM Fusion and Decoder: The fused feature map is refined by CBAM. The decoder comprises symmetric upsampling blocks with skip connections; auxiliary outputs are generated at 64×64 and 128×128 pixel resolutions to provide multi-scale supervision.

3. RESULTS AND EVALUATION

Segmentation performance is evaluated using five complementary metrics [17], [18]. IoU rigorously measures the spatial overlap between predicted and ground-truth masks, while the Dice Score provides a single value balancing precision and recall. Precision measures the proportion of correct predictions among predicted positives; Recall measures the true positive detection rate. High Recall for the Affected class is critically important in pharmacological screening.

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Table 2 presents the per-class evaluation of ViT-UNet-CBAM on the held-out test set. The Background class achieved a Dice of 0.974 and IoU of 0.950; the Healthy class reached a Dice of 0.936 and IoU of 0.880. The Affected class, constituting the most challenging segmentation target due to cell shrinkage and overlapping clusters, achieved a Dice of 0.895 and IoU of 0.810, with Recall = 0.900 and Precision = 0.890. The Irrelevant class reached a Dice of 0.844 and IoU of 0.730.

Table 7: Per-class segmentation performance of ViT-UNet-CBAM on the held-out test set. The Affected (apoptotic) class represents the most challenging target, yet achieves $IoU = 0.810$, $Recall = 0.900$ *(recall) and* $Precision = 0.890$ *(precision).*

Metric	Background (0)	Healthy (1)	Affected (2)	Irrelevant (3)
Dice	0.974	0.936	0.895	0.844
IoU	0.950	0.880	0.810	0.730
Precision	0.970	0.932	0.890	0.835
Recall	0.978	0.940	0.900	0.853
F1 Score	0.974	0.936	0.895	0.844

Table 3 presents the mIoU comparison of ViT-UNet-CBAM against the CNN-based U-Net and SegNet baselines across all classes. ViT-UNet-CBAM achieves the highest mIoU at 0.843, outperforming U-Net (0.820) and SegNet (0.780). The advantage is most pronounced in the Affected class: ViT-UNet-CBAM attains an IoU of 0.810, representing gains of +0.120 over U-Net and +0.210 over SegNet. These gains confirm that the hybrid transformer-convolution design better captures long-range contextual relationships among fragmented apoptotic structures.

The baseline U-Net (mIoU = 0.820), which relies solely on convolutions, excels at encoding local structural features but lacks the long-range receptive field required to model global context. This limitation is directly reflected in its lower performance on the Affected class (IoU = 0.690), where apoptotic cells appear in dense and ambiguous clusters. The dual-path encoder simultaneously processes multi-scale local texture features through a CNN branch and establishes global patch relationships via a ViT branch. The CBAM module functions as an adaptive gate: channel attention identifies diagnostically relevant feature maps, while spatial attention localizes these features to cell boundaries. This design enables the simultaneous achievement of high Recall (0.900) and high Dice (0.895) for the Affected class.

The preprocessing pipeline also makes meaningful contributions. The Morphological Top-Hat Transform enhances the contrast of small apoptotic bodies, the Gabor filter bank accentuates neurite boundary textures, and the bilateral edge transform suppresses background noise while preserving membrane edges. The study has several limitations: the dual-path architecture incurs higher computational cost [19], generalization to other neurotoxic agents has not yet been

ISBN NR: 978-625-5694-92-8

validated, and extension to three-dimensional spheroid cultures represents an important direction for future research [20], [21].

4. GENERAL DISCUSSION AND CONCLUSIONS

This study has presented ViT-UNet-CBAM, a hybrid segmentation architecture designed to meet the distinctive morphological analysis requirements of DOX-treated SH-SY5Y neuroblastoma cultures. The core motivation is the inability of existing architectures to address

Table 8: Per-class and mean IoU (mIoU) comparison of ViT-UNet-CBAM against the U-Net and SegNet baselines. ViT-UNet-CBAM achieves the highest mIoU (0.843) while producing the largest margin on the Affected class (+0.120 over U-Net, +0.210 over SegNet).

Model	Background (0)	Healthy (1)	Affected (2)	Irrelevant (3)	mIoU
ViT-UNet-CBAM (Ours)	0.950	0.880	0.810	0.730	0.843
U-Net	0.940	0.830	0.690	0.670	0.820
SegNet (CNN)	0.930	0.810	0.600	0.590	0.780

the complementary limitations of CNNs and pure Vision Transformers: CNNs lack the long-range receptive field needed to distinguish dense apoptotic clusters, while ViTs cannot retain the pixel-level spatial resolution necessary for delineating fine neurite boundaries. The proposed dual-path encoder processes images simultaneously through a ViT branch for global patch relationships and a CNN branch for multi-scale local texture, with adaptive fusion via CBAM. This design represents a principled response to the biological complexity of chemotherapy-induced apoptosis, as both the global arrangement of cell clusters and the fine structural detail of individual cells carry diagnostic significance.

Empirically, ViT-UNet-CBAM achieves an mIoU of 0.843, surpassing U-Net by 4.3 points and SegNet by 6.3 points. Particularly noteworthy are the model's IoU of 0.810 (+0.120 over U-Net) and Recall of 0.900 for the clinically critical Affected (Apoptotic) class. High recall is especially important in pharmacological screening contexts where missing apoptotic cells carries a higher cost than false positives. The simultaneously high Precision (0.890) demonstrates that the architecture does not achieve high recall at the expense of specificity.

The eleven-transformation preprocessing pipeline constitutes a secondary yet meaningful contribution. Taken together, these contributions establish an objective, scalable, and reproducible basis for quantifying drug-induced cytotoxicity in neuronal cell lines. Future research directions include lightweight alternatives (knowledge distillation or efficient transformer variants), generalization to additional neurotoxic agents, and extension to three-dimensional spheroid cultures.

ACKNOWLEDGEMENT

This study was supported by the Health Institutes of Turkey (TUSEB) under Project No: 44235. The authors would like to thank TUSEB for their support.

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ISBN NR: 978-625-5694-92-8

DEEP LEARNING–BASED NONLINEAR PEAK DECONVOLUTION FOR DOPAMINE QUANTIFICATION FROM MIXED ELECTROCHEMICAL SIGNALS

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ABSTRACT

Reliable electrochemical quantification of dopamine (DA) is challenging when interfering species produce overlapping voltammetric responses in differential pulse voltammetry (DPV) measurements. In particular, hydroquinone (HQ) generates oxidation signals that distort the apparent DA peak through nonlinear interactions, limiting the effectiveness of conventional peak-based analysis. This work presents a deep learning (DL) framework for DA concentration estimation directly from voltammetric signals. The proposed approach combines Fourier-based signal modeling, interpolation-driven synthetic data generation, and Gaussian peak reconstruction to create a dense dataset of physically consistent voltammetric responses, wherein each reconstructed signal is formed by summing Gaussian peak contributions along with a baseline offset. A comprehensive experimental evaluation across diverse model families demonstrates that hybrid convolutional–recurrent architectures achieve the highest prediction accuracy by capturing both local peak morphology and global signal dependencies. These results demonstrate the potential of DL for robust DA quantification in complex electrochemical sensing environments.

Keywords: Nonlinear Peak Deconvolution, Dopamine Detection, Deep Learning, Electrochemical Sensing

1. INTRODUCTION

Electrochemical voltammetry provides a powerful analytical tool for probing redox-active species in chemical and biological environments. In particular, differential pulse voltammetry (DPV) enables highly sensitive detection of electroactive molecules by enhancing faradaic current responses while suppressing capacitive background contributions [1]. These characteristics have made DPV widely used in electrochemical sensing applications, including the detection of biologically important neurotransmitters. Dopamine (DA, 3,4-dihydroxyphenethylamine) is widely recognized as an essential neurotransmitter in the mammalian brain, where it plays a central role in modulating motor behavior, reward mechanisms, learning processes, and higher cognitive functions [2], [3]. Impaired regulation of dopaminergic neurotransmission has been implicated in a range of neurological and psychiatric disorders, including Parkinson's disease, schizophrenia, and addictive behaviors [4], [5]. Consequently, developing reliable techniques for DA quantification has become an

ISBN NR: 978-625-5694-92-8

important objective in both biomedical research and clinical diagnostics [6], [7].

Accurate voltammetric determination of DA in real samples is often hindered by coexisting electroactive interferents whose oxidation potentials lie close to that of DA. Common compounds including ascorbic acid, uric acid, and hydroquinone (HQ, 1,4-dihydroxybenzene) generate voltammetric peaks in similar potential regions, resulting in substantial signal overlap [8], [9]. Among these interferents, HQ is a particularly significant source of interference, as its electrochemical activity produces voltammetric responses that closely coincide with those of DA oxidation [10], [11].

Experimental studies reported in the literature indicate that the coexistence of multiple electroactive species in voltammetric measurements often leads to signal interactions that are not explainable through simple linear peak superposition. In complex electrochemical environments, overlapping redox processes may induce distortions in the recorded voltammetric responses, including peak potential shifts, peak broadening, and nonlinear variations in current intensity [12], [13]. These effects arise from coupled electrochemical behavior and the proximity of oxidation potentials among the involved analytes, which renders the interpretation of individual signals more difficult and diminishes analytical selectivity [14]. Consequently, conventional peak analysis and calibration strategies that assume additive and independent signal contributions often become unreliable for accurate quantification in mixed systems.

To overcome these limitations, computational data-driven approaches have gained increasing attention for the analysis of voltammetric signals. Machine learning methods offer powerful tools for capturing complex and often nonlinear relationships between electrochemical signal patterns and analyte concentrations, which can improve analytical performance in multicomponent sensing environments where overlapping redox responses are present [15], [16]. Previous studies have demonstrated that machine learning algorithms can support voltammetric signal analysis through tasks such as pattern recognition, peak separation, and quantitative prediction [17]. Nevertheless, many of these approaches rely on manually designed signal features, a dependence that may constrain the ability of models to utilize the full informational content present in raw electrochemical measurements.

In this study, a deep learning–based (DL) framework is developed for the quantification of DA from DPV signals. Unlike conventional approaches that rely on manually engineered signal descriptors, the proposed framework operates directly on reconstructed voltammetric sequences, enabling neural networks to learn relevant signal representations in an autonomous manner. The training dataset combines experimentally acquired measurements with synthetically generated signals obtained through Fourier-based signal modeling and Gaussian peak reconstruction. This hybrid dataset generation strategy enables dense sampling of the concentration space while preserving physically meaningful characteristics of the electrochemical peaks.

The remainder of this paper is organized as follows. Section 2 describes the proposed methodology, including experimental data acquisition, Fourier-based signal modeling,

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synthetic data generation, raw signal reconstruction, and the DL models used for concentration estimation. Section 3 presents the dataset construction, evaluation metrics,

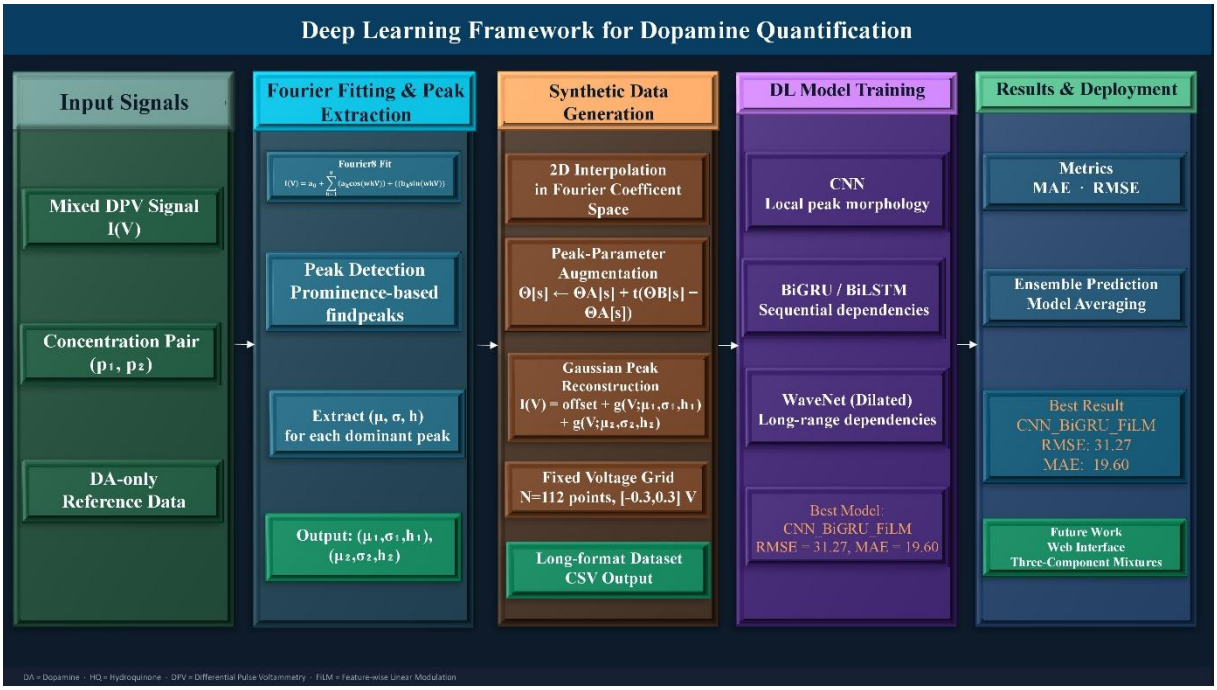

Figure 11. Overview of the proposed framework for DA quantification from DPV signals. The pipeline consists of Fourier-based signal modeling, peak parameter extraction, synthetic data generation through parameter interpolation, Gaussian-based signal reconstruction, long-format dataset assembly, and DL-based concentration estimation at the final stage.

and experimental results. Finally, Section 4 summarizes the main findings and outlines directions for future work.

2. METHOD

Figure 11 illustrates the overall workflow of the proposed framework, from signal modeling and synthetic data generation to raw-signal reconstruction and DL-based concentration estimation.

2.1. Experimental Data Acquisition and Preprocessing

DPV measurements were performed to record the electrochemical responses of DA in the presence of HQ using screen-printed carbon electrodes in a phosphate-buffered saline electrolyte. All voltammograms were obtained under identical experimental conditions within a fixed potential window and sampled along the potential axis to generate current–potential pairs (V, I). Prior to analysis, the raw voltammograms were preprocessed to reduce noise and baseline variations while preserving analyte-dependent peak characteristics. The signals were then aligned onto a common potential grid to ensure consistency across all measurements.

2.2. Fourier-Based Signal Modeling and Peak Parameter Extraction

Each voltammetric signal was represented using a Fourier series to capture the

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nonlinear peak morphology of the electro- chemical response. This representation provides a smooth approximation of the measured current–potential curve and enables consistent peak characterization across different concentration conditions.

Algorithm 1: Fourier8 fitting and two-peak parameter extraction

Input: (V, I)
Output: (μ_1, σ_1, h_1) and (μ_2, σ_2, h_2)
$(V_d, I_d) \leftarrow \text{prepareCurveData}(V, I)$
$\hat{f} \leftarrow \text{fit}(V_d, I_d, \text{fourier8}, \text{Bisquare}, \text{Normalize})$
$V_f \leftarrow \text{linspace}(\min V_d, \max V_d, N_f), I_f \leftarrow \hat{f}(V_f)$
$(P, L, \Pi) \leftarrow \text{findpeaks}(I_f)$; discard boundary peaks
if $P = \emptyset$ **then**
  $L \leftarrow \text{argmax}(I_f); P \leftarrow I_f(L);\ \Pi \leftarrow 1$
Select $M = \min(2, |P|)$ peaks with prominence Π
$(\mu_1, \sigma_1, h_1, \mu_2, \sigma_2, h_2) \leftarrow (\text{NaN}, \text{NaN}, \text{NaN}, \text{NaN}, \text{NaN}, \text{NaN})$
for $k = 1$ **to** M **do**
  $i \leftarrow L_k;\ \mu_k \leftarrow V_f(i);\ h_k \leftarrow I_f(i)$
  Find half − maximum crossings (V_L, V_R) around i (linear interpolation)
  if V_L, V_R exist then
    $\sigma_k \leftarrow \frac{V_R - V_L}{2\sqrt{2\ln 2}}$
Sort detected peaks by decreasing height h_k
Assign the highest peak to index 1 and the second to index 2

Given a voltammetric signal (V, I), the current response was approximated using an eighth-order Fourier model:

$$f(x) = a_0 + \sum_{k=1}^{8} [a_k \cos(kwx) + b_k \sin(kwx)] \tag{1}$$

The model parameters were estimated using robust nonlinear least-squares fitting with bisquare weighting to reduce the influence of noise and outliers. The resulting Fourier function was then evaluated on a dense potential grid to obtain a smooth reconstruction of the voltammetric signal. Following this reconstruction, peak detection was performed on the reconstructed current–potential curve using a prominence-based peak search to identify the dominant oxidation responses.

For each detected peak, three characteristic parameters were extracted: the peak center potential μ, the peak amplitude h, and the peak width σ. The peak center potential μ and amplitude h correspond to the voltage and current values at the detected peak location. The peak width parameter σ was estimated from the full width at half maximum (FWHM) as follows:

$$\sigma = \frac{\text{FWHM}}{2\sqrt{2\ln 2}}. \tag{2}$$

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When multiple peaks were detected, the two peaks with the largest prominence values were retained to capture the dominant oxidation responses of the mixed DA–HQ signal. The detected peaks were subsequently ordered by decreasing amplitude so that the highest peak was assigned to index 1 and the second highest peak to index 2. The complete extraction procedure, including Fourier fitting, peak detection, and parameter estimation, is summarized in Algorithm 1.

2.3. Synthetic Data Generation and Signal Reconstruction

Synthetic signals were generated from the extracted peak parameters to obtain a denser sampling of the DA–HQ concentration space. Interpolation was performed in the peak parameter space (μ, σ, h) across neighboring concentration conditions. Additional parameter sets were then generated by introducing controlled perturbations in the peak parameters for identical concentration pairs. These parameters were subsequently used to reconstruct synthetic voltammetric signals. The generated samples preserve the physical peak morphology while increasing dataset diversity, thereby enhancing the robustness of the subsequent deep learning models.

Once the synthetic parameter sets were established, they were converted into full current–potential signals prior to model training, as the DL models operate directly on voltammetric signals rather than on manually engineered features. For each parameter set, the voltammetric current was reconstructed using a Gaussian peak model:

$$g(V; \mu, \sigma, h) = e^{\left(-\frac{(V-\mu)^2}{2\sigma^2}\right)} h \tag{3}$$

The reconstructed signal was obtained by summing the contributions of the detected peaks together with a baseline offset.

When available, additional baseline peaks were also incorporated:

$$I(V) = \text{offset} + g\left(V; \mu_1, \sigma_1, h_1\right) + g\left(V; \mu_2, \sigma_2, h_2\right) \tag{4}$$

The current was evaluated on a fixed potential grid containing N = 112 uniformly spaced points within the measurement window. Each reconstructed signal was therefore represented as a sequence of sampled current values along the potential axis. For dataset generation, the reconstructed current vector was written in long-format representation. For each signal, N rows were produced containing the sample identifier, mixture concentrations (p_1, p_2), the potential index t, and the corresponding voltage–current pair (V_t, I_t). This procedure converts the peak parameter representation into a dataset suitable for sequence- based DL models. The complete reconstruction and dataset generation process is summarized in Algorithm 2.

2.4. Deep Learning Models

The reconstructed voltammetric sequences were used as inputs to DL models for DA concentration estimation. Each sample consists of a fixed-length current sequence

ISBN NR: 978-625-5694-92-8

representing the voltammetric response of a specific DA–HQ mixture. In addition to the raw signal, a small set of statistical descriptors was extracted to provide complementary information about the overall signal distribution and peak characteristics. A diverse set of

Algorithm 2: Long-format dataset generation by Gaussian reconstruction on a fixed V grid

Input: merged table $\mathcal{D}$ with columns $(p_1, p_2, \text{offset}, \mu_1, \sigma_1, h_1, \mu_2, \sigma_2, h_2)$ and optional $(\mu_{1b}, \sigma_{1b}, h_{1b}, \mu_{2b}, \sigma_{2b}, h_{2b})$

Output: long − format CSV $\mathcal{L}$ with rows $(\text{sample_id}, p_1, p_2, t, V_t, I_t)$

1) Build fixed potential grid

$V \leftarrow \text{linspace}(V_{min}, V_{max}, N), N = 112$

2) Decide whether to include base peaks

if *FORCE_INCLUDE_BASE* is set **then**
  includeBase ← *FORCE_INCLUDE_BASE*
else
  includeBase ← HeuristicCheck($\mathcal{D}$)

3) Stream-write long rows

Initialize output $\mathcal{L} \leftarrow \emptyset$
foreach row i in $\mathcal{D}$ **do**
  Read (p_1, p_2); if p_1 or p_2 is invalid then
    continue
  (a) Reconstruct current vector
  $I(V) \leftarrow \mathbf{0}$
  if offset is finite **then**
    $I(V) \leftarrow I(V) + \text{offset}$
  Add peak-1 if valid:
  $I(V) \leftarrow I(V) + g(V; \mu_1, \sigma_1, h_1)$
  Add peak-2 if valid:
  $I(V) \leftarrow I(V) + g(V; \mu_2, \sigma_2, h_2)$
  if *includeBase = True* **then**
    Add base peak-1 if valid:
    $I(V) \leftarrow I(V) + g(V; \mu_{1b}, \sigma_{1b}, h_{1b})$
    Add base peak-2 if valid:
    $I(V) \leftarrow I(V) + g(V; \mu_{2b}, \sigma_{2b}, h_{2b})$
  Replace NaN/Inf in I(V) with 0
  (b) Write N **rows**
  for $t = 0$ **to** $N - 1$ **do**
    Append $(\text{sample_id} = i, p_1, p_2, t, V_t, I_t)$ to $\mathcal{L}$
Save $\mathcal{L}$ as CSV

Gaussian model:

$g(V; \mu, \sigma, h) = e^{\left(-\frac{(V-\mu)^2}{2\sigma^2}\right)} h$, enforce $\sigma \geq \sigma_{min}$

HeuristicCheck($\mathcal{D}$) (base peaks are physical?)
  Return **True** if:
(i) base columns exist, and
(ii) base amplitude is often nonzero, and
(iii) base centers are not identical duplicates of main centers for most rows
Else return **False**

neural network architectures was evaluated to explore different representation learning

ISBN NR: 978-625-5694-92-8

strategies for voltammetric signal analysis and interpretation. Convolutional neural networks (CNNs) were used to capture local peak morphology and short-range signal patterns. Recurrent architectures, including bidirectional gated recurrent unit (GRU) and long short-term memory (LSTM) networks, were employed to model sequential dependencies along the potential axis. Dilated convolutional models, such as WaveNet-based architectures, were also

Table 9. Representative rows from the reconstructed long-format voltammetric dataset, where each row corresponds to a single potential sample associated with a given DA–HQ concentration pair.

Example of Long-Format Voltammetric Dataset					
sample_id	**p_1 (μM)**	**p_2 (μM)**	**t**	**V (V)**	**I (A)**
0	25.0	50.0	0	-0.3000	1.66×10^{-7}
0	25.0	50.0	1	-0.2946	1.99×10^{-7}
0	25.0	50.0	2	-0.2892	2.42×10^{-7}
0	25.0	50.0	3	-0.2838	2.99×10^{-7}
0	25.0	50.0	4	-0.2784	3.70×10^{-7}
0	25.0	50.0	5	-0.2730	4.58×10^{-7}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
0	25.0	50.0	111	0.3000	8.05×10^{-6}

investigated to capture long-range signal relationships without the use of recurrent layers. In addition, residual and squeeze–excitation enhanced CNN variants were incorporated to improve feature propagation and channel-wise feature weighting. In several architectures, the HQ concentration parameter p_2 was incorporated through feature-wise linear modulation (FiLM), allowing the networks to adapt their internal feature representations according to the interfering species concentration. Finally, ensemble strategies were evaluated by combining the predictions of multiple models. These ensembles aggregate complementary representations learned by different architectural families and thereby yield more stable DA concentration estimation outcomes.

3. EXPERIMENTAL EVALUATION

3.1. Dataset Construction

The dataset used for DL experiments follows the same experimental acquisition protocol and synthetic data generation procedure described in the previous sections. However, the representation used for model training differs from that of the feature-based machine learning approach. Instead of constructing explicit peak-based feature vectors, the DL models operate directly on reconstructed voltammetric signals in the potential–current domain.

3.1.1. Real Electrochemical Data

ISBN NR: 978-625-5694-92-8

All experimental measurements were obtained using DPV under identical electrochemical conditions [1]. Voltammetric responses were systematically recorded for multiple DA and HQ concentration combinations. DA concentrations were set to 25, 50, 100, 250, and 500 µM. For each DA level, HQ concentrations were varied independently over a comparable range, resulting in 24 mixed DA–HQ measurements. In addition, a separate DA-only dataset consisting of five measurements at the same DA concentration levels was acquired to provide reference signals in the absence of HQ interference effects.

3.1.2. Interpolation and Synthetic Data Generation

Synthetic signals were generated to extend the coverage of the DA–HQ concentration space beyond the experimentally measured combinations. Each voltammetric signal was first represented using the Fourier8 model described in Section 2.2. Dominant peak parameters (μ, σ, h) were then extracted from the reconstructed signals. Synthetic samples were produced by performing two-dimensional interpolation in the peak parameter space across the DA and HQ concentration axes. Additional signal instances were generated for identical concentration pairs by introducing controlled perturbations in the peak parameters. These parameters were subsequently used to reconstruct synthetic voltammetric signals while preserving physically consistent peak morphology throughout.

3.1.3. Raw Signal Reconstruction for Deep Learning

In contrast to the feature-based machine learning framework, the DL models operate directly on reconstructed voltammetric waveforms. The synthetic signals generated from peak parameters were therefore converted back to the potential–current domain prior to model training. For each concentration pair (p_1, p_2), the signal was evaluated on a fixed potential grid spanning $[-0.3, 0.3]$ V with 112 uniformly spaced points. This procedure produces a consistent sequence of voltage–current samples representing the full voltammetric response of each mixture. The dataset is stored in long-format form, where each row corresponds to a single potential sample associated with a given mixture concentration. An excerpt of the dataset structure is shown in Table 9. These sequences are used directly as inputs to the DL models during training.

3.2. Evaluation Metrics

Model performance was evaluated using two common regression metrics: mean absolute error (MAE) and root mean square error (RMSE). These metrics measure the discrepancy between the predicted DA concentration $\hat{y}_i$ and the corresponding ground-truth value y_i over N test samples.

The mean absolute error is defined as:

$$\mathrm{MAE} = \frac{1}{N}\sum_{i=1}^{N}|y_i - \hat{y}_i| \,. \tag{5}$$

The root mean square error is defined as:

ISBN NR: 978-625-5694-92-8

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}\,. \tag{6}$$

Table 10. Performance comparison of deep learning architectures for dopamine concentration estimation. Models are grouped according to their architectural families, with accuracy reported in terms of RMSE and MAE.

Deep Learning Model Benchmark Results			
Family	**Model**	**RMSE**	**MAE**
MLP	MLP_RawSignal	57.884	41.638
	MLP_Baseline	78.022	57.663
	MLP_FeatureOnly	56.822	47.672
CNN	CNN_Original	60.663	45.743
	FastCNN	56.429	44.857
	ImprovedCNN_SE	54.399	37.414
	ResidualCNN_SE	59.303	45.220
	AttentionCNN	61.225	44.721
	DenseNet	57.390	40.476
	InceptionLite	59.629	43.128
	FastInception	57.256	46.433
RNN	BiLSTM	63.441	46.215
	GRU_Attn	53.368	36.976
Hybrid	CNN_LSTM_v2	64.131	47.458
	CNN_BiGRU_FiLM	**31.270**	**19.602**
Dilated CNN	WaveNet	57.780	40.470
	FastWaveNet	49.580	34.289
	FastWaveNet_Optimized	32.750	24.495
	WaveNetSE_FiLM	49.420	39.900
ResNet	StrongResidual	51.804	38.513
	FastResidual	51.669	39.216
	PreActResNet1D_FiLM	45.269	35.314
	ResNet1D_SE_FiLM	47.402	33.940
Transformer	TransformerLite	51.864	36.415
Ensemble	MeanEnsemble	47.117	33.473
	BestModelEnsemble	52.971	41.361

ISBN NR: 978-625-5694-92-8

HybridModelEnsemble	43.143	34.787
EnsembleFeatures	62.751	44.698

MAE reflects the average absolute prediction error, while RMSE penalizes larger deviations more strongly due to the squared error term. Together, these metrics provide complementary information about model accuracy and overall robustness.

3.3. Results and Discussion

The predictive performance of the investigated DL models is summarized in Table 10. The architectures are grouped according to their design families to facilitate comparison between different representation learning strategies. Model accuracy is reported using RMSE and MAE, where lower values indicate more accurate DA concentration estimation outcomes. The multilayer perceptron (MLP) models serve as baseline architectures. Because these networks process the input as a flat feature vector, they cannot explicitly exploit the sequential structure of voltammetric signals. Consequently, all MLP variants produce higher prediction errors compared with most sequence-based alternatives. CNNs demonstrate improved performance by learning local peak morphology directly from the voltammetric current sequence. Several CNN variants were evaluated, including ImprovedCNN_SE, DenseNet, and Inception-based models, which consistently reduce the prediction error relative to the MLP baseline models. Recurrent architectures were also investigated to model sequential dependencies along the potential axis. While the BiLSTM model yields relatively higher errors, the attention-based GRU_Attn model shows noticeable improvement, indicating that attention mechanisms help the network focus on informative regions of the electrochemical signal profile. The best overall performance is achieved by hybrid architectures that combine convolutional and recurrent components. In particular, the CNN_BiGRU_FiLM model obtains the lowest prediction error with an RMSE of 31.27 and an MAE of 19.60. In this architecture, convolutional layers capture local peak structures, while the bidirectional GRU models sequential dependencies across the full signal sequence. The FiLM mechanism additionally incorporates the HQ concentration parameter p_2, enabling the network to adapt its internal representations according to the interfering-species concentration. Dilated convolutional models based on WaveNet also achieve competitive predictive performance. The FastWaveNet_Optimized configuration produces an RMSE of 32.75, demonstrating that dilated convolutions can effectively capture long-range signal relationships without recurrent layers. Residual CNN architectures provide stable but moderate improvements, while the lightweight transformer model achieves reasonable accuracy but remains less effective than the best hybrid and dilated convolutional configurations. Finally, ensemble strategies were evaluated by combining predictions from multiple constituent models. Although some ensemble configurations produce competitive results, none surpass the CNN_BiGRU_FiLM architecture in terms of overall accuracy. Overall, the results indicate that architectures capable of jointly capturing local voltammetric peak morphology and broader sequence dependencies provide the most accurate DA concentration estimation outcomes.

4. CONCLUSION

This study presents a DL-based framework for DA quantification from DPV signals recorded in the presence of HQ as an interfering species. Unlike conventional machine learning approaches that rely on manually engineered features, the proposed method operates directly on reconstructed voltammetric sequences, allowing neural networks to learn in an autonomous manner informative representations of the electrochemical response. The framework combines Fourier-based signal modeling, interpolation-driven synthetic data generation, and Gaussian peak reconstruction to generate physically consistent voltammetric signals over a dense concentration space. A comprehensive experimental evaluation across multiple neural network architectures demonstrates that models capable of jointly capturing local peak morphology and sequential signal dependencies achieve the most accurate concentration predictions, with the CNN_BiGRU_FiLM architecture providing the best overall predictive performance. These results demonstrate that DL models trained on raw voltammetric signals can effectively recover analyte concentration information even under nonlinear interference conditions and complex signal distortions. Future work will extend the proposed framework to more complex electrochemical mixtures, including three-component systems, and explore the development of a web-based interface to enable interactive signal analysis and practical deployment of the proposed methodology.

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ISBN NR: 978-625-5694-92-8

A TWO-STAGE GRADIENT BOOSTING PIPELINE FOR VOLTAMMETRIC SIGNAL DECONVOLUTION AND DOPAMINE CONCENTRATION CLASSIFICATION IN TERNARY ELECTROCHEMICAL MIXTURES

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ABSTRACT

Dopamine (DA) quantification in biological samples is central to neuroscience research and clinical electroanalysis. Differential pulse voltammetry (DPV) offers a sensitive detection method, but overlapping oxidation peaks from ascorbic acid (AA) and uric acid (UA) complicate direct DA quantification from mixture signals. This paper proposes a two-stage machine learning pipeline comprising a gradient boosting regression stage for pure DA voltammogram reconstruction from mixture signals, followed by a gradient boosting classification stage for concentration prediction. To address limited experimental data, a Fourier-series representation combined with three-dimensional concentration-space interpolation is used to augment 22 experimental measurements into 1,314 synthetic mixture samples. The best-performing pipeline configuration achieves 89.73% end-to-end classification accuracy across four evaluated model pairs, without requiring prior knowledge of individual component concentrations, demonstrating the viability of data-driven deconvolution for automated electroanalytical quantification.

Keywords: Dopamine Detection, Peak Deconvolution, Differential Pulse Voltammetry, Machine Learning, Gradient Boosting, Fourier Series, Data Augmentation

1. INTRODUCTION

Dopamine (DA) is a neurotransmitter involved in motor control, reward processing, and cognitive function. Abnormal DA levels are associated with Parkinson's disease, schizophrenia, and attention deficit hyperactivity disorder [1,2], making accurate DA quantification important for both clinical diagnostics and neuroscience research.

Differential pulse voltammetry (DPV) is widely used for electrochemical detection due to its high sensitivity, fast response, and low cost [3,4]. However, in biological samples DA coexists with ascorbic acid (AA) and uric acid (UA), whose oxidation potentials overlap with that of DA [5]. This overlap makes selective quantification from raw voltammograms difficult [6].

ISBN NR: 978-625-5694-92-8

Chemometric methods such as partial least squares regression and principal component analysis [7] have been applied to this problem, but they typically assume linear signal–concentration relationships and require careful feature engineering. Deconvolution techniques [8,9] can separate overlapping peaks, yet they often rely on prior knowledge of system parameters. Machine learning provides a data-driven alternative [10], but many existing approaches either require known mixture concentrations during inference or are limited by small datasets.

This paper proposes a two-stage machine learning pipeline that predicts DA concentration from a mixture DPV signal without using concentration inputs. In Stage 1, a regression model estimates the pure DA signal from the mixture voltammogram (peak deconvolution). In Stage 2, a classifier maps the estimated DA signal to a concentration class. To overcome the limited number of experimental measurements, each signal is represented by a 10-harmonic Fourier series, and new training samples are generated by interpolating Fourier coefficients across the three-dimensional concentration space.

The main contributions are as follows: (i) a Gradient Boosting regression model that achieves $R^2 = 0.923$ for DA signal extraction using only the raw voltammogram, (ii) a Fourier-based augmentation scheme that produces 1,314 synthetic mixtures from 22 experimental measurements, (iii) a comparison of four model combinations showing that regression quality is the dominant factor in end-to-end accuracy, and (iv) an error analysis indicating that 80% of misclassifications fall within one concentration step (25 µM).

2. METHOD

2.1. Pipeline Overview

The pipeline takes a raw mixture DPV voltammogram (129 points, −0.207 to 0.497 V) as input and produces a predicted DA concentration in µM. In the first stage, a regression model maps the 129-point mixture signal to a 128-point pure DA signal estimate. In the second stage, a classifier assigns this estimate to one of 19 concentration classes (50–500 µM in 25 µM steps). Concentration values are not used as input features at any point, so the pipeline is applicable when only the measured voltammogram is available.

2.2. Data Collection

The dataset consists of 22 mixture DPV voltammograms containing AA, DA, and UA at concentrations ranging from 50–500 µM (AA), 50–500 µM (DA), and 50–250 µM (UA). Each mixture signal comprises 129 potential–current pairs. In addition, five reference voltammograms of pure DA solutions were measured at 25, 50, 100, 250, and 500 µM, each containing 128 potential–current pairs over a slightly different potential window (−0.300 to 0.398 V).

Table 11. Stage 1 regression performance

Model	R^2	RMSE ($\times 10^{-6}$)
Gradient Boosting	0.923	2.00
Random Forest	0.901	2.65

ISBN NR: 978-625-5694-92-8

2.3. Fourier Series Representation

Each DPV signal is fitted with a 10-harmonic Fourier series [11]

$$f(x) = a_0 + \sum_{n=1}^{10}[a_n \cos(n\omega x) + b_n \sin(n\omega x)] \quad (1)$$

where x is the potential normalized to [0, 1] and ω is the fundamental frequency. Together with a_0 and ω, the coefficients $a_1, \ldots, a_{10}$ and $b_1, \ldots, b_{10}$ yield 22 Fourier parameters. Four additional normalization constants ($x_{\min}$, $x_{\max}$, y_{mean}, y_{std}) are stored for reconstruction, giving 26 parameters per signal. The fitting achieves $R^2 > 0.999$ for all measured voltammograms.

2.4. Data Augmentation

For the mixture signals, a three-dimensional linear interpolator [12] (LinearNDInterpolator) maps concentration triplets (C_{AA}, C_{DA}, C_{UA}) to Fourier parameters. Sampling this interpolator on a regular grid with 25 µM spacing produces 1,314 valid synthetic mixture signals, covering approximately 60% of the full grid (limited by the convex hull of the original 22 measurements). For the pure DA reference signals, one-dimensional interpolation with extrapolation generates 20 signals at 25 µM steps across 25–500 µM, corresponding to 19 distinct concentration levels.

2.5. Stage 1: Regression

The regression stage maps a 129-point mixture signal to a 128-point DA signal estimate. Two ensemble models are compared. Gradient Boosting [13] (GB) uses 100 estimators with maximum depth 5 and learning rate 0.1; each tree corrects the residual errors of the preceding ensemble. Random Forest [14] (RF) uses 100 trees with maximum depth 20, trained independently on bootstrapped subsets and averaged at prediction time. The training set consists of 1,051 mixture–DA signal pairs (80% of 1,314), with the remaining 263 held out for testing. All DA concentration classes are represented in both splits.

2.6. Stage 2: Classification

The classification stage maps a 128-point DA signal to one of 19 concentration classes. The same two model families are evaluated: GB (100 estimators, depth 5, learning rate 0.1, log-loss) and RF (100 trees, depth 20, Gini criterion). Both classifiers are trained on ground-truth pure DA signals augmented with 2% Gaussian noise [15], yielding 50 samples per class (950 total). The noise augmentation is intended to improve robustness to the imperfect signal estimates produced by Stage 1 during inference.

Table 12. Stage 2 classification accuracy on ground-truth DA signals

Model	Accuracy (%)	Test samples
Gradient Boosting	100.0	190
Random Forest	88.5	190

3. EXPERIMENTAL RESULTS

All experiments were implemented in Python 3.13 using scikit-learn [16], NumPy [17], and SciPy [12]. The augmented dataset comprises 1,314 mixture signals split 80/20 for regression

ISBN NR: 978-625-5694-92-8

training and testing, and 950 DA classification samples similarly split into 760 training and 190 test samples. Performance is measured by R^2 and RMSE for regression, classification accuracy on ground-truth DA signals for the standalone classifier, and overall accuracy on all 1,314 mixtures for the end-to-end pipeline.

3.1. Stage 1 Results

Table 11 compares the two regression models. Gradient Boosting achieves $R^2 = 0.923$, outperforming Random Forest ($R^2 = 0.901$). The difference corresponds to a 22% reduction in residual variance ($1-R^2$), suggesting that the sequential error-correction strategy of boosting is better suited to this task than the averaging strategy of Random Forest.

3.2. Stage 2 Results

Table 12 reports classification accuracy on ground-truth DA signals, isolating the classifier from regression errors. Gradient Boosting achieves 100% accuracy on the 190 test samples, while Random Forest reaches 88.5%. This indicates that mapping a clean DA signal to a concentration class is relatively straightforward; the main difficulty lies in obtaining an accurate DA estimate in Stage 1. 3.3. End-to-End Performance

Table 13 reports the end-to-end accuracy for all four regression–classification combinations evaluated on all 1,314 mixture samples. The GB + GB combination achieves the highest accuracy at 89.73%, with two patterns standing out. First, the choice of regression model has a much larger effect than the choice of classifier: replacing GB regression with RF regression drops accuracy by approximately 14 percentage points regardless of the classifier, whereas replacing the GB classifier with RF changes accuracy by at most 1.4 percentage points. Second, the classifier difference is small when regression quality is high (1.37 pp with GB regression) and negligible when it is low (0.08 pp with RF regression). These results confirm that Stage 1 deconvolution quality is the primary bottleneck.

3.4. Error Analysis

In the best pipeline (GB + GB), 135 of 1,314 samples are misclassified. Approximately 80% of these errors are one-step deviations (25 µM), with a mean absolute error of 31.7 µM and a median of 25.0 µM among the misclassified samples. Errors are concentrated in mixtures with low AA concentration (50 µM) combined with high DA

Table 13. End-to-end pipeline accuracy (1,314 mixtures)

Regression + Classification	Accuracy (%)	Correct / Total
GB + GB	89.73	1,179 / 1,314
GB + RF	88.36	1,161 / 1,314
RF + GB	75.65	994 / 1,314
RF + RF	75.57	993 / 1,314

and UA, likely because a smaller AA peak provides less spectral separation between the DA and UA contributions. For AA ≥ 100 µM, accuracy typically exceeds 91%.

3.5. Computational Cost

The full pipeline trains in under two minutes on a standard laptop, with the Gradient Boosting regressor accounting for approximately ten seconds. After training, a single prediction takes less than ten milliseconds.

4. CONCLUSION

This paper presented a two-stage machine learning pipeline for dopamine concentration prediction from mixture DPV signals. The pipeline estimates the pure DA signal via gradient boosting regression ($R^2 = 0.923$) and classifies the concentration using a second Gradient Boosting model, achieving 89.73% end-to-end accuracy on 1,314 augmented mixture samples without requiring prior knowledge of mixture composition. A comparison of four model combinations showed that regression quality is the dominant factor in overall performance. Most misclassifications (80%) deviate by only one concentration step (25 µM), and errors concentrate in mixtures with low AA concentration.

The current approach has several limitations. The concentration range (50–500 µM) is narrow relative to physiological conditions, and the augmented dataset relies on interpolation within the convex hull of 22 experimental measurements. Robustness to electrode fouling, pH variations, and additional interferents has not been evaluated. Future work will address these limitations and explore deep learning architectures for improved signal deconvolution.

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ISBN NR: 978-625-5694-92-8

SYSTEMATIC EVALUATION OF DEEP LEARNING AND HYBRID PIPELINES FOR DOPAMINE SIGNAL DECONVOLUTION IN ELECTROCHEMICAL MIXTURE ANALYSIS

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ABSTRACT

Differential pulse voltammetry (DPV) enables sensitive electrochemical detection of dopamine (DA); however, co-existing interferents such as ascorbic acid (AA) and uric acid (UA) produce overlapping peaks that compromise accurate quantification. This study presents a systematic evaluation of a two-stage deep learning pipeline—comprising a regression stage for signal deconvolution followed by a classification stage for concentration prediction—applied to ternary DA/AA/UA mixtures. Thirty-six model combinations (six regression and six classification architectures) are benchmarked on 1,314 synthetic DPV mixture samples. For signal deconvolution, convolutional–recurrent hybrid networks achieve the highest accuracy (R^2=0.9839), outperforming gradient boosting baselines (R^2=0.9230). For end-to-end concentration prediction, a hybrid pipeline pairing deep learning regression with ensemble classification achieves the best overall accuracy (89.88%), outperforming both pure deep learning (87.52%) and pure machine learning (89.73%) configurations. Analysis reveals that deconvolution quality is the dominant performance bottleneck across all pipelines, and that hybrid architectures combining deep feature extraction with classical ensemble classifiers offer the most robust solution for automated electroanalytical quantification.

Keywords: Deep Learning, Neural Networks, Electrochemical Sensors, Signal Deconvolution, Dopamine Detection, Voltammetry, Hybrid Machine Learning

1. INTRODUCTION

Dopamine (DA, 3,4-dihydroxyphenethylamine) is a catecholamine neurotransmitter involved in motor control, reward-motivated behavior, and cognitive function [1]. Its dysregulation underlies neurological and psychiatric disorders including Parkinson's disease, schizophrenia, and addiction [2]. Accurate quantification of DA in biological samples is therefore important for both neuroscience research and clinical diagnostics. Electrochemical techniques, especially differential pulse voltammetry (DPV), are widely used for DA detection because they are sensitive, fast, and compatible with miniaturized sensors [3,4]. In practice, biological fluids also contain electroactive species that oxidize at similar potentials, most notably ascorbic acid (AA,

ISBN NR: 978-625-5694-92-8

vitamin C) and uric acid (UA). These interferents are typically present at concentrations 100–1000 times higher than DA [5]. As a result, the recorded voltammograms often include strongly overlapping peaks, which makes direct quantification from peak height or area unreliable [6]. The fundamental challenge in mixed voltammetric analysis can be formulated as a signal deconvolution problem. Let $y_{\mathrm{mix}}(V) \in \mathbb{R}^n$ represent the measured current response as a function of applied potential V, which can be approximated as:

$$\boldsymbol{y}_{\mathrm{mix}}(V) \approx f([\mathrm{AA}], [\mathrm{DA}], [\mathrm{UA}]; V) + \boldsymbol{\varepsilon} \quad (1)$$

where [AA], [DA], [UA] are analyte concentrations, $f(\cdot)$ denotes the (generally non-linear) electrochemical response, and ε captures measurement noise and baseline drift. The goal is to recover the dopamine contribution $y_{\mathrm{DA}}(V)$ and then estimate [DA] from the mixture measurement $y_{\mathrm{mix}}(V)$. Traditional strategies (e.g., standard addition, electrode surface modification, and classical chemometrics) can struggle when peaks overlap strongly. Machine learning has shown promise for voltammetric analysis [7], but many approaches still depend on hand-crafted features and may miss subtle patterns in raw electrochemical signals. Deep neural networks can learn features directly from raw data and approximate complex non-linear mappings [8]. Convolutional neural networks (CNNs) extract local patterns using learnable filters [9], recurrent models such as long short-term memory (LSTM) networks capture dependencies in sequences [10], and Transformers use self-attention to model long-range interactions without recurrence [11]. Combining convolutional and recurrent components often yields strong performance in time-series problems [12].

This work provides a systematic evaluation of deep learning architectures for dopamine quantification in multi-component electrochemical mixtures. Our main contributions are:

1. We evaluate 36 combinations of six regression models (four deep learning, two machine learning) and six classification models across 1,314 test samples.
2. We show that convolutional-LSTM hybrid networks achieve 6.6% higher regression performance (R^2=0.9839 vs 0.9230) than gradient boosting for signal deconvolution.
3. We find that optimal end-to-end performance (89.88%) is obtained through hybrid pipelines combining deep learning regression with ensemble classification, rather than pure deep learning or machine learning approaches.
4. We identify signal deconvolution quality as the primary performance bottleneck, with regression R^2 correlating more strongly with end-to-end accuracy than classification metrics.
5. We observe architecture–task specificity: CNN-LSTM networks excel at regression but underperform at classification, while Transformer architectures show the opposite pattern.

2. RELATED WORK

Electrochemical dopamine detection has been widely studied using voltammetric techniques such as cyclic voltammetry (CV), differential pulse voltammetry (DPV), and square wave voltammetry (SWV) [4,13]. To improve selectivity, many studies modify the electrode surface

ISBN NR: 978-625-5694-92-8

(e.g., with conducting polymers, metal nanoparticles, or carbon nanomaterials) to promote electrocatalysis and/or suppress interfering species [14,15]. Although effective in many cases, these strategies often require careful tuning and can suffer from limited reproducibility across electrodes and experiments [16].

Classical chemometric methods for resolving overlapping peaks include partial least squares (PLS) regression, principal component regression (PCR), and multivariate curve resolution (MCR) [17]. These approaches can work well when overlap is moderate, but their performance typically degrades for strongly mixed DA/AA/UA signals. Non-linear models (e.g., early artificial neural networks) have also been investigated [18]; however, comprehensive comparisons across modern deep learning architectures are still limited.

Recent work has applied machine learning models such as support vector machines (SVM), random forests [19], and gradient boosting [20] to electrochemical datasets [7,16]. In many cases, the input to these models is a set of hand-crafted features (e.g., peak position, height, area, and width). While this can produce good results, feature engineering requires domain expertise and may overlook information present in the full signal. In addition, much of the literature emphasizes classification (binary/ternary) rather than estimating concentrations quantitatively.

Deep learning has also been applied successfully in related spectroscopic areas, including Raman spectroscopy [21], mass spectrometry [22], and near-infrared spectroscopy [23]. CNNs can learn informative representations directly from raw spectra [9,24], and LSTMs [10] and Transformers [11] can model sequential structure in time-series measurements. In contrast, deep learning for voltammetric signal deconvolution has been explored less, and this work aims to help close that gap.

3. METHODOLOGY

3.1. Dataset Composition and Preparation

3.1.1. Experimental Data Acquisition

The dataset comprises differential pulse voltammetry measurements of synthetic ternary mixtures containing ascorbic acid, dopamine, and uric acid. Individual component signals were recorded using a standard three-electrode cell configuration with a glassy carbon working electrode [14], Ag/AgCl reference electrode, and platinum wire counter electrode in phosphate buffer saline (PBS, pH 7.4) [6]. Differential pulse voltammograms were acquired with the following parameters: pulse amplitude 50 mV, pulse width 50 ms, scan rate 20 mV/s, potential range −0.3 to 0.5 V [4].

Pure dopamine standards were measured at five concentrations (25, 50, 100, 250, and 500 µM). Twenty-two mixture samples were prepared with varying AA, DA, and UA concentrations in the range 50–500 µM. Interpolation in Fourier parameter space (Section 3.1.3) subsequently expanded these measurements to 19 DA concentration levels (50–500 µM in 25 µM steps) and 1,314 synthetic mixtures.

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3.1.2. Signal Representation

Each voltammogram is represented as a discrete signal vector. Mixture signals $x_{\text{mix}} \in \mathbb{R}^{129}$ span 129 potential points from −0.207 to 0.497 V, while pure DA signals $y_{\text{DA}} \in \mathbb{R}^{128}$ span 128 points from −0.300 to 0.398 V. This dimensional difference arises from the different potential windows required for optimal signal acquisition in mixture versus single-analyte measurements.

3.1.3. Data Augmentation

To address the limited availability of experimental measurements, we employ Fourier series interpolation for systematic data augmentation. Each voltammogram is fitted to a 10-harmonic Fourier series [25]:

$$\hat{y}(x) = a_0 + \sum_{k=1}^{10}[a_k \cos(kwx) + b_k \sin(kwx)] \tag{2}$$

where x represents normalized potential, w is the fundamental frequency, and $\{\{a_0, a_k, b_k\}\}_{k=1}^{10}$ are fitted coefficients. Signals are normalized to zero mean and unit variance prior to fitting to ensure numerical stability. This representation achieves $R^2 > 0.999$ for all measured voltammograms. Interpolation is performed in parameter space using LinearNDInterpolator [26] for mixture signals (3D interpolation across AA, DA, UA concentration space) and cubic spline interpolation for pure DA signals (1D interpolation across DA concentration). This procedure generates 1,314 synthetic mixture samples with corresponding pure DA signals at 19 concentration levels (50–500 µM, excluding 25 µM due to absence in mixture dataset).

For classification model training, we apply Gaussian noise augmentation to pure DA signals [27], generating 50 noisy replicates per concentration class:

$$\boldsymbol{y}_{\text{aug}}^{(i)} = \boldsymbol{y}_{\text{DA}} + \mathbb{N}\left(0,\, 0.02 \cdot \sigma_{\boldsymbol{y}}\right) \tag{3}$$

where σ_y denotes the standard deviation of the original signal. This yields 950 total samples (19 classes × 50 samples/class) for classification training and evaluation.

3.2. Two-Stage Analytical Pipeline

Our approach decomposes the analytical task into two sequential stages. In the first stage (signal regression), a model learns a mapping g: $\mathbb{R}^{129} \rightarrow \mathbb{R}^{128}$ that recovers the pure DA signal from a mixture voltammogram $x_{\text{mix}} \in \mathbb{R}^{129}$:

$$\hat{\boldsymbol{y}}_{\text{DA}} = g\left(\boldsymbol{x}_{\text{mix}};\, \boldsymbol{\theta}_g\right) \tag{4}$$

where θ_g represents model parameters optimized via mean squared error (MSE) minimization:

$$\mathcal{L}_{\text{reg}} = \frac{1}{N}\sum_{i=1}^{N}\left\|\boldsymbol{y}_{\text{DA}}^{(i)} - \hat{\boldsymbol{y}}_{\text{DA}}^{(i)}\right\|_2^2 \tag{5}$$

In the second stage (concentration classification), a model maps a DA signal $y_{\text{DA}} \in \mathbb{R}^{128}$ (either ground truth or regression-predicted) to one of 19 concentration classes:

$$\hat{c} = h(\boldsymbol{y}_{\text{DA}};\, \boldsymbol{\theta}_h) \tag{6}$$

where θ_h is optimized via cross-entropy loss:

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$$\mathcal{L}_{\text{cls}} = -\frac{1}{N}\sum_{i=1}^{N} \log p\left(c^{(i)} \mid \boldsymbol{y}_{\text{DA}}^{(i)};\, \boldsymbol{\theta}_h\right) \tag{7}$$

For end-to-end evaluation, we combine both stages as $\hat{c} = h(g(x_{\text{mix}}))$ and report classification accuracy on held-out mixture samples.

3.3. Deep Learning Architectures

We evaluate four neural network architectures for both regression and classification tasks. All models receive input signals normalized to zero mean and unit standard deviation via z-score transformation.

3.3.1. 1D Convolutional Network (CNN1D)

The CNN1D architecture employs three convolutional blocks for hierarchical feature extraction:

$$\begin{aligned} \boldsymbol{h}^{(1)} &= \text{ReLU}\big(\text{Conv1D}_{64}(\boldsymbol{x};\, k=5,\, s=2)\big) \\ \boldsymbol{h}^{(2)} &= \text{ReLU}\left(\text{Conv1D}_{128}\big(\boldsymbol{h}^{(1)};\, k=5,\, s=2\big)\right) \\ \boldsymbol{h}^{(3)} &= \text{ReLU}\left(\text{Conv1D}_{256}\big(\boldsymbol{h}^{(2)};\, k=5,\, s=2\big)\right) \end{aligned} \tag{8}$$

where Conv1D_c denotes 1D convolution with c output channels, kernel size k, and stride s. The feature maps are flattened and passed through fully connected layers:

$$\boldsymbol{z} = \text{Dropout}_{0.3}\left(\text{ReLU}\left(\boldsymbol{W}_1\, \text{Flatten}\big(\boldsymbol{h}^{(3)}\big)\right)\right) \tag{9}$$

For regression, the output layer produces $\hat{y} = W_2 z$. For classification, a softmax layer outputs class probabilities: $p(c|x) = \text{Softmax}(W_2 z)$.

3.3.2. Bidirectional LSTM (BiLSTM)

The BiLSTM architecture processes the input sequence in both forward and backward directions:

$$\begin{aligned} \overrightarrow{\boldsymbol{h}}_t &= \text{LSTM}_f\big(\boldsymbol{x}_t,\, \overrightarrow{\boldsymbol{h}}_{t-1}\big) \\ \overleftarrow{\boldsymbol{h}}_t &= \text{LSTM}_b\big(\boldsymbol{x}_t,\, \overleftarrow{\boldsymbol{h}}_{t+1}\big) \\ \boldsymbol{h}_t &= \big[\overrightarrow{\boldsymbol{h}}_t;\, \overleftarrow{\boldsymbol{h}}_t\big] \end{aligned} \tag{10}$$

where $[\cdot;\cdot]$ denotes concatenation. We employ two stacked BiLSTM layers with hidden dimension 128, followed by fully connected layers with dropout (p=0.3) for regularization. The final hidden state is used for prediction.

ISBN NR: 978-625-5694-92-8

Table 14. Regression Performance Comparison

Model	R^2	RMSE ($\times 10^{-6}$)	MAE ($\times 10^{-6}$)
CNN-LSTM Hybrid	0.9839	0.863	0.347
BiLSTM	0.9837	0.915	0.381
CNN1D	0.9724	1.156	0.489
Transformer	0.9531	1.574	0.654
Gradient Boosting	0.9230	2.000	–
Random Forest	0.9010	2.650	–

3.3.3. CNN-LSTM Hybrid

The hybrid architecture combines convolutional feature extraction with recurrent temporal modeling:

$$\begin{aligned} \boldsymbol{h}^{(c)} &= \mathrm{Conv1D}_{128}\left(\mathrm{Conv1D}_{64}(\boldsymbol{x})\right) \\ \boldsymbol{h}^{(r)} &= \mathrm{BiLSTM}_{64}\left(\boldsymbol{h}^{(c)}\right) \end{aligned} \tag{11}$$

This architecture leverages CNNs for local feature extraction and LSTMs for capturing long-range dependencies in the feature sequence.

3.3.4. Transformer

The Transformer model employs multi-head self-attention without recurrence:

$$\mathrm{Attention}(\boldsymbol{Q}, \boldsymbol{K}, \boldsymbol{V}) = \mathrm{softmax}\left(\frac{\boldsymbol{Q}\boldsymbol{K}^T}{\sqrt{d_k}}\right)\boldsymbol{V} \tag{12}$$

where Q, K, V are query, key, and value matrices derived from input embeddings via learned projections. Our implementation uses 4 attention heads, embedding dimension 256, 4 encoder layers, and feedforward dimension 1024. Positional encoding is added to input embeddings to incorporate sequence order information.

3.4. Machine Learning Baselines

We compare the deep learning architectures against two ensemble learning methods. Random Forest (RF) [19] trains 100 independent decision trees (maximum depth 20, minimum samples per leaf 2, Gini criterion) on bootstrapped subsets and averages their predictions. Gradient Boosting (GB) [20] builds 100 trees sequentially, with each tree correcting the residual errors of the preceding ensemble (learning rate 0.1, maximum depth 5, least-squares loss for regression, log-loss for classification). Both methods operate on the raw signal vectors without explicit feature engineering.

3.5. Training Procedure

All deep learning models are optimized with Adam [28] using an initial learning rate of 0.001 (0.0005 for Transformers), reduced by a factor of 0.5 when the validation loss plateaus for 10 consecutive epochs. Regularization consists of dropout [29] (p = 0.2–0.4 depending on the layer), weight decay $\lambda = 10^{-5}$, and early stopping with patience of 20 epochs.

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Table 15. Classification Accuracy on Ground Truth DA Signals

Model	Accuracy (%)	Test Samples
Transformer	100.0	190
Gradient Boosting	100.0	190
BiLSTM	94.7	190
Random Forest	88.5	190
CNN1D	87.9	190
CNN-LSTM Hybrid	71.1	190

Models are trained for up to 100 epochs with batch size 32 on an 80/20 stratified train–test split. Input signals are z-score normalized using statistics computed from the training set. All random seeds are fixed for reproducibility.

3.5. Training Procedure

All deep learning models are optimized with Adam [28] using an initial learning rate of 0.001 (0.0005 for Transformers), reduced by a factor of 0.5 when the validation loss plateaus for 10 consecutive epochs. Regularization consists of dropout [29] (p = 0.2–0.4 depending on the layer), weight decay $\lambda = 10^{-5}$, and early stopping with patience of 20 epochs. Models are trained for up to 100 epochs with batch size 32 on an 80/20 stratified train–test split. Input signals are z-score normalized using statistics computed from the training set. All random seeds are fixed for reproducibility.

3.6. Evaluation Metrics

Regression performance is measured by the coefficient of determination (R^2), root mean squared error (RMSE), and mean absolute error (MAE). Classification performance is assessed by accuracy, precision, recall, and F1-score. We report classifier accuracy both on ground truth DA signals (to isolate the classifier from regression errors) and on end-to-end mixture samples (to capture error propagation through both stages).

4. EXPERIMENTAL RESULTS

4.1. Regression Performance: Mixture to DA Signal Deconvolution

Table **11** presents regression metrics for all evaluated models. Deep learning architectures demonstrate superior performance compared to machine learning baselines, with the CNN-LSTM Hybrid achieving the highest coefficient of determination (R^2=0.9839).

The CNN–LSTM hybrid achieves a 6.6% higher R^2 than the best machine learning baseline (gradient boosting), which corresponds to a 57% reduction in unexplained variance. A likely reason is that the model can capture both local signal patterns (via CNN layers) and longer-range dependencies (via LSTM layers) directly from the raw voltammograms, without manual feature design.

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Table 16. DL Regression + ML Classification

Regression + Classification	Accuracy (%)	Correct/Total
CNN-LSTM + Random Forest	89.88	1181/1314
CNN-LSTM + Gradient Boosting	89.42	1175/1314
BiLSTM + Random Forest	86.91	1142/1314
BiLSTM + Gradient Boosting	86.07	1131/1314
CNN1D + Gradient Boosting	81.96	1077/1314
CNN1D + Random Forest	81.74	1074/1314
Transformer + Gradient Boosting	72.45	952/1314
Transformer + Random Forest	71.61	941/1314

Table 17. ML Regression + ML Classification

Regression + Classification	Acc. (%)	Correct/Total
GB + GB	89.73	1179/1314
GB + RF	88.36	1161/1314
RF + GB	75.65	994/1314
RF + RF	75.57	993/1314

The Transformer achieves perfect classification on ground truth signals (Section 4.2) but yields the weakest regression performance (R^2=0.9531). This indicates that, under the available data size, self-attention may be more effective for sequence classification than for dense, point-wise signal regression.

4.2. Classification Performance: DA Signal to Concentration

Table **12** reports classification accuracy evaluated on ground truth pure DA signals (i.e., without using regression outputs). This isolates the classifier performance from regression errors. Both the Transformer model and the gradient boosting classifier achieve perfect classification (100% accuracy) on pure DA signals. This suggests that, once the DA component is isolated, mapping the signal to a concentration class is relatively straightforward. In contrast, the CNN–LSTM hybrid performs poorly as a classifier (71.1%) despite its strong regression performance, pointing to an architecture–task mismatch that is discussed in Section 5.

4.3. End-to-End Performance: Comprehensive Model Combination Analysis

We evaluated all 36 combinations obtained by pairing six regression models with six classification models. Table **13**–Table **19** summarize the end-to-end results by model family. The best end-to-end accuracy (89.88%) is obtained by combining deep learning regression (CNN–LSTM) with machine learning classification (random forest), exceeding the best pure DL pipeline (87.52%) by 2.36 percentage points and slightly surpassing the best pure ML

ISBN NR: 978-625-5694-92-8

pipeline (89.73%). Notably, the top eight combinations all employ deep learning for regression, confirming that deconvolution accuracy is the primary bottleneck.

Table 20 summarizes the best-performing combination within each of the four category types.

Table 18. DL Regression + DL Classification (Pure DL)

Regression + Classification	Accuracy (%)	Correct/Total
CNN-LSTM + Transformer	87.52	1150/1314
CNN-LSTM + BiLSTM	86.91	1142/1314
BiLSTM + Transformer	85.01	1117/1314
CNN1D + Transformer	79.98	1051/1314
BiLSTM + BiLSTM	79.15	1040/1314
CNN-LSTM + CNN1D	78.46	1031/1314
BiLSTM + CNN1D	74.66	981/1314
CNN1D + BiLSTM	74.51	979/1314
CNN1D + CNN1D	72.91	958/1314
Transformer + BiLSTM	67.73	890/1314
Transformer + Transformer	66.44	873/1314
Transformer + CNN1D	65.68	863/1314
CNN-LSTM + CNN-LSTM	58.52	769/1314
BiLSTM + CNN-LSTM	57.69	758/1314
CNN1D + CNN-LSTM	52.13	685/1314
Transformer + CNN-LSTM	47.11	619/1314

Table 19. ML Regression + DL Classification

Regression + Classification	Accuracy (%)	Correct/Total
GB + Transformer	87.29	1147/1314
GB + BiLSTM	86.15	1132/1314
RF + Transformer	74.81	983/1314
RF + BiLSTM	72.53	953/1314
GB + CNN1D	68.72	903/1314
RF + CNN1D	63.70	837/1314
GB + CNN-LSTM	54.72	719/1314
RF + CNN-LSTM	49.77	654/1314

ISBN NR: 978-625-5694-92-8

The best end-to-end accuracy (89.88%) is obtained by combining deep learning regression (CNN–LSTM) with machine learning classification (random forest), exceeding the best pure DL pipeline (87.52%) by 2.36 percentage points and slightly surpassing the best pure ML pipeline (89.73%). Notably, the top eight combinations all employ deep learning for regression, confirming that deconvolution accuracy is the primary bottleneck.

Table 20. Optimal Performance by Category

Category	Best Model	Accuracy (%)
DL Reg + ML Class	CNN-LSTM + RF	89.88
ML Reg + ML Class	GB + GB	89.73
DL Reg + DL Class	CNN-LSTM + Transformer	87.52
ML Reg + DL Class	GB + Transformer	87.29

A clear architecture–task mismatch emerges from the results: the CNN–LSTM hybrid yields the best regression (R^2 = 0.9839) but performs poorly as a classifier (best end-to-end with CNN–LSTM classifier: 58.52%), whereas the Transformer achieves perfect classification (100%) but relatively weak regression (R^2=0.9531). Furthermore, pure DL combinations underperform hybrid pipelines despite perfect classification on ground truth signals (Transformer: 100%), suggesting that ensemble classifiers are more robust to imperfect regression outputs than neural classifiers in this setting.

4.4. Error Analysis

In the best-performing pipeline (CNN–LSTM + RF, 89.88%), 133 of the 1,314 test samples are misclassified. Approximately 80% of these errors are single-step deviations (±25 µM), with a mean absolute concentration error of 28.9 µM and a maximum of 125 µM (fewer than 5% of errors). Misclassifications are concentrated in mixtures with low AA concentration (50 µM) combined with high DA and UA, where the reduced spectral separation between analyte peaks makes deconvolution more difficult. Figure **12** presents a multi-panel visualization comparing machine learning and deep learning performance across regression, classification, and end-to-end metrics.

5. DISCUSSION

5.1. Why Hybrid DL–ML Outperforms Pure Approaches

Deep learning achieves superior regression (R^2=0.9839 vs 0.9230, +6.6%), likely because CNN layers extract local peak shape features while LSTM layers capture how the signal evolves across potential, enabling more accurate point-wise reconstruction. However, the best end-to-end system (89.88%) combines DL regression with ML classification, outperforming pure DL (87.52%). This likely reflects a train–test mismatch: classifiers are trained on clean (ground truth) DA signals but must operate on imperfect regression outputs at test time. Ensemble methods (random forest and gradient boosting) appear more tolerant to this shift than neural classifiers, especially with limited classification data (950 samples). The architecture–task

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mismatch is also clear: CNN–LSTM achieves R^2=0.9839 for regression but only 71.1% classification accuracy, whereas the Transformer shows the reverse trend (R^2=0.9531 and 100% classification). This suggests that architectures well-suited for dense reconstruction are not necessarily optimal for discrete classification when data are limited.

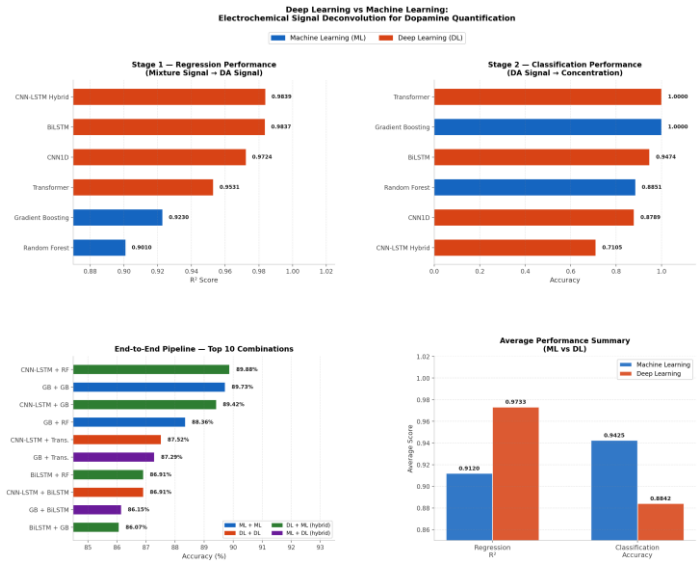

Figure 12. Comparative performance analysis of machine learning and deep learning approaches across (a) regression R^2, (b) classification accuracy on ground truth, (c) average performance by model type, and (d) best models per category. Deep learning demonstrates clear superiority in regression tasks while machine learning maintains competitive overall performance through robust classification

Regression quality remains the primary bottleneck, as improving deconvolution is more impactful than further tuning classification: all top-eight systems use deep learning regression.

5.2. Limitations and Future Work

Our synthetic dataset (1,314 samples generated via Fourier interpolation) may not capture all electrochemical non-linearities. In addition, we only consider DA/AA/UA mixtures, whereas biological samples may contain additional interferents. Future work should validate the pipeline on larger experimental datasets, investigate transfer learning for small-data regimes, and incorporate uncertainty quantification for practical use.

6. WEB APPLICATION

To make the pipeline accessible to researchers without machine learning expertise, we developed a web application that implements all 36 model combinations evaluated in this study. The application is publicly available at peakdeconvolution.com.

The system uses a Next.js frontend with a Firebase Cloud Functions backend. All 16 trained models (12 PyTorch and 4 scikit-learn) are deployed as serverless functions, achieving response times of 2–4 seconds for deep learning models and sub-second latency for the machine learning baselines. Users can select from the 22 experimental mixture presets (Figure 13), upload custom voltammetric data in CSV format (Figure 14), or specify concentrations manually to generate

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synthetic inputs. Regression and classification models can be selected independently (Figure 15), allowing users to explore any of the 36 combinations and compare their outputs. The interface displays the predicted DA concentration, error metrics (when the true concentration is known), and interactive plots of both the input mixture signal and the extracted DA signal (Figure 16).

Figure 13. Preset mixture selection interface with 22 experimental samples organized into five difficulty categories. Each card displays the constituent AA, DA, and UA concentrations

Figure 14. Custom signal upload interface supporting CSV/TXT files. Uploaded signals are automatically interpolated to 129 points to match model input requirements

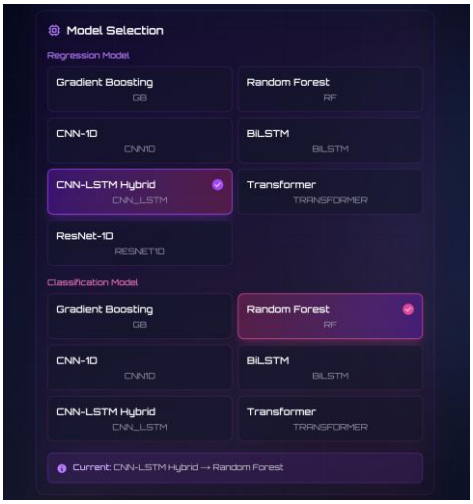

Figure 15. Model selection interface with separate panels for regression and classification architectures. The example shows the optimal configuration (CNN-LSTM Hybrid regression + Random Forest classification)

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Figure 16. Results panel showing predicted DA concentration, error metrics, input mixture composition, and interactive voltammograms of the mixture signal and extracted DA signal

7. CONCLUSION

This study benchmarked 36 model combinations for automated dopamine quantification from ternary DPV mixtures. The CNN–LSTM hybrid provided the best signal deconvolution (R^2 = 0.9839), and the highest end-to-end accuracy (89.88%) was achieved by combining this deep learning regressor with a random forest classifier. Regression quality proved to be the primary performance bottleneck, and the results indicate that matching the model architecture to each pipeline stage is more effective than applying a single paradigm throughout.

Based on these findings, we recommend CNN–LSTM regression paired with random forest classification for practical deployment, as implemented in our web application at peakdeconvolution.com.

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ISBN NR: 978-625-5694-92-8

MACHINE-LEARNING-BASED PEAK DECONVOLUTION FOR DOPAMINE AND HYDROQUINONE QUANTIFICATION IN DIFFERENTIAL PULSE VOLTAMMETRY

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ABSTRACT

Simultaneous electrochemical detection of dopamine (DA) and hydroquinone (HQ) via differential pulse voltammetry (DPV) is challenging due to overlapping oxidation peaks that compromise selective quantification. This study addresses the problem through three complementary approaches. First, a residual convolutional neural network trained on synthetic voltammograms with realistic analyte response interactions achieves $R^2 = 0.987$ for DA and $R^2 = 0.951$ for HQ concentration prediction. Second, feature-based classification using support vector machines on experimental data yields validation accuracies of 83.3% for DA and 72.7% for HQ, with the lower HQ accuracy reflecting greater ambiguity near its oxidation potential. Third, a transfer learning framework trains ensemble regressors on CNN-augmented synthetic voltammograms and evaluates on real experimental measurements, achieving $R^2 > 0.95$ for both compounds. The proposed methods perform consistently in the 25–500 µM range, with a moderate accuracy reduction at 25 µM, demonstrating the viability of data-driven peak deconvolution for selective binary mixture electroanalysis.

Keywords: Dopamine, Hydroquinone, Peak Deconvolution, Differential Pulse Voltammetry, Machine Learning, Transfer Learning, Support Vector Machines

1. INTRODUCTION

Voltammetric techniques are essential for the detection of electroactive substances in complex samples. The electrochemical techniques utilized in this study involve measuring the current in relation to the applied voltage, which produces distinct peaks that are indicative of the oxidation or reduction reactions of particular analytes. The position and height of these peaks provide both qualitative and quantitative information about the substances present in a sample [1,2].

Dopamine is an important neurotransmitter in the brain [3], while hydroquinone is widely used in industrial and pharmaceutical applications and has been identified as an environmental contaminant in aquatic systems [4]. Electrochemical detection is possible for both substances, although their oxidation peaks occur around the similar potential. Therefore, electrochemical detection of dopamine and hydroquinone is challenging since their oxidation peaks overlap [5,6].

ISBN NR: 978-625-5694-92-8

Traditional approaches rely on curve fitting techniques, such as Gaussian or Lorentzian models, to separate overlapping peaks. These methods require prior assumptions about peak shapes, baseline functions, and the number of underlying components. When peaks overlap severely, manual deconvolution becomes unreliable and subjective. Machine learning provides an alternative by learning patterns directly from experimental data without assuming specific parametric forms [7]. This study investigated peak deconvolution using two strategies. First, synthetic voltammograms were generated that include realistic effects like competitive adsorption and peak shifts. This provided enough data to train deep neural networks and test whether they could learn to separate the peaks. Second, real DA-HQ mixtures were measured at five concentrations (25, 50, 100, 250, and 500 µM) using screen-printed carbon electrodes. Features were extracted from these measurements and used to train classifiers. The goal was to determine if machine learning could automate peak deconvolution without manual curve fitting [8].

2. EXPERIMENTAL SETUP

2.1. Materials and Electrode Preparation

We used analytical-grade dopamine hydrochloride and hydroquinone dissolved in 0.1 M phosphate-buffered saline (PBS, pH 7.4). Screen-printed carbon electrodes (SPCEs) with Ag/AgCl reference were modified by drop-casting carbon ink to improve conductivity [9]. The modified electrodes were dried at room temperature before use. Stock solutions (1 mM) were prepared and diluted to working concentrations of 25, 50, 100, 250, and 500 µM. Both individual compounds and all possible mixture combinations were measured at these concentrations. This gave us 24 mixture samples plus individual reference measurements.

2.2. Voltammetric Measurements

DPV measurements were performed from −0.6 V to +0.6 V using a potentiostat controlled by NOVA software. Each concentration was measured in triplicate. The raw voltammograms showed the expected overlapping peaks around 0.2 V for DA and slightly lower for HQ, confirming the deconvolution challenge we aimed to address. Figure **12** presents representative DPV measurements from our DA-HQ mixture experiments. The overlapping nature of the electrochemical peaks is evident, particularly in the potential region around 0.1–0.3 V where both compounds oxidize. These experimental observations motivated our machine learning approach, as traditional peak-fitting methods would struggle with such severely overlapped signals.

3. METHODS

3.1. Synthetic Dataset Generation

Overfitting would make it difficult to train a deep neural network with just 24 experimental examples. Therefore, we used mathematical peak models to create a synthetic dataset of 100 mixture voltammograms.

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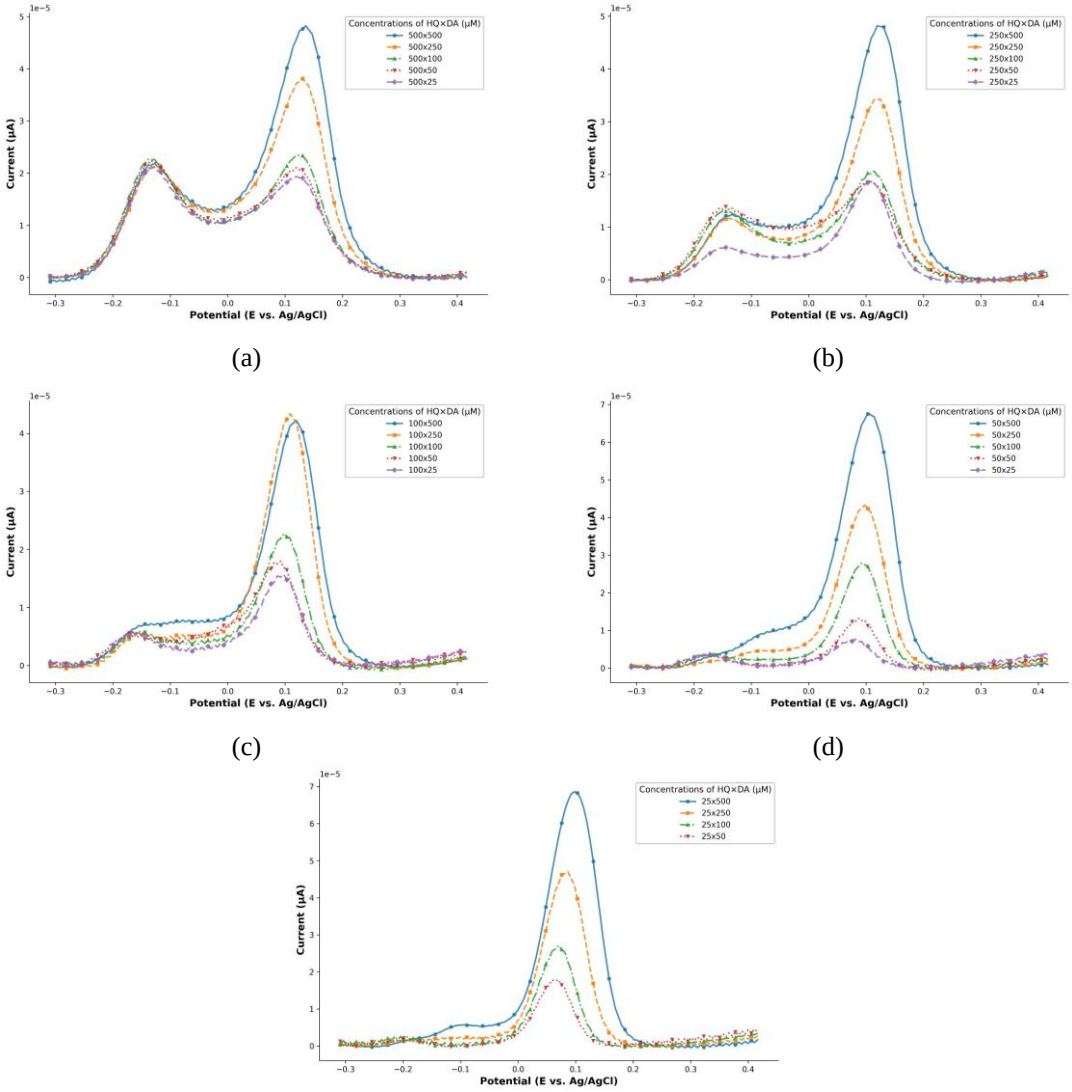

(a) (b) (c) (d) (e)

Figure 17. Experimental DPV voltammograms of DA-HQ mixtures at different concentration combinations, demonstrating the overlapping peak challenge

The goal was to apply nonlinear effects found in actual electrochemistry to better reflect real electrochemical conditions.

3.1.1. Peak Shape Modeling

Individual voltammetric peaks were generated using mathematical models. For dopamine, a Gaussian function was used:

$$I_{\text{Gaussian}}(E) = A \cdot \exp\left(-\frac{(E - E_p)^2}{2\sigma^2}\right) \quad (1)$$

where A is the peak amplitude, E_p is the peak potential, and σ is the peak width parameter. For hydroquinone, an Exponentially Modified Gaussian (EMG) function was employed to capture asymmetric peak shapes:

$$I_{\text{EMG}}(E) = A \cdot \frac{\lambda}{2} \exp\left(\frac{\lambda}{2}(2\mu + \lambda\sigma^2 - 2E)\right) \operatorname{erfc}\left(\frac{\mu + \lambda\sigma^2 - E}{\sqrt{2}\sigma}\right) \quad (2)$$

ISBN NR: 978-625-5694-92-8

where μ is the peak center, λ is the exponential decay parameter, and erfc is the complementary error function.

3.1.2. Nonlinear Interaction Effects

The synthetic signals were not generated by simple linear addition. Four nonlinear effects were modeled to make the synthetic data more representative of real electrochemical interactions.

First, competitive adsorption was modeled using Michaelis–Menten kinetics with competitive inhibition:

$$A_{\mathrm{DA}} = \frac{A_{0,\mathrm{DA}} \cdot V_{\mathrm{max,DA}} \cdot \frac{C_{\mathrm{DA}}}{K_{\mathrm{m,DA}} + C_{\mathrm{DA}}}}{1 + K_{\mathrm{HQ}} \cdot C_{\mathrm{HQ}} + K_{\mathrm{DA}} \cdot C_{\mathrm{DA}}} \tag{3}$$

where V_{max} and K_{m} are Michaelis–Menten parameters and K_{HQ}, K_{DA} are competitive adsorption constants. Second, peak positions shift in the presence of the other compound:

$$E_{\mathrm{p,DA}} = E^0_{\mathrm{p,DA}} + \alpha \cdot C_{\mathrm{HQ}}, \quad E_{\mathrm{p,HQ}} = E^0_{\mathrm{p,HQ}} + \alpha \cdot C_{\mathrm{DA}} \tag{4}$$

where α = 0.015 V is the shift parameter. Third, peak widths increase in mixtures:

$$\sigma_{\mathrm{DA}} = \sigma^0_{\mathrm{DA}} \cdot \left(1 + \beta \cdot C_{\mathrm{HQ}}\right), \quad \sigma_{\mathrm{HQ}} = \sigma^0_{\mathrm{HQ}} \cdot (1 + \beta \cdot C_{\mathrm{DA}}) \tag{5}$$

where β = 0.25 is the broadening parameter.

Fourth, a catalytic interaction term captures electrochemical cross-talk between the two analytes:

$$I_{\mathrm{interaction}} = k_{\mathrm{inter}} \cdot \frac{I_{\mathrm{DA}} \cdot I_{\mathrm{HQ}}}{\max(I_{\mathrm{DA}}) \cdot \max(I_{\mathrm{HQ}})} \tag{6}$$

where k_{inter} = 0.06. The final mixture signal is the sum of the individual contributions and the interaction term:

$$I_{\mathrm{mixture}} = I_{\mathrm{DA}} + I_{\mathrm{HQ}} + I_{\mathrm{interaction}} \tag{7}$$

Together, these effects ensure that the mixture signal differs from the simple sum of individual signals, ensuring that the mixture signal cannot be separated by simple linear superposition.

3.2. Neural Network Regression on Synthetic Data

As a baseline, 18 hand-crafted features (peak positions, heights, widths, areas, and regional statistics) were extracted from each synthetic voltammogram and used to train a feedforward neural network with two hidden layers. This model achieved R^2 = 0.96 for DA and R^2 = 0.81 for HQ on the test set (20 samples), with mean errors of approximately 5–6%.

To avoid manual feature extraction, a residual convolutional neural network (ResNet) [10,11] was trained directly on the raw 1000-point voltammograms. Residual connections enabled training of a deeper architecture, yielding R^2 = 0.987 for DA and R^2 = 0.951 for HQ. Training converged after 141 epochs with early stopping (approximately 47 seconds). The ResNet outperformed the feature-based model for both compounds, with an improvement of 17 percentage points for HQ, suggesting that the convolutional filters capture patterns in the raw signal that hand-crafted features do not represent.

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3.3. Feature Engineering for Experimental Data

For the real experimental data, the problem was formulated as classification rather than regression: given a mixture voltammogram, assign each component to one of five concentration levels (25, 50, 100, 250, and 500 µM). An initial feature set of 38 descriptors (basic statistics, peak characteristics, and regional analysis) was evaluated using the MATLAB Classification Learner. The resulting HQ classification accuracy of 59% indicated that these features did not capture sufficient information to separate the overlapping peaks. The feature set was therefore expanded to 113 descriptors by incorporating percentile-based statistics (Q25, Q75, IQR), a third peak in the analysis, peak widths measured at full, half, and quarter height, eight narrow potential windows instead of three, gradient-based features (first and second derivatives), and shape descriptors (RMS, crest factor). This finer-grained representation provided more detail about how the peaks overlap and interact.

4. RESULTS AND DISCUSSION

4.1. Classification Performance

For dopamine, a cubic SVM [12] achieved 83.3% validation accuracy using all 113 features. The 500 µM class was identified correctly in all cases, while lower concentrations exhibited minor errors, mostly between adjacent levels. Reducing the feature set to 30 via feature selection preserved the same 83.3% accuracy, indicating that a large proportion of the original 113 features were redundant. For hydroquinone, classification proved more difficult. Linear discriminant analysis reached 63.6% accuracy with the full feature set. Feature selection to 50 descriptors improved accuracy to 72.7%, suggesting that the full set contained noisy features that degraded generalization. High concentrations (250 and 500 µM) were classified nearly perfectly for both compounds. The main difficulty was at 25 µM, particularly for HQ, where all samples were misclassified as higher concentrations. At this level the peaks are small relative to the noise floor, with 100% false negative rate for HQ at 25 µM, while higher concentrations achieve 75–100% true positive rate.

4.2. Analysis and Interpretation

DA is easier to classify than HQ (83% vs. 73% accuracy), likely because DA produces larger and sharper peaks with a higher signal-to-noise ratio. The HQ response may also be more susceptible to surface fouling effects in mixtures.

Feature design had a substantial impact on performance. For HQ, accuracy increased from 59% (38 features) to 64% (113 features) and further to 73% after feature selection. The most informative descriptors were the eight-window regional analysis and peak widths measured at multiple heights, which captured subtle shape differences that the initial feature set did not represent.

The poor performance at 25 µM remains a limitation. At this concentration, the signal amplitude is comparable to instrumental noise, making reliable classification difficult. More sensitive electrode materials or ensemble methods designed for low-concentration regimes may help address this in future work.

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For the experimental dataset (24 samples), feature-based classifiers outperformed the neural network models, which require larger training sets to generalize effectively. Feature-based models also offer greater interpretability, since the contribution of individual features can be inspected, and lower computational cost at inference.

5. TRANSFER LEARNING VIA ML-GENERATED SYNTHETIC DATA

5.1. Motivation and Approach

The feature-based classification approach described in Section 3 achieved 83.3% accuracy for DA and 72.7% for HQ. However, this required extensive manual feature engineering (113 features) and was limited by the small dataset size (24 mixture samples). We reasoned that a data-driven approach could eliminate manual feature design and potentially improve performance if sufficient training data were available.

To overcome this data scarcity, a two-stage transfer learning framework was developed [13]. In the first stage, a machine learning model is trained on the 24 real mixture signals to learn the relationship between individual DA and HQ signals and their mixture, and this model is then used to generate 1000 synthetic mixture voltammograms with known concentrations. In the second stage, regression models are trained on the synthetic samples to predict DA and HQ concentrations from mixture signals and validated on the original 24 real measurements.

5.2. ML-Based Synthetic Data Generation

We formulated synthetic data generation as a regression problem. For each voltage point in a mixture voltammogram, we predict the current based on:

$$I_{\text{mixture}}(V) = f\big(I_{\text{DA}}(V), I_{\text{HQ}}(V), C_{\text{DA}}, C_{\text{HQ}}, V\big) \tag{8}$$

where f is a machine learning model, I_{DA} and I_{HQ} are the individual component currents at the target concentrations, and C_{DA}, C_{HQ} are the concentrations.

Among the regression algorithms evaluated, gradient boosting [14] achieved the best performance (R^2 = 0.985 on 5-fold cross-validation), trained on 5,232 data points (24 mixtures × 218 voltage points).

Using this model, 1000 synthetic mixture voltammograms were generated by sampling DA and HQ concentrations uniformly from 25–500 µM, obtaining individual reference signals via linear interpolation from experimental data, and predicting the mixture current at each voltage point. No artificial noise was added to preserve signal quality.

Table 21. Performance of ML regression models on 24 real DA-HQ mixtures. All models were trained on 800 synthetic samples

Model	DA MAE (µM)	*DA* R^2	HQ MAE (µM)	*HQ* R^2
Random Forest	27.4	0.957	30.7	0.951
Gradient Boosting	59.0	0.891	28.8	0.973
Neural Network	42.3	0.946	61.0	0.880

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The resulting synthetic dataset covers the concentration space continuously, unlike the real dataset, which contains only five discrete levels.

5.3. Regression Models for Peak Deconvolution

Three regression models were trained on 800 synthetic samples, validated on 200 synthetic samples, and tested on all 24 real measurements. Each model predicts DA and HQ concentrations simultaneously from the raw 127-point voltammogram. A random forest regressor [15] (200 trees, maximum depth 20) provided the most balanced performance (training $R^2 = 0.998$, validation $R^2 = 0.994$). A gradient boosting regressor [14] (200 estimators, learning rate 0.05), wrapped with MultiOutputRegressor for joint DA/HQ prediction, performed best for HQ. A multilayer perceptron with three hidden layers (256–128–64 neurons), Adam optimizer [16], ReLU activation, and early stopping after 500 iterations served as the neural network baseline. All models were implemented in scikit-learn [17] and used z-score normalization on input features.

5.4. Results on Real Data

Table **11** summarizes the performance of all three models on the 24 real mixture measurements. The Random Forest model achieved the best overall performance with $R^2 > 0.95$ for both compounds. Figure **13** shows scatter plots of predicted vs. true concentrations for all three models. The Random Forest predictions cluster tightly around the ideal diagonal line, with only minor deviations at the lowest concentration (25 µM).

5.5. Comparison with Feature-Based Classification

The transfer learning approach offers several advantages over the feature-based classification method described in Section 3. It provides continuous concentration estimates ($R^2 = 0.957$ for DA) rather than discrete class labels (83.3% accuracy), operates directly on the raw 127-point voltammograms without requiring 113 hand-crafted features, and benefits from training on 1000 synthetic samples instead of 24 real measurements. Models trained entirely on synthetic data achieved $R^2 > 0.95$ on real measurements, confirming the quality of the ML-generated data. The main limitation shared by both approaches is poor performance at 25 µM, although the regression models provide quantitative uncertainty estimates (MAE ≈ 30 µM) that allow assessment of prediction confidence.

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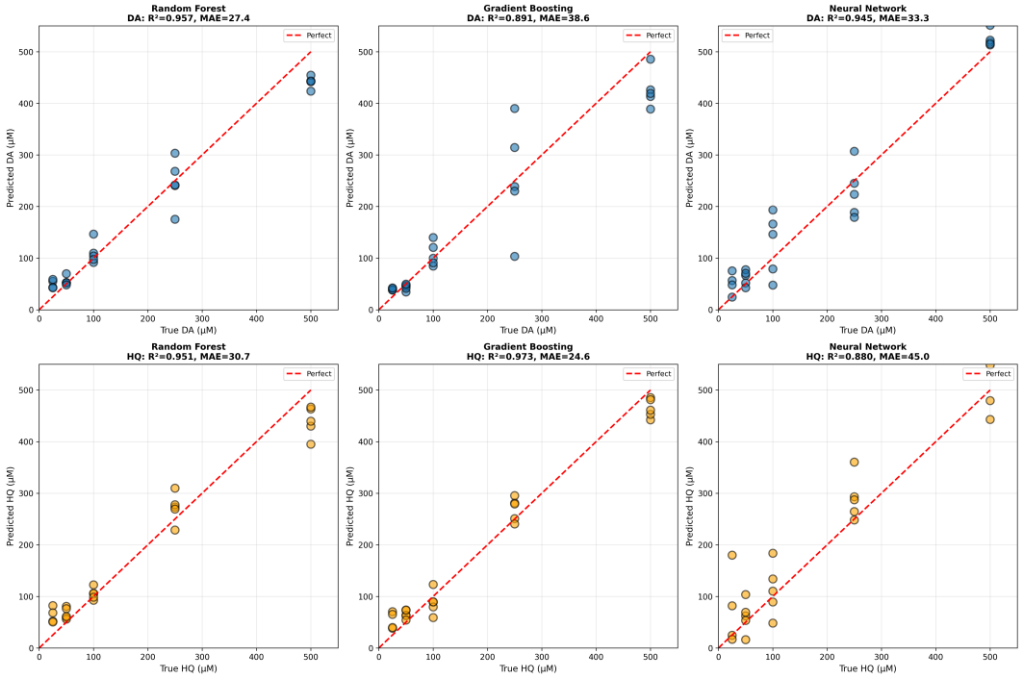

Figure 18. Predicted vs. true concentrations for DA (left) and HQ (right) using three regression models. Random Forest (top) shows the best agreement with ideal predictions (dashed line)

5.6. Discussion

The results indicate that machine learning models can learn the nonlinear relationship between individual DA and HQ signals and their mixtures. The gradient boosting model (R^2 = 0.985) captured competitive adsorption, peak shifts, and other electrochemical interactions without explicit mathematical modeling of these effects. The success of the transfer learning approach—training on synthetic data and testing on real measurements—suggests that the ML-generated voltammograms reproduce the relevant statistical properties of real data. This strategy may be valuable for electrochemical systems where large labeled datasets are difficult or expensive to obtain. Future work could extend the framework to lower concentrations (<25 μM) by incorporating noise models, or to more complex multi-component mixtures beyond binary DA–HQ systems.

6. CONCLUSION

This study demonstrated that machine learning can separate overlapping DA and HQ peaks in differential pulse voltammetry through two complementary approaches. Feature-based classification with support vector machines achieved 83% accuracy for DA and 73% for HQ on experimental data. A transfer learning framework, in which ensemble regressors were trained on ML-generated synthetic voltammograms and validated on real measurements, achieved R^2 > 0.95 for both compounds without manual feature engineering. Both approaches perform reliably in the 25–500 μM concentration range, with reduced accuracy at the lowest tested level (25 μM).

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ISBN NR: 978-625-5694-92-8

MULTI-TASK 3D CT REPORT GENERATION WITH ORGAN-DISEASE AWARE FUSION AND STATE SPACE ENCODERS

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ABSTRACT

Automated radiology report generation from three-dimensional chest computed tomography volumes requires models capable of capturing long-range spatial dependencies while preserving anatomical context. Recent studies explore volumetric report generation with large architectures, yet there is limited analysis of how decoder design influences joint disease classification and report generation under a shared encoder representation. This study investigates a framework that combines a partially frozen state space model encoder with multiple decoders for chest CT analysis. The framework incorporates organ–disease aware feature fusion, organ-group token shuffling, and graded diagnostic text prompts to guide disease-conditioned report generation, together with disease-specific heatmaps for visual attribution. A controlled comparison of decoder configurations under identical encoder settings highlights differences between diagnostic prediction and report generation performance. The findings support modular encoder–decoder designs based on state space model representations for efficient and anatomically informed CT report generation.

Keywords: Medical report generation, 3D computed tomography, state space models, multi-task learning, decoder benchmark, explainable AI.

5. INTRODUCTION

Computed tomography (CT) remains a significant imaging modality in clinical practice, contributing to a steady increase in the volume of data that requires interpretation by radiologists. A single chest CT examination consists of numerous slices covering multiple anatomical regions, often containing several co-existing abnormalities. This increasing workload, combined with a relatively limited expansion of the radiologist workforce, has introduced challenges related to reporting efficiency and consistency [1]. As a result, automated systems that can assist in generating preliminary reports and highlighting clinically relevant

ISBN NR: 978-625-5694-92-8

findings have gained significant attention.

Recent developments in deep learning and vision-language modeling have enabled automated analysis of 3D medical images with promising performance. Early approaches such as CT2Rep [2] utilized transformer-based decoders with relational memory to generate reports from volumetric data. Subsequent studies have explored disease-aware mechanisms and anatomical guidance to improve clinical relevance. For example, Dia-LLaMA [3] incorporated disease-conditioned attention, while CT-GRAPH [4] introduced hierarchical anatomical representations. Region-focused approaches, including MedRegion-CT [5] and Reg2RG [6], emphasized localized feature extraction to improve interpretability. More recent frameworks such as 3D-CT-GPT [7] and CT-AGRG [8] have further advanced report generation quality by integrating large language models.

In parallel, vision-language foundation models have expanded the scope of medical image understanding. Models such as Merlin [11], RadFM [12], and MedVista3D [10] demonstrate strong capabilities across detection, classification, and report generation tasks. Despite these advances, their high computational requirements limit practical deployment in many clinical settings. This has increased interest in more efficient architectures that can balance performance and resource usage. Another approach involves state space models (SSMs), which provide an alternative to transformer-based architectures. The Mamba framework [15] introduces linear complexity while maintaining the ability to model long-range dependencies. Variants such as SegMamba [16] and U-Mamba [17] have demonstrated effectiveness in medical image segmentation. Building on these developments, the Y-Mamba architecture enables simultaneous organ segmentation and disease detection within a unified framework, offering structured visual representations that can be leveraged for downstream tasks. Despite the progress in automated CT report generation, several limitations remain. Many existing approaches rely on large-scale models with high computational demands, making them less suitable for routine clinical deployment. In addition, explicit connections between generated text and corresponding spatial evidence in the input volume are often limited, which affects interpretability. Furthermore, the influence of decoder design and pre-training strategies on multi-task performance has not been systematically examined under controlled conditions.

This study introduces a multi-task framework for 3D chest CT analysis that combines a partially frozen Y-Mamba encoder with lightweight, interchangeable decoders for disease classification and report generation. The proposed approach integrates organ and disease representations through a dedicated fusion mechanism and incorporates diagnostic text conditioning to improve generation quality. In addition, a controlled experimental setup is designed to analyze the impact of different decoder architectures under a shared encoder configuration. Through this design, the study aims to provide a resource-efficient and clinically relevant solution for automated CT report generation while offering insights into architectural choices for future research.

The remainder of this paper is organized as follows. Section 2 describes the proposed framework. Section 3 presents experimental setup and results. Section 4 discusses findings and their implications. Section 5 provides concluding remarks.

ISBN NR: 978-625-5694-92-8

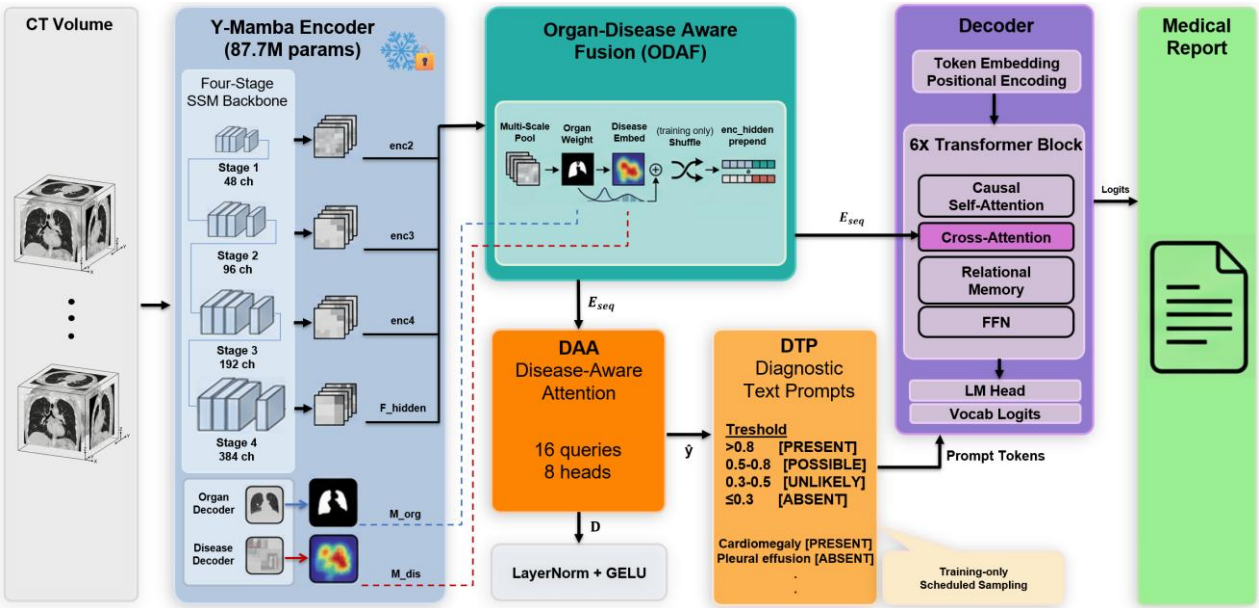

Figure 19: Overview of the framework

6. METHOD

The framework processes a 3D CT volume through a pre-trained Y-Mamba encoder to extract multi-scale visual features, organ segmentation masks, and disease anomaly maps. These representations are fused via the Organ-Disease Aware Fusion (ODAF) module into a spatially-aware sequence that serves as cross-attention context for a trainable decoder. A Disease-Aware Attention (DAA) head performs multi-label classification, whose outputs condition report generation through diagnostic text prompts. The decoder generates the medical report autoregressively with cross-attention to the fused visual features. The complete pipeline is illustrated in Figure 19.

6.1. Y-Mamba Encoder

The proposed framework uses a pre-trained Y-Mamba encoder with a Y-shaped hierarchical structure designed for joint organ segmentation and disease detection from 3D chest CT data. The encoder is based on the Mamba state space model [15] and processes volumetric features efficiently while capturing long-range dependencies. The architecture includes a four-stage backbone composed of Gated Spatial Convolution (GSC) blocks and Mamba layers. Multi-scale feature representations are extracted from input volumes of size (1, 64, 128, 128), with progressively increasing channel dimensions. Two parallel decoder branches generate organ segmentation masks and disease anomaly maps, while a compact bottleneck representation is obtained at the deepest level. The encoder is initially kept frozen to preserve its pre-trained representations. At later stages of training, selective unfreezing is applied to higher-level layers and the disease-related decoder branch using a reduced learning rate, while earlier layers remain fixed. This strategy allows adaptation of high-level features without disrupting low-level spatial information. Due to numerical stability requirements, the encoder operates in full precision during training, while the remaining components use mixed precision.

ISBN NR: 978-625-5694-92-8

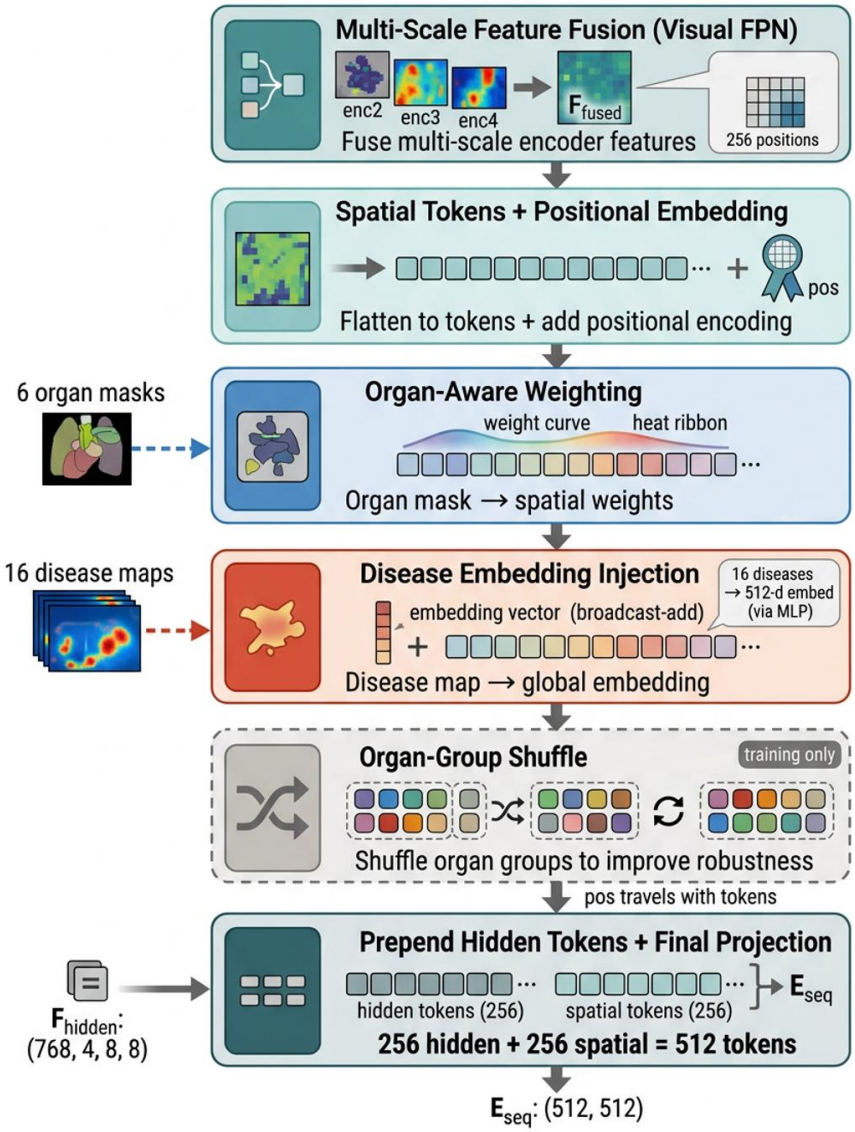

Figure 20: Detailed data flow of the ODAF module

6.2. Organ-Disease Aware Fusion and Organ-Group Shuffle

The ODAF module transforms encoder features into a decoder-compatible sequence through six steps, illustrated in Figure 20.

Multi-scale feature fusion: An FPN-style module combines features from encoder stages 2–4 via adaptive average pooling to the deepest spatial resolution, concatenation, and 1×1×1 convolution with residual connection.

Spatial flattening and positional embedding: The fused features are reshaped to a sequence, and learnable positional embeddings are added to preserve spatial information.

Organ-aware weighting: Organ masks are downsampled via adaptive average pooling to match the fused spatial resolution. For each spatial position i, the organ importance weight is computed as:

$$w_i = \mathrm{Softmax}_i\left(\frac{1}{6}\sum_{k=1}^{6}\widehat{M}_{\mathrm{org}}^{(k,i)}\right) \quad (1)$$

ISBN NR: 978-625-5694-92-8

where the softmax is taken over spatial positions. The weight w_i is a scalar that upweights tokens at positions with high overall organ activation, regardless of organ identity. Features are modulated with a residual connection:

$$\boldsymbol{s}'_i = s_i \cdot (1 + w_i) \tag{2}$$

Disease embedding: A disease presence vector is computed from disease anomaly maps by applying a global spatial max-pool over all voxels followed by sigmoid activation: $p = \sigma(\max_{d,h,w} M_{dis}^{(c,d,h,w)}) \in [0,1]^{16}$, yielding a per-disease soft presence indicator. This vector is encoded through a two-layer MLP and broadcast-added to all spatial tokens:

$$\boldsymbol{s}''_i = \boldsymbol{s}'_i + \mathrm{MLP}(\boldsymbol{p}) \tag{3}$$

Organ-group shuffle (training only): Spatial tokens are assigned to their dominant organ based on argmax of downsampled organ masks. Within each training batch, organ groups are randomly permuted, creating a shuffled token ordering. This mechanism prevents the decoder from memorizing fixed spatial positions, acting as feature-level data augmentation. Positional embeddings are added before the shuffle step; consequently, when tokens are permuted, their positional information travels with the feature vectors. This preserves each token's spatial identity while breaking the global token ordering seen by the decoder, forcing cross-attention to rely on feature content rather than fixed positional patterns.

Hidden feature integration and projection: The encoder bottleneck $\mathbf{F}_{hidden}$ is flattened, projected to the decoder dimension, and prepended to the spatial sequence. A final linear projection with layer normalization maps the features to the decoder embedding space where the 512-token sequence comprises 256 tokens from the bottleneck and 256 from the fused spatial features.

6.3. Disease-Aware Attention and Diagnostic Text Prompts

Disease-Aware Attention (DAA): The DAA module, adapted from the disease-aware attention paradigm introduced by Dia-LLaMA [3], replaces global average pooling with a learnable attention mechanism for multi-label classification. Sixteen learnable disease query vectors $Q \in \mathbb{R}^{16\times512}$ attend to the encoder sequence via multi-head cross-attention with 8 heads:

$$D = \mathrm{Softmax}\left(\frac{Q\,E_{\mathrm{seq}}^{\top}}{\sqrt{d_k}}\right) E_{\mathrm{seq}} \tag{4}$$

The resulting disease features pass through a three-layer classifier (512 → 256 → 1 with LayerNorm, GELU, and Dropout) to produce per-disease probabilities $\hat{y} \in [0,1]^{16}$.

Diagnostic Text Prompts (DTP): Disease predictions are converted to a natural language prompt prepended to the decoder input. We employ a four-level grading system providing finer-grained conditioning than binary signals:

$$\mathrm{status}(p_d) = \begin{cases} [\mathrm{PRESENT}] & \text{if } p_d > 0.8 \\ [\mathrm{POSSIBLE}] & \text{if } 0.5 < p_d \le 0.8 \\ [\mathrm{UNLIKELY}] & \text{if } 0.3 < p_d \le 0.5 \\ [\mathrm{ABSENT}] & \text{if } p_d \le 0.3 \end{cases} \tag{5}$$

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The prompt takes the form "Cardiomegaly [PRESENT]. Pericardial effusion [ABSENT]. …" and is tokenized (maximum 80 tokens) and prepended to the decoder input. Thresholds were selected to provide approximately balanced bin populations based on the validation set prediction distribution; sensitivity analysis across alternative threshold configurations is left to future work.

During training, scheduled sampling with teacher forcing ratio $r(t) = \max(0.75, 1.0 - (t - t_w) \cdot \gamma)$ gradually transitions from ground-truth labels to predicted probabilities, where t is the current epoch, $t_w = 3$ is the warmup length (matching the generation-only warmup phase), and $\gamma = 0.02$ is the decay rate. The 0.75 floor ensures that the decoder always receives ground-truth DTP labels for at least 75% of training samples, preventing the accumulation of cascading errors from early-training classification inaccuracies.

6.4. Decoder Architectures

To isolate the effect of decoder choice from encoder variation, we define a standardized encoder-decoder interface: each decoder receives the same fused encoder sequence $E_{seq} \in \mathbb{R}^{512\times512}$ via cross-attention and produces autoregressive token predictions. The GPT-2 Custom decoder uses byte-pair encoding (BPE) with a vocabulary of 50,257 tokens, while the BiomedBERT decoder uses WordPiece tokenization with 28,895 tokens. Reports are tokenized with the decoder's native tokenizer, with a maximum sequence length of 300 tokens. We evaluate two decoder configurations:

GPT-2 Custom (512-dim, 6 layers, 8 heads): a lightweight causal decoder based on the GPT-2 architecture [21], trained from scratch. Each of the 6 transformer blocks contains causal self-attention, cross-attention to the encoder sequence, and a feed-forward network with 4× expansion. The decoder includes a relational memory module, adapted from memory-augmented approaches in CT2Rep [2]. Unlike the original CT2Rep implementation, which uses content-based addressing with a multi-head relational memory update rule, our implementation employs a simpler gated cross-attention mechanism with a fixed memory bank of 64 learnable slots per block:

$$g = \sigma\big(W_g[h;\ \mathrm{Attn}(h, M)]\big), \quad h' = h + g \odot \mathrm{Attn}(h, M) \tag{6}$$

where h is the decoder hidden state, $M \in \mathbb{R}^{64\times512}$ is the learnable memory bank, and g is a learned gate.

BiomedBERT Causal (768-dim, 12 layers, 12 heads): a BERT architecture initialized from BiomedBERT [22] and repurposed as a causal language model through three modifications: (i) causal (lower-triangular) attention masking, (ii) 12 cross-attention adapter modules injected between self-attention and feed-forward blocks, and (iii) a new language modeling head. The masked language modeling head is discarded and replaced with a new linear projection to vocabulary logits. Token-type embeddings are set to a single segment type (type 0). The [CLS] token is not used; generation begins from a [BOS] token mapped to BiomedBERT's [CLS] embedding. Word and position embeddings are initialized from BiomedBERT, providing a biomedical language prior.

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6.5. Training Methodology

Multi-task loss: The training objective combines classification and generation losses:

$$\mathcal{L} = \lambda_{\text{cls}} \cdot \mathcal{L}_{\text{cls}} + \lambda_{\text{gen}} \cdot \mathcal{L}_{\text{gen}} + \lambda_{\text{align}} \cdot \mathcal{L}_{\text{align}} \tag{7}$$

where $\mathscr{L}_{\text{cls}}$ is frequency-weighted binary cross-entropy over 16 diseases:

$$\mathcal{L}_{\text{cls}} = -\frac{1}{C}\sum_{c=1}^{C} \alpha_c [y_c \log(\hat{y}_c) + (1 - y_c) \log(1 - \hat{y}_c)] \tag{8}$$

with per-disease positive class weights $\alpha_c = \min((1 - f_c)/f_c, 5.0)$ where f_c is the training set prevalence for disease c, and negative class weight 1.0. $\mathscr{L}_{\text{gen}}$ is cross-entropy with label smoothing ($\varepsilon = 0.1$) over the vocabulary. The alignment loss $\mathscr{L}_{\text{align}}$ encourages spatial agreement between cross-attention weights and disease-specific activations. Specifically, the aggregate cross-attention distribution $\bar{a}$ (averaged over layers and heads, normalized to sum to one) is compared to the normalized disease activation map $\bar{d}$ (weighted by ground-truth disease presence) via mean squared error:

$$\mathcal{L}_{\text{align}} = \frac{1}{N}\sum_{i=1}^{N} \left(\bar{a}_i - \bar{d}_i\right)^2 \tag{9}$$

where $N = 512$ is the number of spatial tokens and both distributions are ℓ_1-normalized. This loss is activated only in the fine-tuning phase (epoch 23+) with $\lambda_{\text{align}} = 0.1$.

Training curriculum: We employ a three-phase schedule: (i) *warmup* (epochs 0–2): generation loss only ($\lambda_{\text{cls}} = 0$, $\lambda_{\text{gen}} = 1$), DTP disabled; (ii) *joint* (epochs 3–22): full multi-task loss (λ_{cls} ramped from 0.3 to 0.5, $\lambda_{\text{gen}} = 1$) with DTP scheduled sampling; (iii) *fine-tune* (epochs 23+): alignment loss activated ($\lambda_{\text{align}} = 0.1$) with optional selective encoder unfreezing at reduced learning rate (2×10^{-6}).

Visual attribution: The framework generates per-disease spatial heatmaps from the Y-Mamba disease decoder, providing visual evidence for detected pathologies. These heatmaps highlight volumetric regions contributing to each disease prediction.

7. EXPERIMENTS

7.1. Dataset

We evaluate on RadGenome-ChestCT [19], a large-scale dataset of 3D chest CT volumes paired with structured region-level reports. After filtering for complete annotations (CT volume, organ masks, disease labels, and report text), the dataset comprises 25,687 CT volumes, split into 24,123 training and 1,564 validation volumes. Each volume is annotated with region-level reports covering six anatomical organs and labeled for 16 thoracic diseases derived from the CT-RATE annotation layer [18]. The CT-RATE layer defines 18 binary labels; we exclude *medical material* and *fracture* as they represent incidental findings outside the scope of chest CT disease reporting, yielding 16 target diseases. No separate held-out test set is used; all reported metrics are computed on the validation split, which is also used for model selection. This may introduce optimistic bias, and results should be interpreted accordingly.

The 16 target diseases span six organ groups: *Lung* (8 diseases: emphysema, atelectasis, lung nodule, lung opacity, pulmonary fibrotic sequela, mosaic attenuation pattern, consolidation,

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interlobular septal thickening), *Heart* (3: cardiomegaly, pericardial effusion, coronary artery wall calcification), *Pleura* (1: pleural effusion), *Mediastinum* (1: lymphadenopathy), *Esophagus* (1: hiatal hernia), and *Trachea & Bronchi* (2: peribronchial thickening, bronchiectasis). Note that peribronchial thickening and bronchiectasis are clinically associated with the tracheobronchial tree but are computationally mapped to the lung organ mask in the disease-organ assignment, as the segmentation model captures these pathologies within the lung parenchyma. The dataset exhibits class imbalance, with prevalence rates ranging from 7.1% (pericardial effusion) to 45.5% (lung nodule). Volumes are resampled to (64, 128, 128) voxels to match the Y-Mamba encoder's expected input resolution. Reports have an average reference length of approximately 195 tokens.

Preprocessing: CT volumes are resampled to (64, 128, 128) voxels via trilinear interpolation. Organ masks are resampled using nearest-neighbor interpolation to preserve label integrity. The Y-Mamba encoder applies Hounsfield Unit (HU) windowing with center −600 and width 1500 (effective range [−1350, 150] HU), capturing lung parenchyma and mediastinal soft tissue. Intensity values are normalized to [0, 1] within the HU window. No data augmentation is applied, as the encoder was pre-trained with its own augmentation pipeline.

7.2. Evaluation Metrics

Classification: We report macro-averaged AUROC across 16 diseases, along with F1 score, precision, and recall.

Generation: We evaluate BLEU-4 [23] for *n*-gram precision, METEOR [24] for synonym-aware similarity, and ROUGE-L [25] for recall-oriented overlap with reference reports. Multi-label classification metrics (F1, precision, recall) are computed at a fixed threshold of 0.5 for all diseases. AUROC is threshold-independent.

All metrics are reported from the single checkpoint that achieves the best validation AUROC during training, ensuring that all values correspond to a single deployable model configuration. Classification metrics (AUROC, F1) are computed on the full validation set at every evaluation cycle (every 2 epochs), while generation metrics (BLEU-4, METEOR, ROUGE-L) are computed on a fixed 50-sample subset at the best-AUROC checkpoint. Early stopping monitors validation loss with a patience of 24 training epochs. The "Train" column in Table 22 reports the maximum number of trainable parameters (including those schedulable for unfreezing), not the count at any specific epoch.

Table 22: Multi-decoder benchmark on RadGenome-ChestCT

Decoder	Params (Tot./Train)	AUROC	F1	BLEU-4	METEOR	ROUGE-L
GPT-2 Custom	178M/152M	**0.680**	**0.194**	0.139	0.318	0.256
BiomedBERT Causal	253M/227M	0.665	0.188	**0.168**	**0.348**	**0.296**

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7.3. Implementation Details

All experiments use 2× NVIDIA RTX A6000 GPUs (48 GB each) with DataParallel distribution, PyTorch 2.6+, and CUDA 12.8. Automatic mixed precision (AMP) with GradScaler is employed. We use the AdamW optimizer [27] with a base learning rate of 5×10^{-5} for trainable parameters and 2×10^{-6} for unfrozen encoder components, with weight decay 0.01 (encoder: 0.05). The CosineAnnealingLR scheduler [28] decays the learning rate to 1×10^{-6}. Gradient clipping is applied at norm 1.0. Batch sizes are decoder-dependent and optimized for dual-GPU memory: 48 for GPT-2 Custom (∼6 GB VRAM per GPU), 24 for BiomedBERT Causal (∼16 GB per GPU with gradient checkpointing). Training halts via early stopping when the validation loss does not improve for 12 consecutive evaluation cycles (every 2 epochs, effectively 24 epochs of patience). Generation metrics in Table 22 are computed on a fixed subset of 50 validation samples (first 50 in deterministic order, seed 42) at the best-AUROC checkpoint for each decoder. During-training monitoring uses the same subset every 3 epochs. The deterministic ordering ensures comparability across decoders. Generation uses beam search (width 4, length penalty 1.0). All experiments use random seed 42.

7.4. Implementation Details

Table 22 presents the controlled decoder comparison. All configurations share the same Y-Mamba encoder (with identical selective unfreezing schedule), ODAF fusion, DAA classification head, and DTP mechanism, differing only in decoder architecture and capacity. The GPT-2 Custom decoder achieves the best classification (AUROC 0.680) while requiring ∼2.7× less GPU memory than the BiomedBERT Causal decoder (∼6 GB vs. ∼16 GB per GPU). The BiomedBERT Causal decoder achieves the strongest generation quality across all text metrics (BLEU-4 0.168, METEOR 0.348, ROUGE-L 0.296) and generates reports of near-reference length (190.4 vs. 195.2 reference tokens). Both decoders produce reports close to reference length: GPT-2 Custom generates 187.3 tokens (96% of reference) and BiomedBERT Causal generates 190.4 tokens (97%).

7.5. Per-Disease Analysis

Table 23 presents per-disease AUROC values for the GPT-2 Custom decoder configuration, organized by anatomical organ group. Performance varies substantially across diseases, correlating with morphological distinctiveness and prevalence.

Table 23: Per-disease AUROC for the GPT-2 Custom decoder

Organ Group	Disease	AUROC	Prev. (%)
Lung	Emphysema	0.642	19.4
	Atelectasis	0.610	25.6
	Lung nodule	0.599	45.5
	Lung opacity	0.567	36.7
	Pulm. fibrotic sequela	0.632	26.7
	Mosaic att. pattern	0.693	7.4

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	Consolidation	0.637	17.6
	Interlob. septal thick.	0.739	7.9
	Lung mean	*0.640*	—
Heart	Cardiomegaly	0.827	10.7
	Pericardial effusion	0.723	7.1
	Coronary art. calc.	0.782	24.8
	Heart mean	*0.777*	—
Pleura	Pleural effusion	0.843	11.9
Mediastinum	Lymphadenopathy	0.696	25.3
Esophagus	Hiatal hernia	0.619	14.2
Trachea & Bronchi	Peribronchial thick.	0.606	10.3
	Bronchiectasis	0.667	10.0
	Trachea & Bronchi mean	*0.637*	—
Average		**0.680**	—

Diseases with clear morphological CT signatures achieve the highest classification accuracy: pleural effusion (AUROC 0.843), cardiomegaly (0.827), and coronary artery wall calcification (0.782). Conditions presenting with diffuse or subtle imaging features are more challenging: lung opacity (0.567), lung nodule (0.599), and peribronchial thickening (0.606). The relatively low AUROC for lung nodule, despite its high prevalence (45.5%), may reflect the difficulty of detecting small focal lesions at the reduced resolution of 64 × 128 × 128. Interlobular septal thickening (0.739) achieves relatively high AUROC despite low prevalence (7.9%), suggesting that its distinctive linear pattern is well-captured by the SSM encoder. Figure 21 visualizes the per-disease AUROC distribution alongside prevalence rates. Table 24 traces the evolution of the framework across training configurations, revealing the contribution of each component.

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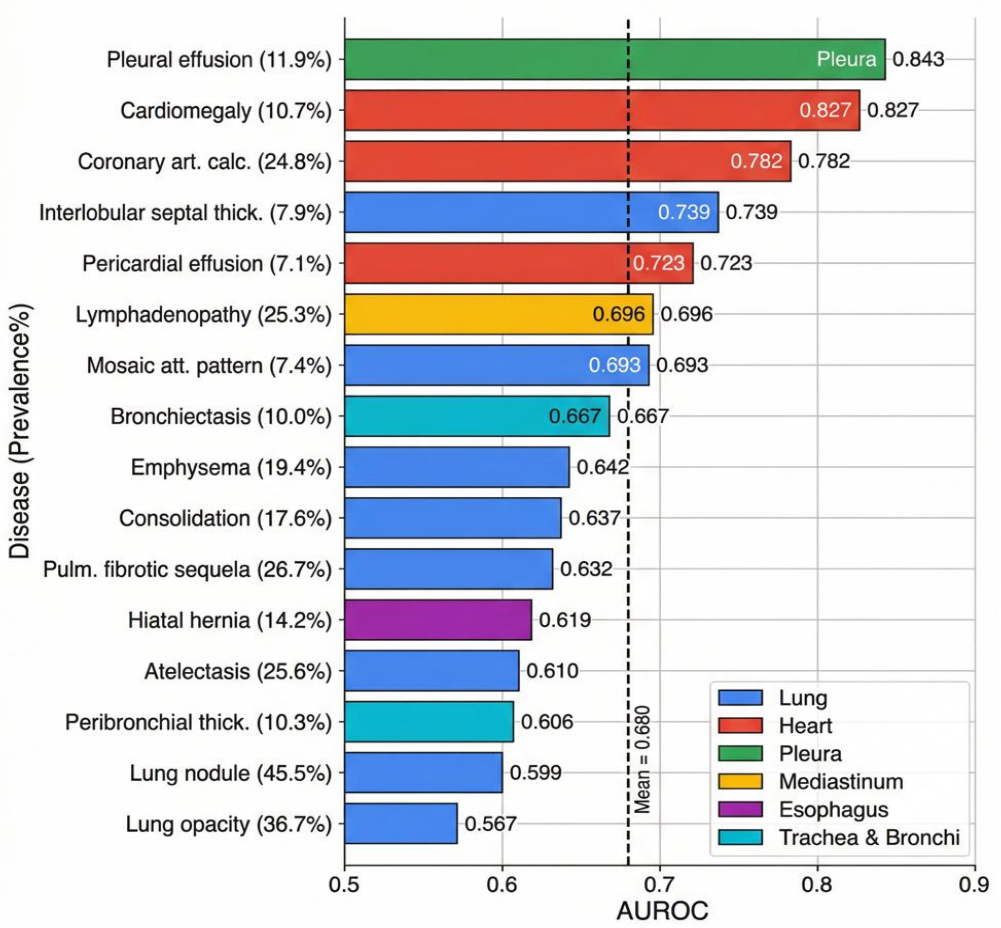

Figure 21: Per-disease AUROC shown as horizontal bars for the GPT-2 Custom decoder and sorted by descending performance. Prevalence percentages indicate class frequency in the training set. Bars are color coded by organ group with Lung in blue, Heart in red, Pleura in green, Mediastinum in orange, Esophagus in violet, and Trachea & Bronchi in cyan.

8. DISCUSSION

8.1. Design Insights

The controlled benchmark, in which only the decoder varies while the encoder, fusion module, and training protocol remain constant, yields three empirical observations.

Observation 1: Encoder freezing preserves disease discrimination: The GPT-2 Custom configuration achieves the strongest classification among tested configurations (AUROC 0.680), outperforming selective unfreezing (0.650) and BiomedBERT Causal (0.665). This suggests that the Y-Mamba encoder's pre-trained disease-discriminative representations are disrupted by backpropagated generation gradients, even at reduced learning rates. The degradation under selective unfreezing may be attributed to catastrophic forgetting of the encoder's pre-trained disease maps, which serve dual roles: they provide input to the ODAF fusion module and supervision signals for the DAA classification head.

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Table 24. Ablation study across training configurations for the GPT-2 Custom decoder

Config.	AUROC	F1	BLEU-4	METEOR	Key Changes
Full Pipeline	**0.680**	**0.194**	0.139	0.318	ODAF + multi-scale + enc_hidden
+ Selective Unfreeze	0.650	0.167	**0.175**	**0.334**	Partial encoder unfreezing

When encoder parameters shift, these representations drift from their pre-trained distribution, degrading both the quality of the fused encoder sequence and the classification target alignment.

Observation 2: Biomedical language priors improve generation quality: The BiomedBERT-initialized decoder achieves a 15.6% relative improvement in ROUGE-L over GPT-2 Custom (0.296 vs. 0.256) and generates reports of near-reference length (190.4 vs. 195.2 tokens). Domain-specific pre-training appears to compensate for the encoder-decoder distribution gap.

Observation 3: Resource efficiency varies 2.7× across decoders: The GPT-2 Custom decoder requires ∼6 GB VRAM per GPU versus ∼16 GB for BiomedBERT (2.7× difference), enabling batch sizes of 48 versus 24 on identical hardware.

8.2. Clinical Implications

The per-disease AUROC analysis reveals clinically relevant patterns: diseases with distinctive morphological CT signatures (pleural effusion 0.843, cardiomegaly 0.827) achieve the highest accuracy, suggesting potential utility for automated triage of these conditions. Diffuse conditions (lung opacity 0.567, lung nodule 0.599) remain challenging at the current input resolution and would require additional radiologist oversight. The 2.7× VRAM difference between decoders (∼6 GB vs. ∼16 GB per GPU) has potential deployment implications: resource-constrained settings could deploy the custom decoder for classification-focused triage, while research centers could leverage the BiomedBERT decoder for higher-quality report generation.

9. CONCLUSION

We presented a multi-task framework for 3D CT report generation that couples a partially frozen Y-Mamba state space model encoder with lightweight, interchangeable decoders. The controlled decoder benchmark on RadGenome-ChestCT suggests that initial encoder freezing preserves classification accuracy (AUROC 0.680), biomedical language priors improve generation quality (ROUGE-L 0.296, METEOR 0.348), and the 2.7× VRAM efficiency advantage of lightweight decoders provides a practical pathway for resource-constrained deployment. These observations offer empirical guidelines for balancing accuracy, generation quality, and resource efficiency in 3D CT report generation systems.

ACKNOWLEDGMENT

This study was supported by Scientific and Technological Research Council of Turkey (TUBITAK) under the Grant Number 325S593 and TUBITAK 2209-A Research Project Support Programme for Undergraduate Students (Project No: 1919B012403476). The authors thank to TUBITAK for their supports.

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ISBN NR: 978-625-5694-92-8

A BENCHMARK STUDY OF DEEP LEARNING ARCHITECTURES FOR MULTI-ORGAN SEGMENTATION IN CHEST CT VOLUMES

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ABSTRACT

Automated organ segmentation in three-dimensional (3D) chest computed tomography (CT) is widely used in clinical analysis and computer-aided medical image computing applications. However, systematic comparisons of recent deep learning architectures under identical experimental conditions remain limited. In this study, five 3D segmentation models are evaluated for segmentation of lung and abdominal regions using the RadGenome-ChestCT dataset. The evaluated models include convolutional networks, a transformer-based model, and state space model (SSM) inspired architectures. All models are trained under identical settings using isotropic 96×96×96 voxel inputs, a combined BCE–Dice loss, the AdamW optimizer, and a cosine annealing learning rate schedule to ensure a fair comparison. The experimental results indicate that both convolutional and SSM-inspired models achieve strong segmentation performance, while model size alone does not determine accuracy. In addition, SSM-inspired models demonstrate competitive performance with substantially fewer parameters. These findings provide practical guidance for selecting parameter-efficient architectures for volumetric medical image segmentation tasks.

Keywords: Medical image segmentation, 3D chest CT, deep learning, benchmark, U-Net, Mamba, state space models, organ segmentation.

10. INTRODUCTION

Accurate organ segmentation in chest computed tomography (CT) supports many clinical and research tasks such as radiation therapy planning, volumetric analysis, and computer-aided diagnosis [5] G. Litjens, T. Kooi, B. E. Bejnordi, et al., “A survey on deep learning in medical image analysis,” Medical Image Analysis, vol. 42, pp. 60–88, 2017.. Unlike classification tasks that assign a single label to an entire image or volume, segmentation requires dense voxel-level predictions that delineate anatomical structures within complex three-dimensional data. Chest CT scans

typically contain hundreds of slices, which requires models capable of capturing both local spatial details and global volumetric context.

Deep learning methods have become the dominant approach for medical image segmentation during the last decade. The U-Net architecture [1] O. Ronneberger, P. Fischer, and T. Brox, "U-Net: Convolutional networks for biomedical image segmentation," in Proc. Med. Image Comput. Comput. Assist. Interv. (MICCAI), pp. 234–241, 2015. introduced an encoder–decoder structure with skip connections that combine spatial information from shallow layers with semantic representations from deeper layers. Its volumetric extension, 3D U-Net [2] Ö. Çiçek, A. Abdulkadir, S. S. Lienkamp, T. Brox, and O. Ronneberger, "3D U-Net: Learning dense volumetric segmentation from sparse annotation," in Proc. Med. Image Comput. Comput. Assist. Interv. (MICCAI), pp. 424–432, 2016., enabled direct segmentation of three-dimensional medical images and has been widely adopted for CT and MRI analysis. Additional developments improved segmentation performance through architectural modifications such as Dice-based optimization [3] F. Milletari, N. Navab, and S.-A. Ahmadi, "V-Net: Fully convolutional neural networks for volumetric medical image segmentation," in Proc. Int. Conf. 3D Vis. (3DV), pp. 565–571, 2016., residual connections [4] K. He, X. Zhang, S. Ren, and J. Sun, "Deep residual learning for image recognition," in Proc. IEEE Conf. Comput. Vis. Pattern Recognit. (CVPR), pp. 770–778, 2016., and dense feature propagation [6] G. Huang, Z. Liu, L. van der Maaten, and K. Q. Weinberger, "Densely connected convolutional networks," in Proc. IEEE Conf. Comput. Vis. Pattern Recognit. (CVPR), pp. 4700–4708, 2017.. Nested skip connections in UNet++ [7] Z. Zhou, M. M. R. Siddiquee, N. Tajbakhsh, and J. Liang, "UNet++: A nested U-Net architecture for medical image segmentation," in Proc. Deep Learn. Med. Image Anal. (DLMIA), pp. 3–11, 2018. were introduced to reduce the semantic gap between encoder and decoder features. The nnU-Net framework later demonstrated that carefully configured preprocessing, augmentation, and training strategies can achieve strong segmentation performance across diverse biomedical datasets using a standardized U-Net architecture [9] F. Isensee, P. F. Jaeger, S. A. A. Kohl, J. Petersen, and K. H. Maier-Hein, "nnU-Net: A self-configuring method for deep learning-based biomedical image segmentation," Nature Methods, vol. 18, no. 2, pp. 203–211, 2021..

Recent research has investigated architecture that model long-range spatial dependencies more explicitly. Vision Transformers introduced self-attention mechanisms that capture global relationships between image patches [8] A. Dosovitskiy, L. Beyer, A. Kolesnikov, et al., "An image is worth 16x16 words: Transformers for image recognition at scale," in Proc. Int. Conf. Learn. Represent. (ICLR), 2021.. Transformer-based segmentation models such as UNETR [10] A. Hatamizadeh, Y. Tang, V. Nath, et al., "UNETR: Transformers for 3D medical image segmentation," in Proc. IEEE/CVF Winter Conf. Appl. Comput. Vis. (WACV), pp. 574–584, 2022. and Swin UNETR [11] Y. Tang, D. Yang, W. Li, et al., "Self-supervised pre-training of Swin Transformers for 3D medical image analysis," in Proc. IEEE/CVF Conf. Comput. Vis. Pattern Recognit. (CVPR), pp. 20730–20740, 2022. adapt these mechanisms to volumetric medical imaging by combining transformer encoders with convolutional decoders. Although these architectures demonstrate strong performance on several benchmarks, transformer models often require large parameter counts and considerable computational resources when applied to high-resolution three-dimensional volumes. More recently, state space model (SSM) based architectures inspired by Mamba have been introduced for visual representation learning [13] A. Gu and T. Dao, "Mamba: Linear-time

sequence modeling with selective state spaces," arXiv preprint arXiv:2312.00752, 2023.. Building upon structured state space sequence modeling approaches [12] A. Gu, K. Goel, and C. Ré, "Efficiently modeling long sequences with structured state spaces," in Proc. Int. Conf. Learn. Represent. (ICLR), 2022., segmentation architectures such as U-Mamba [14] J. Ma, F. Li, and B. Wang, "U-Mamba: Enhancing long-range dependency for biomedical image segmentation," arXiv preprint arXiv:2401.04722, 2024. and SegMamba [15] Z. Xing, T. Ye, Y. Yang, G. Liu, and L. Zhu, "SegMamba: Long-range sequential modeling Mamba for 3D medical image segmentation," in Proc. Med. Image Comput. Comput. Assist. Interv. (MICCAI), 2024. integrate state space blocks into encoder–decoder frameworks. These models aim to capture long-range spatial relationships while maintaining linear computational complexity with respect to sequence length. VM-UNet [16] J. Ruan and S. Xiang, "VM-UNet: Vision Mamba UNet for medical image segmentation," arXiv preprint arXiv:2402.02491, 2024. further explores segmentation architectures built around state space modeling. Despite the growing number of proposed architectures, direct comparisons between models remain difficult because many experiments rely on different datasets, preprocessing pipelines, and optimization strategies. These differences obscure the effect of architectural design. In addition, the relationship between model capacity and segmentation accuracy for volumetric organ segmentation has received limited systematic analysis.

This study presents a controlled benchmark of five deep learning architectures for binary segmentation of lung and abdomen regions in chest CT volumes from the RadGenome-ChestCT dataset [20] I. E. Hamamci, S. Er, B. Menze, et al., "RadGenome-ChestCT: A grounded vision-language dataset for chest CT analysis," arXiv preprint arXiv:2404.16754, 2024.. The dataset provides large-scale volumetric CT scans with organ-level segmentation masks and structured annotations derived from the CT-RATE corpus [19] I. E. Hamamci, S. Er, F. Almas, A. G. Simsek, S. N. Esirgun, et al., "A foundation model utilizing chest CT volumes and radiology reports for supervised-level zero-shot detection of abnormalities," in Proc. Eur. Conf. Comput. Vis. (ECCV), 2024.. The evaluated models include convolution-based architectures (nnU-Net-like and ResUNet3D), a transformer-based architecture (Swin UNETR), and two state space model inspired architectures (U-Mamba and SegMamba). All models are trained using identical preprocessing, augmentation, and optimization settings in order to enable a fair comparison of architectural characteristics.

The main contributions of this study are summarized as follows:

- A controlled benchmark comparison of five segmentation architectures under identical experimental conditions.
- An evaluation of lung and abdomen segmentation performance using multiple complementary metrics.
- An analysis of the relationship between parameter count, training efficiency, and segmentation accuracy in volumetric medical image segmentation.

The remainder of this paper is organized as follows. Section II describes the dataset, preprocessing pipeline, model architectures, and training configuration. Section III presents the experimental results. Section III discusses the findings. Section IV concludes the paper and outlines future directions.

ISBN NR: 978-625-5694-92-8

11. METHOD

This section describes the dataset, preprocessing pipeline, data augmentation strategy, model architecture, training configuration, and evaluation protocol used in the experiments. All architectures are trained and evaluated under identical experimental conditions in order to isolate the effect of architectural design.

11.1. Dataset

Experiments are conducted using the RadGenome-ChestCT dataset [20] I. E. Hamamci, S. Er, B. Menze, et al., "RadGenome-ChestCT: A grounded vision-language dataset for chest CT analysis," arXiv preprint arXiv:2404.16754, 2024., a large-scale collection of non-contrast chest CT volumes accompanied by organ-level segmentation masks. The dataset provides binary region annotations for ten anatomical structures, including lung, abdomen, heart, pleura, bone, breast, esophagus mediastinum, thyroid, trachea and bronchi. The present study focuses on two organs with completed experiments: lung and abdomen. Each sample contains a volumetric CT scan and a corresponding organ mask stored as PyTorch .pt tensor files. The CT volumes retain the original Hounsfield Unit (HU) intensity values, while the segmentation masks consist of binary voxel labels in the set $\{0,1\}$ that delineate the target anatomical structure. The dataset contains 24,129 training volumes and 1,564 validation volumes. The official validation split is also used as the test set, meaning that validation and test samples correspond to the same volumes. This characteristic represents a known limitation of the dataset and is considered when interpreting the experimental results.

11.2. Preprocessing

All CT volumes pass through the same preprocessing pipeline across all architectures in order to standardize spatial resolution and intensity distribution.

First, CT intensities are normalized to reduce numerical variability during training. Raw Hounsfield Unit values are scaled using

$$x' = \frac{x}{1000} \tag{1}$$

ISBN NR: 978-625-5694-92-8

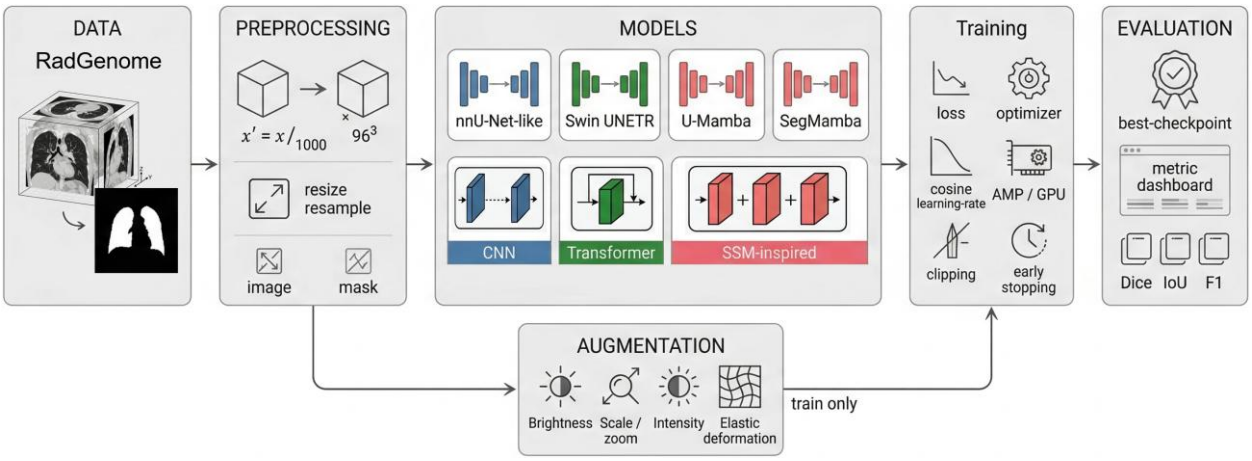

Figure 22: Overview of the experimental pipeline

This transformation preserves the HU distribution while bringing values into a numerically stable range. Intensity clipping is not applied so that the full HU range remains available to the model. Second, spatial resolution is standardized across all samples. Each CT volume and its corresponding segmentation mask are resized to an isotropic grid of 96 × 96 × 96 voxels. Trilinear interpolation is used for CT volumes, while nearest-neighbor interpolation is used for binary masks to preserve discrete label boundaries.

11.3. Data Augmentation

Data augmentation is applied online during training to increase robustness to variations in imaging conditions. Four stochastic transformations are used.

1) *Brightness and contrast (p = 0.5):* A brightness offset sampled from [−0.1, 0.1] × σ_image and a contrast factor from [0.9, 1.1] are applied to the CT volume.
2) *Random scale (p = 0.3):* An isotropic zoom with scale factor sampled from [0.9, 1.1] is applied to the volume and mask, followed by resizing back to 96^3.
3) *Intensity scale (p = 0.3):* A multiplicative factor in the range [0.9, 1.1] scales CT intensities.
4) *Elastic deformation (p = 0.2*)**:** Three-dimensional elastic transformations are generated using Gaussian-smoothed displacement fields with smoothness σ ∈ [5, 7] and magnitude in [50, 100] voxels.

Spatial transformations apply to both CT volumes and masks. Validation and test data do not include augmentation.

11.4. Deep Learning Architectures

Five segmentation architectures are evaluated: nnU-Net-like, Swin UNETR, U-Mamba, SegMamba, and ResUNet3D. All models follow an encoder–decoder structure with skip connections that transfer spatial information from encoder layers to decoder layers.

ISBN NR: 978-625-5694-92-8

Table 25: Overview of Benchmarked Architectures

Model	Family	Params	Batch
nnU-Net-like	CNN	~13M	24
Swin UNETR	Transformer	~60M	20
U-Mamba	SSM-inspired	~2.4M	28
SegMamba	SSM-inspired	~1.4M	32
ResUNet3D	CNN	~27M	16

The architectures differ in the computational blocks used for feature extraction. The nnU-Net-like configuration follows the MONAI [22] M. J. Cardoso, W. Li, R. Brown, et al., "MONAI: An open-source framework for deep learning in healthcare," arXiv preprint arXiv:2211.02701, 2022. implementation of a 3D U-Net designed to approximate the nnU-Net framework [9] F. Isensee, P. F. Jaeger, S. A. A. Kohl, J. Petersen, and K. H. Maier-Hein, "nnU-Net: A self-configuring method for deep learning-based biomedical image segmentation," Nature Methods, vol. 18, no. 2, pp. 203–211, 2021.. The encoder contains five resolution levels with channel dimensions (32, 64, 128, 256, 320) and strided convolutions for downsampling.

Swin UNETR [11] Y. Tang, D. Yang, W. Li, et al., "Self-supervised pre-training of Swin Transformers for 3D medical image analysis," in Proc. IEEE/CVF Conf. Comput. Vis. Pattern Recognit. (CVPR), pp. 20730–20740, 2022. uses a transformer encoder with shifted window self-attention. Hierarchical transformer stages extract multi-scale features that are then decoded using convolutional upsampling layers connected through skip connections. U-Mamba integrates state space model inspired blocks into a U-Net-style encoder–decoder structure. The core block combines pointwise projection, depthwise convolution, and gated feature modulation:

$$\mathrm{SSM}(x) = x + \mathrm{IN}\left(\mathrm{SiLU}\left(\mathrm{DWConv}(v) \odot \sigma\big(\mathrm{Gate}(v)\big)\right)\right) \tag{2}$$

where $v = \mathrm{Conv}_{1\times1\times1}(x)$, IN denotes instance normalization, σ denotes the sigmoid function, and $\odot$ indicates element-wise multiplication.

SegMamba follows the same architectural design as U-Mamba but uses a narrower channel configuration, which reduces the total parameter count to approximately 1.4 million.

ResUNet3D uses residual convolutional blocks within a four-level encoder–decoder structure. Each residual block contains two convolutional layers with instance normalization and identity skip connections.

11.5. Training Procedure

All models are trained under identical optimization settings to ensure consistent experimental conditions. The AdamW optimizer [17] I. Loshchilov and F. Hutter, "Decoupled weight decay regularization," in Proc. Int. Conf. Learn. Represent. (ICLR), 2019. is employed with an initial learning rate of 1×10^{-4} and a weight decay value of 1×10^{-5}. The learning rate is adjusted throughout training using a cosine annealing schedule over 100 epochs, allowing gradual reduction toward a lower bound to stabilize convergence. The training objective combines binary cross-entropy loss and Dice loss with equal weighting. This formulation balances pixel-wise classification accuracy with overlap-based region consistency, enabling more stable

ISBN NR: 978-625-5694-92-8

learning for segmentation tasks. Automatic mixed precision (AMP) is used during training to reduce GPU memory consumption and improve computational efficiency. Gradient clipping is applied with a maximum norm of 1.0 to prevent instability during backpropagation.

ISBN NR: 978-625-5694-92-8

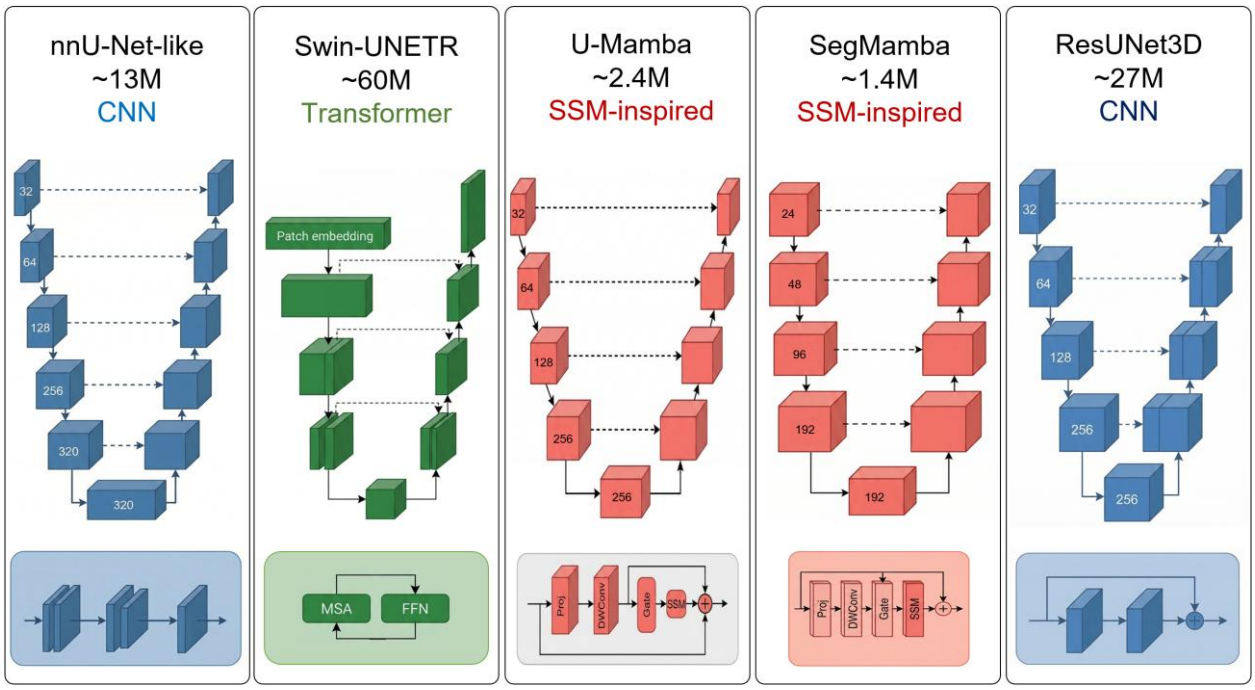

Figure 23: Comparison of the five benchmarked architectures

Early stopping is introduced based on validation performance, and training is terminated if no improvement in the validation Dice score is observed for 20 consecutive epochs. All experiments are conducted on two NVIDIA RTX A6000 GPUs with 48 GB VRAM using the PyTorch DataParallel framework.

11.6. Evaluation Metrics

Segmentation performance is evaluated using six metrics computed on the test set. The Dice Similarity Coefficient (DSC) measures volumetric overlap between prediction P and ground truth G:

$$\mathrm{DSC} = \frac{2|P \cap G|}{|P| + |G|} \tag{3}$$

Intersection over Union (IoU) measures the ratio of intersection to union:

$$\mathrm{IoU} = \frac{|P \cap G|}{|P \cup G|} \tag{4}$$

Additional voxel-level metrics include precision, recall, F1 score, and specificity. Together these metrics describe overlap accuracy, detection completeness, prediction reliability, and background classification performance.

12. EXPERIMENTAL RESULTS AND DISCUSSION

This section presents the segmentation results for lung and abdomen regions and discusses the observed differences across architectures. The analysis focuses on segmentation accuracy, parameter efficiency, and training time under identical experimental settings.

ISBN NR: 978-625-5694-92-8

Table 26: Lung Segmentation Results on RadGenome-ChestCT Test Set

Model	Params	Dice	IoU	Precision	Recall	F1	Specificity	Epochs	Time
nnU-Net-like	~13M	**0.9460**	**0.9028**	0.9439	**0.9491**	**0.9465**	0.9951	80/100	11h 26m
U-Mamba	~2.4M	0.9450	0.9009	0.9434	0.9472	0.9453	0.9951	78/100	32h 12m
SegMamba	~1.4M	0.9446	0.9003	**0.9445**	0.9453	0.9449	**0.9952**	89/100	31h 14m
ResUNet3D †	~27M	0.8593	0.7734	0.8693	0.8624	0.8656	0.9876	22/100	29h 0m

†ResUNet3D result is from an initial-pipeline run (best epoch 2, early stopped at epoch 22); not directly comparable.
Swin UNETR failed during lung training (runtime crash) and is excluded from this table.

12.1. Lung Segmentation

The lung segmentation results show very small differences among nnU-Net-like, U-Mamba, and SegMamba. Their Dice values range from 0.9446 to 0.9460, and the gap between the highest and lowest score is only 0.0014. The nnU-Net-like model achieves the highest Dice, IoU, recall, and F1 score, while SegMamba produces the highest precision and specificity. These values indicate that all three models generate highly accurate lung masks with stable foreground and background separation. This pattern suggests that lung segmentation is well supported by several architectural designs when the input resolution, optimization settings, and augmentation strategy are held constant. The high contrast between lung parenchyma and surrounding tissues in CT likely supports this behavior. Because the lung boundary is relatively distinct, both convolution-based and SSM-inspired models can extract sufficient structural information from the input volume. ResUNet3D produces a clearly lower Dice value than the other models. However, this result comes from an incomplete training process, where the best checkpoint was saved at epoch 2 and training stopped at epoch 22. For that reason, this result should be interpreted with caution and should not be used as a direct indicator of architectural inferiority.

12.2. Abdomen Segmentation

The abdomen segmentation task produces a different ranking. U-Mamba achieves the highest Dice, IoU, precision, F1 score, and specificity, while nnU-Net-like produces the highest recall. SegMamba follows closely behind U-Mamba, and the difference between the top three models is small. The Dice gap between U-Mamba and nnU-Net-like is 0.0051, which indicates that all three models provide competitive abdomen segmentation performance.

In contrast to the lung results, the best abdomen score is obtained by an SSM-inspired architecture rather than a convolution-based architecture. This difference suggests that the abdomen region benefits from feature extraction behavior that differs from the lung region. Abdomen boundaries often involve softer transitions and lower intensity contrast than lung boundaries. Under such conditions, the gated state-space style processing in U-Mamba may support more effective representation of broader contextual structure.

ISBN NR: 978-625-5694-92-8

Table 27: Abdomen Segmentation Results on RadGenome-ChestCT Test Set

Model	Params	Dice	IoU	Precision	Recall	F1	Specificity	Epochs	Time
U-Mamba	~2.4M	**0.9072**	**0.8368**	**0.8902**	0.9266	**0.9080**	**0.9901**	68/100	27h 58m
SegMamba	~1.4M	0.9044	0.8325	0.8880	0.9237	0.9055	0.9899	80/100	27h 56m
nnU-Net-like	~13M	0.9021	0.8290	0.8807	**0.9268**	0.9032	0.9891	47/100	6h 22m
Swin UNETR	~60M	0.8447	0.7458	0.8459	0.8561	0.8508	0.9861	52/100	51h 27m

Swin UNETR yields the lowest abdomen Dice despite having the largest parameter count. It also requires the longest training time by a wide margin. This result indicates that larger model size alone does not guarantee better segmentation performance. The transformer-based architecture may require a different input scale, longer training schedule, or more extensive pretraining in order to fully exploit its capacity in volumetric segmentation tasks.

The nnU-Net-like model again stands out in training efficiency. It completes abdomen training in 6 hours and 22 minutes, while U-Mamba and SegMamba require nearly 28 hours and Swin UNETR exceeds 51 hours. This difference supports the practical advantage of well-optimized convolution-based models when computational cost is considered together with segmentation accuracy.

12.3. Cross-Organ Comparison

A clear pattern appears across both organs. Lung segmentation produces higher Dice scores than abdomen segmentation for all comparable models. This outcome is consistent with the anatomical structure of the two regions. The lung region is characterized by a strong density contrast relative to surrounding tissues, whereas abdomen boundaries often include adjacent soft tissues with less distinct intensity differences.

The ranking of the architectures changes between organs. The nnU-Net-like model ranks first for lung segmentation, while U-Mamba ranks first for abdomen segmentation. This variation indicates that no single architecture provides the best result for all anatomical targets. Different organs present different boundary characteristics, contrast distributions, and contextual dependencies. These differences affect how effectively a given architecture captures the relevant spatial information.

The results also show that parameter count is not a reliable predictor of segmentation accuracy. SegMamba and U-Mamba contain 1.4M and 2.4M parameters, respectively, yet they achieve performance very close to or better than nnU-Net-like with 13M parameters. Swin UNETR contains approximately 60M parameters but does not achieve the highest result in any completed experiment. This pattern supports the view that architectural design and optimization behavior are more informative than model size alone in this setting.

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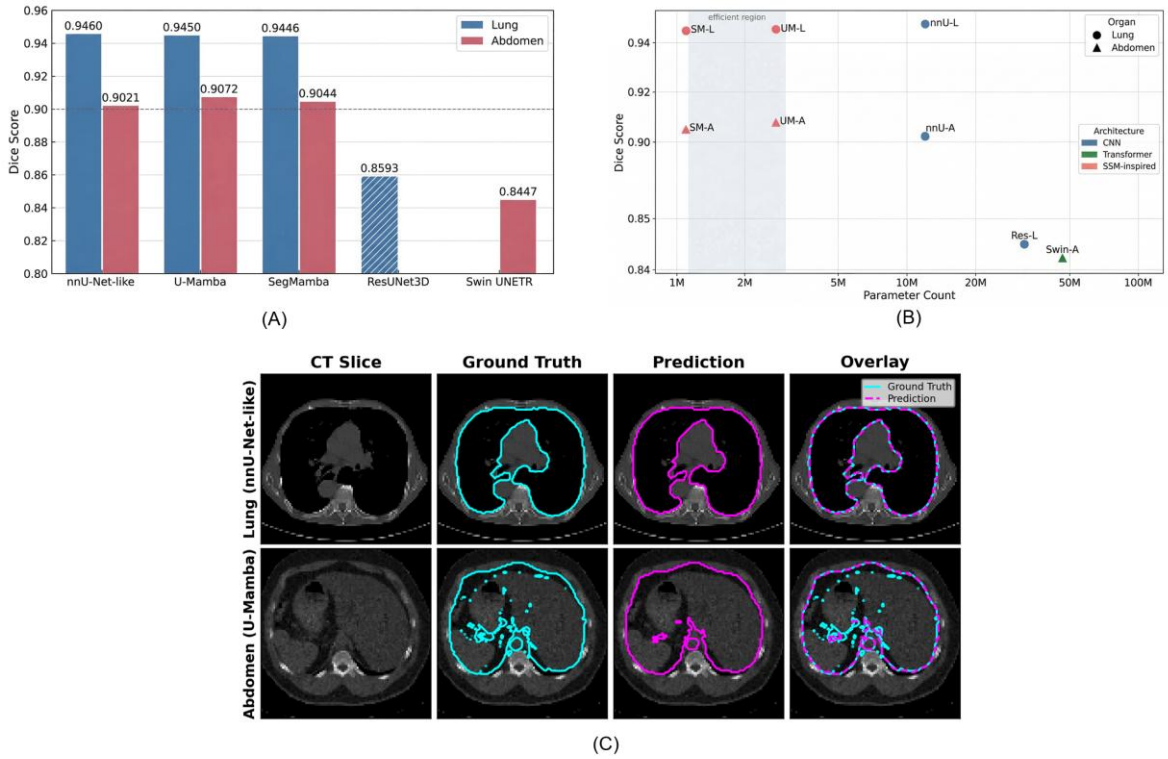

Figure 24: Results visualization. (a) Dice scores by architecture and organ. (b) Dice score vs. parameter count. (c) Representative segmentation overlays for lung and abdomen from the best-performing model on each organ.

13. CONCLUSION

This study presented a benchmark comparison of five 3D deep learning architectures for binary organ segmentation of lung and abdomen regions in chest CT volumes. The experimental results showed that both convolution-based and state space model inspired architectures can produce strong segmentation performance under identical training conditions. The comparison also showed that model size alone is not a sufficient indicator of segmentation accuracy. Among the evaluated models, the SSM-inspired architectures provided a favorable balance between segmentation performance and parameter efficiency. These findings indicate that lightweight architectures can serve as effective alternatives to larger models in volumetric medical image segmentation. Future research can extend the benchmark to the remaining anatomical regions in the dataset and include external validation on CT data acquired from different clinical centers and scanner types. In addition, alternative loss functions and more advanced state space mechanisms may provide further improvements in segmentation performance and computational efficiency.

ACKNOWLEDGMENT

This study was supported by Scientific and Technological Research Council of Turkey (TUBITAK) under the Grant Number 325S593 and TUBITAK 2209-A Research Project Support Programme for Undergraduate Students (Project No: 1919B012403476). The authors thank to TUBITAK for their supports.

Table 28: Best Dice Scores by Architecture and Organ

Model	Params	Lung	Abdomen	Avg.
nnU-Net-like	13M	0.9460	0.9021	0.9241
U-Mamba	2.4M	0.9450	0.9072	0.9261
SegMamba	1.4M	0.9446	0.9044	0.9245
Swin UNETR	60M	—	0.8447	—
ResUNet3D†	27M	0.8593	—	—

†Incomplete run; — indicates unavailable result.

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ISBN NR: 978-625-5694-92-8

MULTI-LABEL THORACIC DISEASE CLASSIFICATION IN CHEST CT VOLUMES: A COMPARATIVE STUDY OF MAMBA-BASED STATE SPACE MODELS

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ABSTRACT

Automated multi-label classification of thoracic diseases from chest computed tomography (CT) volumes can support radiology workflows by enabling simultaneous screening of multiple conditions from a single volumetric scan. However, volumetric CT analysis requires models that can represent both local anatomical patterns and long-range spatial dependencies while maintaining computational efficiency. Convolutional neural networks capture local features effectively but they are limited in modeling long-range spatial dependencies, whereas Vision Transformers address this limitation at the cost of high computational complexity for three-dimensional volumetric data. State space models (SSMs), particularly Mamba-based architectures, provide an alternative formulation with linear computational complexity and efficient long-range modeling. In this study, Y-Mamba and U-Mamba are evaluated for multi-label classification of 16 thoracic diseases from chest CT volumes using the RadGenome-ChestCT dataset (20,000 volumes) with CT-RATE annotations. Both architectures achieve comparable overall classification performance (mean AUROC = 0.8008), with stronger discrimination for diseases associated with distinct radiological patterns and reduced performance for rare or diffuse abnormalities. These findings indicate that Mamba-based SSMs offer a computationally efficient alternative for volumetric chest CT classification, with disease-level performance variability suggesting that lesion conspicuity and class prevalence are key factors in multi-label CT analysis.

Keywords: Computed Tomography, Deep Learning, Mamba, Multi-label Classification, State Space Models.

14. INTRODUCTION

The interpretation of medical imaging studies requires substantial time and expertise in modern radiology practice. Chest CT (computed tomography) volumes, which provide detailed 3D (three-dimensional) volumetric representations of chest anatomy, are frequently ordered imaging examinations. Radiologists must systematically evaluate these complex volumes for a multitude of potential pathologies, a process that is time-consuming, subject to inter-reader variability, and further challenged by increasing imaging volumes.

Automated multi-label disease classification systems aim to assist radiologists by providing preliminary assessments, prioritizing urgent cases, and reducing diagnostic errors. However, developing such systems for chest CT presents computational and methodological challenges. The volumetric nature of CT data, typically comprising hundreds of axial slices, demands architectures capable of capturing both local anatomical features and long-range spatial dependencies across the entire scan volume.

Convolutional neural networks (CNNs) have been widely adopted for medical image analysis [1]. While effective for capturing local features through hierarchical convolution operations, CNNs are constrained by their fixed receptive fields. Capturing global context requires either very deep networks or large kernel sizes, both of which increase computational cost and risk overfitting, particularly in data-limited medical imaging settings [2]. Vision Transformers (ViTs) address this limitation through self-attention mechanisms that can model global dependencies [3]. However, the self-attention operation exhibits quadratic computational complexity $\mathcal{O}(\mathrm{N}^2)$ with respect to the sequence length N, which poses computational challenges for high-resolution 3D medical images with large token counts. For 3D medical image analysis, 3D CNNs such as 3D ResNet [4] and V-Net [5] have been employed but face computational challenges due to the cubic growth of parameters and memory requirements. Vision Transformers [6] and their medical imaging variants such as UNETR [7] and Swin UNETR [8] have reported improved classification accuracy by capturing global context through self-attention. However, the quadratic complexity of self-attention limits scalability to high-resolution volumetric data.

SSMs (State space models) have been proposed as an alternative that addresses the limitations of both approaches. Originating from classical control theory, modern SSMs such as the Structured State Space Sequence Model (S4) and its selective variant Mamba achieve linear computational complexity $\mathcal{O}(\mathrm{N})$ while maintaining the ability to model long-range dependencies through continuous-time dynamical systems. The Mamba architecture, in particular, introduces a selective scan mechanism that enables input-dependent state transitions, allowing the model to adaptively focus on relevant features in the input sequence. These properties make SSM-based architectures suitable for processing 3D medical images, where computational efficiency is an important consideration [9, 10].

Automated analysis of chest CT volumes has been an active research area, particularly accelerated by the COVID-19 pandemic. CT-Net proposed a contrastive learning framework for chest CT classification. CT-CLIP introduced a contrastive language-image pre-training approach specifically designed for chest CT, leveraging paired CT volumes and radiology

ISBN NR: 978-625-5694-92-8

reports from the RadGenome-ChestCT corpus for self-supervised representation learning. The Chest-OMDL framework demonstrated optimized multi-disease learning from chest CT using multi-resolution feature extraction and frequency-weighted loss functions, achieving competitive performance on the CT-RATE dataset. Multi-label classification presents unique challenges compared to single-label classification, as multiple diseases can co-occur within a single volume. Approaches to handle label co-occurrence include graph-based methods, attention-based methods, and asymmetric loss functions. For thoracic disease classification specifically, handling class imbalance through weighted loss functions has been shown to improve performance across both common and rare pathologies.

In this paper, we present a comparative study of Y-Mamba and U-Mamba architectures for multi-label chest disease classification from chest CT volumes. To the best of our knowledge, this is the first systematic comparison of these two SSM-based architectures for multi-label classification of chest diseases from volumetric CT data. Our main contributions are as follows:

- We adapt and evaluate two state-of-the-art SSM-based architectures, Y-Mamba and U-Mamba, for multi-label classification of 16 chest diseases from chest CT volumes.
- We conduct a comprehensive comparative analysis on the RadGenome-ChestCT dataset one of the largest publicly available chest CT benchmarks, providing detailed per-disease performance metrics.
- We analyze the strengths and limitations of each architecture across different disease categories, offering insights into the suitability of SSM-based methods for volumetric medical image classification.

The remainder of this paper is organized as follows. Section 6 describes the preprocessing pipeline, model architectures, and training methodology. Section 3 presents the dataset, evaluation metrics, and experimental results with detailed per-disease analysis and discussion. Section 4 provides concluding remarks and future research directions.

15. METHOD

In this section, we describe our proposed multi-label disease classification approach using SSM-based architectures, including the preprocessing pipeline, model architectures, and training methodology.

15.1. Dataset Preprocessing

Each CT volume undergoes a standardized preprocessing pipeline to ensure consistency across the dataset. The preprocessing steps are as follows:

1) **Intensity windowing:** Hounsfield Unit (HU) values are clipped to the range [-1000, +1000] to focus on clinically relevant tissue densities and then normalized to [0, 1].
2) **Spatial resampling:** All volumes are resampled to a uniform resolution and resized to $64 \times 128 \times 128$ voxels (depth × height × width) using trilinear interpolation, balancing spatial resolution with computational feasibility.

ISBN NR: 978-625-5694-92-8

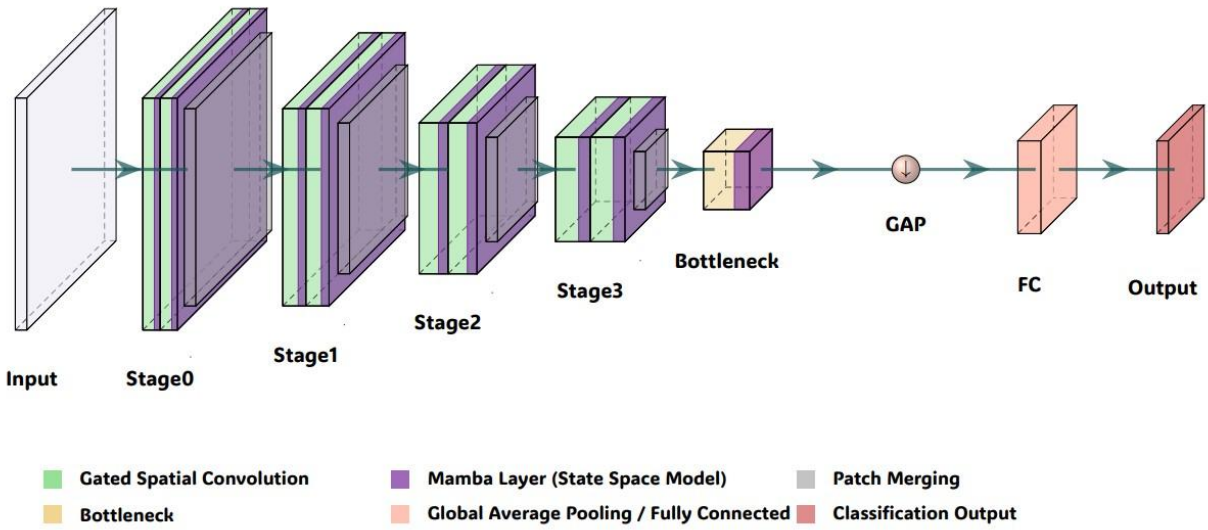

Figure 25: The Proposed Y-Mamba Architecture

3) **Data augmentation:** During training, random augmentations are applied including random horizontal flipping, random rotation (±10°), random intensity scaling (±10%), and 3D elastic deformation to improve generalization and reduce overfitting. Elastic deformation applies smooth, random spatial distortions to the volume by displacing voxels according to a deformation field generated from a coarse grid of $4 \times 4 \times 4$ control points with a maximum displacement magnitude of 7 voxels, followed by cubic interpolation to produce a smooth warp. This augmentation simulates natural anatomical variability across patients, encouraging the model to learn features that are robust to shape and positional variations.

15.2. Y-Mamba Architectures

Y-Mamba employs a Y-shaped hierarchical architecture originally designed for 3D medical image segmentation, which we adapt for multi-label classification. The architecture consists of a shared hierarchical encoder and two parallel decoder branches, forming the characteristic Y-shape topology.

The encoder follows a multi-scale design with four resolution stages. At each stage, the input volume is processed through a combination of Gated Spatial Convolution (GSC) blocks and MambaLayer blocks. The GSC block applies depthwise separable 3D convolutions with gating mechanisms to efficiently extract local spatial features while controlling information flow:

$$\mathrm{GSC}(X) = \sigma\big(\mathrm{DWConv}(X)\big) \odot \mathrm{Conv}_{1\times1\times1}(X) \tag{1}$$

where σ denotes the sigmoid activation function, DWConv represents the depthwise 3D convolution, and $\odot$ indicates element-wise multiplication. The MambaLayer block is the core component that enables long-range dependency modeling. It processes the feature maps by first flattening them into sequences and then applying the selective state space mechanism:

$$h'(t) = Ah(t) + B(t)x(t) \tag{2}$$

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Table 29: Overall Performance Comparison of Y-Mamba and U-Mamba Architectures

Model	AUROC	Accuracy	F1
Y-Mamba	**0.8008**	0.7267	**0.4829**
U-Mamba	0.8002	**0.7280**	0.4804

$$y(t) = C(t)h(t) \tag{3}$$

where A is the state transition matrix, $\mathrm{B(t)}$ and $\mathrm{C(t)}$ are input-dependent projection matrices computed through linear projections of the input, and $\mathrm{h(t)}$ is the hidden state. The input-dependent nature of $\mathrm{B(t)}$ and $\mathrm{C(t)}$ enables the selective scan mechanism, allowing the model to adaptively filter and retain relevant information. Between encoder stages, patch merging operations reduce the spatial resolution by a factor of 2 in each dimension while doubling the channel dimension, creating a multi-scale feature pyramid with resolutions $\{64 \times 128 \times 128, 32 \times 64 \times 64, 16 \times 32 \times 32, 8 \times 16 \times 16\}$.

For classification, we modify the Y-Mamba architecture by replacing the segmentation decoder heads with a global average pooling layer followed by a fully connected classification layer with sigmoid activation for multi-label prediction:

$$\hat{y} = \sigma(W \cdot \mathrm{GAP}(z_L) + b) \tag{4}$$

where z_L represents the encoder output at the deepest level, GAP denotes global average pooling, W and b are the classification layer parameters, and $\hat{y} \in [0,1]^{16}$ is the predicted probability vector for 16 disease categories.

15.3. U-Mamba Architecture

U-Mamba integrates Mamba blocks into the established U-Net encoder-decoder framework, creating a hybrid architecture that combines the local feature extraction strength of convolutional operations with the long-range dependency modeling capability of state space models. The encoder consists of convolutional downsampling blocks followed by Mamba-augmented residual blocks. Each Mamba residual block first processes the input through standard 3D convolutional layers with instance normalization and LeakyReLU activation, then applies a Mamba block to the feature maps to capture long-range dependencies:

$$Z_l = \mathrm{Mamba}\big(\mathrm{Conv3D}(Z_{l-1})\big) + Z_{l-1} \tag{5}$$

where Z_l denotes the feature maps at encoder level l and the residual connection ensures stable gradient flow during training. The decoder follows the symmetric U-Net structure with skip connections from the encoder to the corresponding decoder levels, enabling the recovery of fine-grained spatial information. Transposed 3D convolutions are used for upsampling at each decoder level. Similar to the Y-Mamba adaptation, we replace the segmentation output with a classification head consisting of global average pooling and a fully connected layer:

$$\hat{y} = \sigma(W \cdot \mathrm{GAP}(z_{\mathrm{btlnc}}) + b) \tag{6}$$

where z_{btlnc} represents the bottleneck features of the U-shaped architecture.

ISBN NR: 978-625-5694-92-8

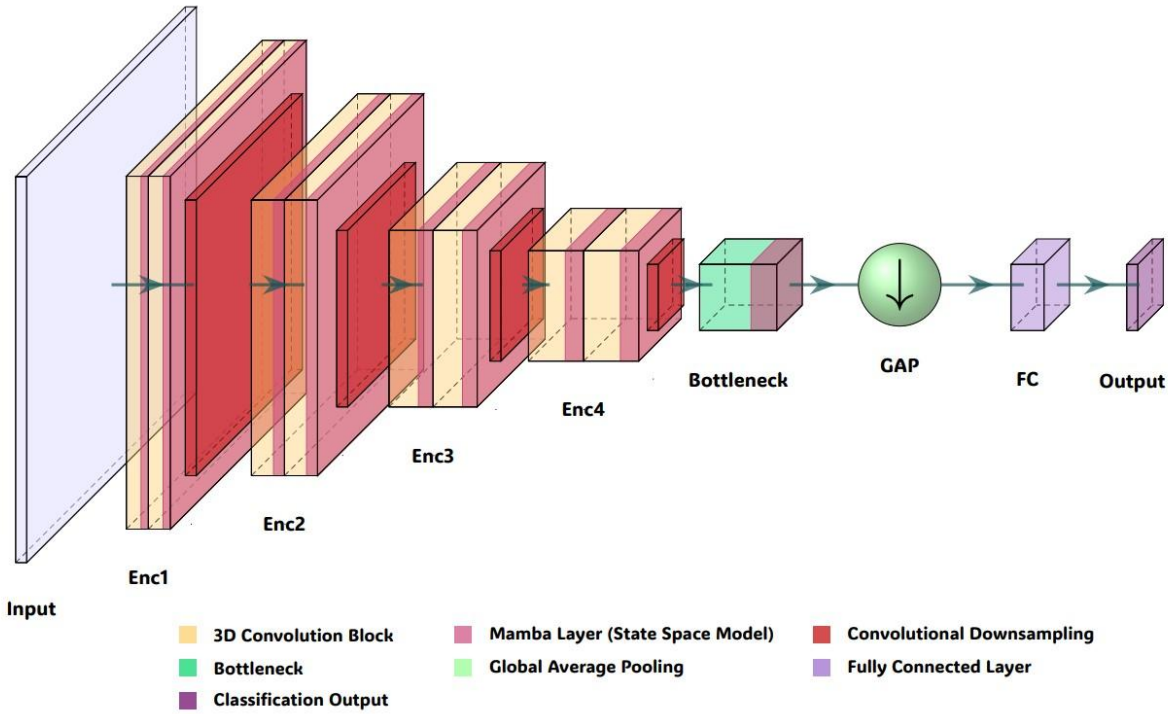

Figure 26: The Proposed U-Mamba Architecture

15.4. Training Methodology

Both architectures are trained using a frequency-weighted binary cross-entropy (BCE) loss function to address the significant class imbalance present in the dataset:

$$\mathcal{L} = -\frac{1}{C}\sum_{c=1}^{C} \alpha_c [y_c \log(\hat{y}_c) + (1 - y_c)\log(1 - \hat{y}_c)] \tag{7}$$

where $C = 16$ is the number of disease categories, $y_c \in \{0,1\}$ is the ground truth label, $\hat{y}_c \in [0,1]$ is the predicted probability, and α_c is the frequency-based weight for class c:

$$\alpha_c = \frac{N_{\text{total}}}{C \cdot N_c} \tag{8}$$

where N_{total} is the total number of training samples and N_c is the number of positive samples for class c. This weighting scheme assigns higher loss contributions to underrepresented classes, encouraging the model to learn discriminative features for rare pathologies.

Both models are optimized using the AdamW optimizer [11] with an initial learning rate of 1×10^{-4} and a weight decay of 1×10^{-5}. A cosine annealing learning rate scheduler is employed to gradually reduce the learning rate over the course of training:

$$\eta_t = \eta_m in + 1/2(\eta_m ax - \eta_m in)\left(1 + cos\left((t\pi)/T\right)\right) \tag{9}$$

where η_t is the learning rate at epoch t, $\eta_{\max} = 1 \times 10^{-4}$ is the initial learning rate, $\eta_{\min} = 1 \times 10^{-6}$ is the minimum learning rate, and $T = 150$ is the total number of training epochs.

Training is conducted on two NVIDIA RTX A6000 GPUs connected via NVLink with a total batch size of 8. Gradient clipping with a maximum norm of 1.0 is applied to prevent gradient explosion.

16. RESULT AND DISCUSSION

In this section, we present the dataset, evaluation metrics, experimental results of both Y-Mamba and U-Mamba architectures on the RadGenome-ChestCT dataset and discuss the

ISBN NR: 978-625-5694-92-8

implications of our findings.

16.1. Dataset

We employ the RadGenome-ChestCT dataset, a large-scale corpus that provides volumetric chest CT volumes, organ segmentation masks, and structured disease annotations. To enable supervised classification which provides structured multi-label disease annotations in the form of binary (one-hot) label vectors for each CT volume. In our pipeline, we use only the raw CT volumes and the corresponding binary disease labels; no radiology reports or natural language processing are involved. Together, these resources constitute one of the largest publicly available benchmarks for CT analysis.

The RadGenome-ChestCT dataset comprises 25,692 non-contrast chest CT volumes from 21,304 unique patients, with structured multi-label disease annotations. Following the methodology established in, we focus on 16 disease categories organized by anatomical organ system [12]. The 16 target disease categories span six organ groups: *Lung* (8 diseases: emphysema, atelectasis, lung nodule, lung opacity, pulmonary fibrotic sequela, mosaic attenuation pattern, consolidation, and interlobular septal thickening), *Heart* (3: cardiomegaly, pericardial effusion, and coronary artery wall calcification), *Pleura* (1: pleural effusion), *Mediastinum* (1: lymphadenopathy), *Esophagus* (1: hiatal hernia), and *Trachea & Bronchi* (2: peribronchial thickening and bronchiectasis). The dataset exhibits class imbalance, with prevalence rates varying substantially across conditions, from rare findings such as mosaic attenuation pattern and interlobular septal thickening to common pathologies such as lung opacity and coronary artery wall calcification.

The dataset is split into training, validation, and test sets following the official partition, ensuring no patient overlaps between splits. The training set contains approximately 20,000 volumes, with the remaining volumes distributed between validation and test sets.

16.2. Evaluation Metrics

We evaluate model performance using the following metrics, computed per disease category and averaged across all 16 classes:

Area Under the Receiver Operating Characteristic Curve (AUROC): Measures the model's discriminative ability across all classification thresholds, providing a threshold-independent assessment of performance:

$$\mathrm{AUROC} = \int_0^1 \mathrm{TPR}\big(\mathrm{FPR}^{-1}(t)\big)\, dt \tag{10}$$

F1 Score: The harmonic mean of precision and recall, computed at a threshold of 0.5:

$$\mathrm{F1} = \frac{2 \cdot \mathrm{Precision} \cdot \mathrm{Recall}}{\mathrm{Precision} + \mathrm{Recall}} \tag{11}$$

Accuracy: The overall proportion of correct predictions:

$$\mathrm{Accuracy} = \frac{\mathrm{TP} + \mathrm{TN}}{\mathrm{TP} + \mathrm{TN} + \mathrm{FP} + \mathrm{FN}} \tag{12}$$

Table 30: Per-Disease Performance of U-Mamba Architecture

Organ	Disease	AUROC	Acc.	F1
Lung	Emphysema	0.7572	0.7056	0.4625
	Atelectasis	0.7586	0.6545	0.5233
	Lung nodule	0.6136	0.5862	0.5846

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	Lung opacity	0.8434	0.7759	0.7071
	Pulm. fibrotic seq.	0.6374	0.6565	0.4244
	Mosaic att. pattern	0.8401	0.6943	0.2983
	Consolidation	0.8987	0.8031	0.5926
	Interlob. septal thick.	0.8436	0.6605	0.2789
Heart	Cardiomegaly	0.9463	0.8508	0.5322
	Pericardial effusion	0.8099	0.8183	0.3382
	Coronary art. calc.	0.8805	0.7566	0.6405
Pleura	Pleural effusion	0.9863	0.9463	0.7980
Mediastinum	Lymphadenopathy	0.7264	0.6890	0.5068
Esophagus	Hiatal hernia	0.7922	0.7374	0.4244
Trachea & Bronchi	Peribronchial thick.	0.7588	0.6605	0.2967
	Bronchiectasis	0.7106	0.6519	0.2779
Average		**0.8002**	**0.7280**	**0.4804**

16.3. Experimental Results

Table **29** presents the overall performance comparison between Y-Mamba and U-Mamba architectures across all evaluation metrics, averaged over 16 disease categories. Both architectures achieve comparable performance with near-identical overall metrics. Y-Mamba achieves a marginally higher AUROC of 0.8008 compared to 0.8002 for U-Mamba, and a slightly higher F1 score. Conversely, U-Mamba attains marginally higher accuracy. The F1 scores reflect the challenging nature of the multi-label classification task, particularly given the significant class imbalance in the dataset. The negligible overall performance gap suggests that both architectures are equally effective for this task, with neither holding a decisive advantage.

Table 31 presents the per-disease performance of Y-Mamba. Performance varies substantially across categories: pleural effusion (0.9851) and cardiomegaly (0.9423) achieve the highest AUROC, as these conditions present distinctive radiological patterns. Conversely, lung nodule (0.6230) and pulmonary fibrotic sequela (0.6328) are the most challenging, likely due to the small focal nature of nodules at $64 \times 128 \times 128$ resolution and the diffuse manifestation of fibrotic sequela. Table 30 shows U-Mamba's per-disease results, which follow a similar pattern to Y-Mamba. The same categories rank highest and lowest, though U-Mamba achieves marginally higher AUROC on several conditions such as cardiomegaly and pleural effusion. The results demonstrate that SSM-based architectures achieve competitive performance for multi-label thoracic disease classification with substantially lower computational cost.

Table 31: Per-Disease Performance of Y-Mamba Architecture

Organ	Disease	AUROC	Acc.	F1
Lung	Emphysema	0.7602	0.6373	0.4390
	Atelectasis	0.7518	0.6698	0.5293

ISBN NR: 978-625-5694-92-8

	Lung nodule	0.6230	0.6088	0.5674
	Lung opacity	0.8392	0.7891	0.7066
	Pulm. fibrotic seq.	0.6328	0.5723	0.4557
	Mosaic att. pattern	0.8461	0.7812	0.3478
	Consolidation	0.8941	0.8156	0.5959
	Interlob. septal thick.	0.8614	0.7487	0.3244
Heart	Cardiomegaly	0.9423	0.8475	0.5306
	Pericardial effusion	0.8158	0.7765	0.3219
	Coronary art. calc.	0.8724	0.7692	0.6427
Pleura	Pleural effusion	0.9851	0.9410	0.7802
Mediastinum	Lymphadenopathy	0.7404	0.6545	0.5014
Esophagus	Hiatal hernia	0.7854	0.6830	0.3980
Trachea & Bronchi	Peribronchial thick.	0.7378	0.6943	0.3088
	Bronchiectasis	0.7248	0.6379	0.2759
Average		**0.8008**	**0.7267**	**0.4829**

The linear complexity $\mathcal{O}(\mathrm{N})$ of the selective state space mechanism, compared to the quadratic $\mathcal{O}(\mathrm{N}^2)$ of self-attention, is critical for 3D volumes where the sequence length ($64 \times 128 \times 128 \approx 10^6$ voxels) makes a full attention matrix infeasible. The selective scan provides comparable global context modeling while adaptively focusing on diagnostically relevant regions.

The near-identical overall performance of Y-Mamba and U-Mamba indicates that the selective state space mechanism, rather than the specific macro-architecture, is the primary driver of effectiveness. The mixed per-disease results suggest that Y-Mamba's GSC blocks and U-Mamba's skip connections may capture complementary feature representations suited to different pathology types.

17. CONCLUSION

In this paper, we presented a comparative study of two state space model architectures, Y-Mamba and U-Mamba, for multi-label classification of 16 thoracic diseases from chest CT volumes. Using the RadGenome-ChestCT dataset, we demonstrated that both architectures achieve competitive performance, with Y-Mamba attaining an average AUROC of 0.8008 and U-Mamba achieving 0.8002. Both models exhibited strong discrimination for conditions with distinctive imaging patterns, such as pleural effusion and cardiomegaly, while facing challenges with rare or diffuse pathologies.

Our findings suggest that SSM-based architectures are viable alternatives to CNN and Transformer-based approaches for volumetric medical image classification, offering the key advantage of linear computational complexity. The comparable performance of Y-Mamba and U-Mamba suggests that the selective state space mechanism is the primary driver of effectiveness, with the specific macro-architecture playing a secondary role.

Future work will focus on several directions: exploring higher input resolutions to improve detection of small focal abnormalities, investigating ensemble approaches combining both architectures, extending the framework to incorporate multi-modal inputs such as clinical metadata and radiology reports, evaluating generalization across multiple datasets and clinical sites, and developing disease-specific threshold optimization strategies for clinical deployment.

ACKNOWLEDGEMENTS

This study was supported by Scientific and Technological Research Council of Turkey (TUBITAK) under the Grant Number 325S593 and TUBITAK 2209-B Research Project Support Programme for Undergraduate Students (Project No: 1139B412402748). The authors thank to TUBITAK for their supports.

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ISBN NR: 978-625-5694-92-8

PLEURAL EFFUSION CLASSIFICATION IN CHEST CT VOLUMES: A COMPARATIVE STUDY OF CNN AND VISION TRANSFORMER

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ABSTRACT

Pleural effusion is a common clinical finding on chest computed tomography (CT) that requires timely detection for accurate treatment. Despite extensive application of deep learning to thoracic image analysis, binary classification of pleural effusion directly from volumetric CT data remains underexplored, with most prior work focusing on chest radiographs rather than three-dimensional volumes. This study evaluates four deep learning architectures-two residual networks (ResNet18, ResNet50), DenseNet121, and a Vision Transformer (ViT)-for pleural effusion classification from chest CT volumes in the RadGenome-ChestCT dataset, which comprises 20,000 volumes with pronounced class imbalance. All architectures are trained from scratch under identical experimental settings, employing focal loss to mitigate class imbalance, while CT volumes are uniformly resampled to ensure consistent spatial resolution. The comparative analysis demonstrates that convolutional neural network-based architectures outperform the transformer-based architecture in this task, with DenseNet121 achieving the highest classification performance (Accuracy = 0.9495; F1 = 0.8808). The performance advantage of DenseNet121 likely reflects its dense connectivity structure, which promotes feature propagation and reuse across layers. These findings suggest that convolutional architectures retain a practical advantage over vision transformers for organ-focused volumetric classification tasks at limited dataset scales, offering actionable guidance for architectural selection in CT-based medical image analysis.

Keywords: Classification, Computed Tomography, Deep Learning, Pleural Effusion, Vision Transformer.

ISBN NR: 978-625-5694-92-8

18. INTRODUCTION

Pleural effusion, defined as the abnormal accumulation of fluid within the pleural cavity, is one of the most frequently observed findings in thoracic imaging. It may arise from a wide range of underlying conditions, including congestive heart failure, pneumonia, malignancy, and hepatic cirrhosis. Accurate identification of pleural effusion is therefore necessary for appropriate clinical evaluation and treatment planning. Chest computed tomography (CT) provides detailed three-dimensional (3D) visualization of thoracic anatomy and is commonly used to characterize pleural abnormalities. However, manual examination of volumetric CT data is time-consuming and may be affected by inter-observer variability, particularly in high-volume clinical environments [1]. Automated systems capable of detecting pleural effusion directly from CT volumes could assist radiologists by providing rapid preliminary assessments and facilitating prioritization of critical cases.

Deep learning methods have become widely adopted in medical image analysis during the last decade. Convolutional neural networks (CNNs), in particular, have demonstrated strong performance across a variety of medical image classification tasks [2, 3]. Residual networks (ResNet) introduced skip connections that enable the training of deeper architectures by alleviating the vanishing gradient problem. Dense convolutional networks (DenseNet) further improved feature propagation through dense connectivity, where each layer receives inputs from all preceding layers. In thoracic imaging, DenseNet-121 was employed in the CheXNet system to achieve radiologist-level performance for pneumonia detection from chest radiographs [4]. However, the direct extension of these architectures from two-dimensional (2D) radiographs to volumetric CT data introduces significant computational challenges due to increased memory consumption and parameter complexity [5]. Transformer-based vision architecture has recently emerged as an alternative paradigm for image representation learning. Vision Transformers (ViT) architecture global relationships through self-attention mechanisms applied to image patches [6]. Unlike CNN architectures that primarily capture local spatial patterns through convolutional kernels, ViT can learn long-range dependencies across the entire image. Transformer-based approaches have been adapted to medical imaging tasks through architectures such as UNETR [7] and Swin UNETR [8]. Nevertheless, self-attention operations introduce quadratic computational complexity with respect to the number of tokens, and transformer architectures generally require large-scale datasets for stable training. These requirements present practical limitations for many medical imaging applications, where annotated datasets are often relatively small. Although recent studies have explored multi-label disease classification from chest CT volumes, organ-specific binary classification tasks have received comparatively less attention [9]. In our companion study investigating multi-label classification using state-space architecture architectures, pleural effusion consistently achieved among the highest per-disease AUROC scores. This observation indicates that pleural effusion exhibits distinctive radiological characteristics that may be effectively captured by automated architectures. Consequently, a dedicated binary classification framework may provide practical advantages for targeted screening scenarios where rapid identification of a single pathology is required.

ISBN NR: 978-625-5694-92-8

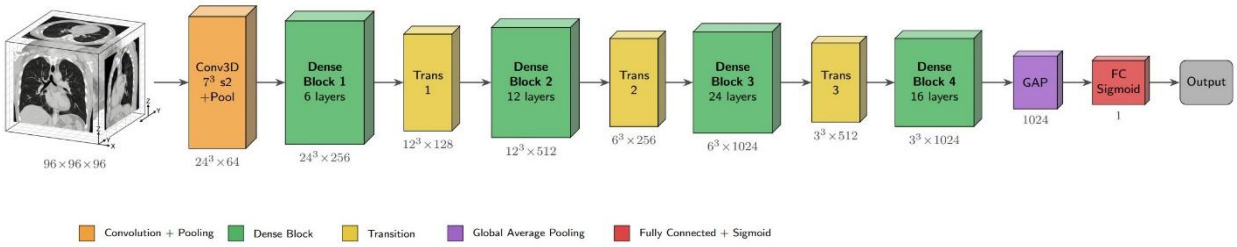

Figure 27: The Proposed DenseNet121 Architecture

In this study, a systematic comparison of four deep learning architectures for pleural effusion classification from chest CT volumes is presented. The evaluated architectures include ResNet18, ResNet50, DenseNet121, and Vision Transformer. The contributions of this study can be summarized as follows:

A comparative evaluation of four representative deep learning architectures for binary pleural effusion classification from chest CT volumes is presented, enabling a systematic comparison between convolutional and transformer-based approaches. Extensive experiments are conducted on the RadGenome-ChestCT dataset [10], one of the largest publicly available chest CT datasets, using isotropic 96×96×96 volumetric inputs and focal loss to address class imbalance. The behavior of Vision Transformer architectures in this setting is analyzed, and the factors influencing their performance, including limited data scale, short token sequences, and the absence of volumetric pretraining—are examined.

The remainder of this paper is organized as follows. Section 19 describes the preprocessing pipeline, network architecture, and training strategy. Section 3 presents the dataset, evaluation metrics, and experimental results with detailed analysis. Finally, Section 4 concludes the study and outlines potential directions for future research.

19. METHOD

This section presents the proposed framework for binary pleural effusion classification from chest CT volumes. The methodology consists of three main components: data preprocessing, architectures, and the training strategy applied during architecture optimization.

19.1. Dataset Preprocessing

All CT volumes are processed through a standardized preprocessing pipeline to ensure consistent spatial resolution and intensity distributions across the dataset.

First, intensity normalization is applied using Hounsfield Unit (HU) windowing. The HU values are clipped to the range [-1000, +1000], which covers the clinically relevant density interval from air-filled lung regions to dense calcified structures. The clipped values are subsequently normalized to the range [0,1].

Second, all CT volumes are resampled to a fixed isotropic spatial resolution and resized to $96 \times 96 \times 96$ voxels using trilinear interpolation. The isotropic representation ensures that anatomical structures and pleural fluid accumulations are consistently represented across different orientations and patient acquisitions. Finally, data augmentation is applied during training to improve architecture generalization and mitigate overfitting. The augmentation strategy includes random horizontal flipping, random rotation within ±10°, random intensity

ISBN NR: 978-625-5694-92-8

scaling within ±10%, and three-dimensional elastic deformation. These transformations introduce variability in spatial configuration and intensity distribution while preserving the underlying anatomical structure.

19.2. Deep Learning Architectures

Four deep learning architectures are evaluated for pleural effusion classification, representing two major architectural paradigms: convolutional neural networks and transformer-based vision architectures. All architectures are adapted to operate on volumetric CT data by replacing two-dimensional operations with their three-dimensional counterparts.

1) *Resnet:* Residual Networks (ResNet18 and ResNet50) employ residual connections that enable identity mappings across convolutional blocks, allowing deeper networks to be trained without performance degradation. The residual block computes

$$y = \mathcal{F}(x, \{W_i\}) + x \tag{1}$$

where $\mathbf{x}$ and $\mathbf{y}$ denote the input and output feature representations, $\mathcal{F}$ represents the residual transformation learned by stacked convolutional layers, and W_i denotes the learnable parameters. ResNet18 utilizes basic residual blocks consisting of two $3 \times 3 \times 3$ convolutional layers. ResNet50 employs bottleneck residual blocks composed of $1 \times 1 \times 1$, $3 \times 3 \times 3$, and $1 \times 1 \times 1$ convolutions, enabling deeper networks while maintaining computational efficiency.

2) *DenseNet:* DenseNet121 extends residual connectivity by introducing dense connections between all layers within each dense block. Each layer receives the concatenated feature maps from all preceding layers:

$$x_l = H_l([x_0, x_1, \dots, x_{l-1}]) \tag{2}$$

where $[\mathbf{x_0}, \mathbf{x}1, \dots, \mathbf{x}l - 1]$ represents feature map concatenation and H_l denotes a composite function consisting of batch normalization, ReLU activation, and $3 \times 3 \times 3$ convolution.

This dense connectivity enhances gradient propagation, encourages feature reuse, and reduces parameter redundancy. The DenseNet121 architecture contains four dense blocks with growth rate $k = 32$, resulting in a total depth of 121 layers.

3) *ViT:* The ViT processes volumetric inputs by dividing the CT volume into non-overlapping three-dimensional patches. Each patch is linearly projected into an embedding vector, forming a sequence of tokens that are processed by transformer encoder layers.

Table 32: Test Set Performance for Binary Pleural Effusion Classification

Model	Accuracy	Precision	Recall	F1
ResNet18	0.9370	0.8321	**0.8924**	0.8586
ResNet50	0.9384	**0.8570**	0.8306	0.8431
DenseNet121	**0.9444**	0.8538	0.8893	**0.8704**
ViT	0.8847	0.4424	0.5000	0.4694

ISBN NR: 978-625-5694-92-8

Each encoder layer consists of multi-head self-attention (MSA) followed by a feed-forward network (FFN). The attention mechanism is defined as

$$\text{Attention}(Q, K, V) = \text{softmax}\left(\frac{QK^T}{\sqrt{d_k}}\right)V \tag{3}$$

where **Q**, **K**, and **V** represent the query, key, and value matrices, respectively, and d_k denotes the key dimensionality.

Multiple attention heads operate in parallel:

$$\text{MSA}(Z) = \text{Concat}(\text{head}_1, \dots, \text{head}_h)W^O \tag{4}$$

A learnable classification token is appended to the patch sequence. The final representation of this token is used for binary classification.

4) *Classification Head:* All architectures employ a unified classification head to ensure fair comparison. The final feature representation is aggregated using global average pooling (GAP) and passed to a fully connected layer with sigmoid activation:

$$\hat{y} = \sigma(w^T \text{GAP}(z) + b) \tag{5}$$

where **z** denotes the final feature representation, **w** and b are learnable parameters, and $\hat{y} \in [0,1]$ represents the predicted probability of pleural effusion.

19.3. Training Strategy

All architecture optimization is performed using focal loss to address class imbalance between positive and negative samples [11]:

$$\mathcal{L}_{\mathcal{FL}} = -\alpha_t(1 - p_t)^\gamma \log(p_t) \tag{6}$$

where $p_t = \hat{y}$ when $y = 1$ and $p_t = 1 - \hat{y}$ otherwise. The balancing factor is set to $\alpha = 0.25$ and the focusing parameter to $\gamma = 2.0$. This loss formulation reduces the influence of well-classified samples and emphasizes harder training examples. All architectures are trained using the AdamW optimizer with an initial learning rate of 1×10^{-4} and weight decay of 1×10^{-5} [12]. A step decay learning rate schedule is employed:

$$\eta_t = \eta_0 \cdot 0.5^{\lfloor t/s \rfloor} \tag{7}$$

where η_0 denotes the initial learning rate, t represents the training epoch, and s is the step interval controlling the decay frequency. Training is performed on two NVIDIA RTX A6000 GPUs connected via NVLink with a total batch size of 8. All architectures are trained from scratch without pretrained weights to ensure a fair comparison under identical experimental conditions.

Table 33: Best Validation Performance for Binary Pleural Effusion Classification

Model	Accuracy	Precision	Recall	F1
ResNet18	0.9403	0.8551	0.9033	0.8594
ResNet50	0.9387	0.8608	0.8718	0.8467
DenseNet121	**0.9495**	**0.8875**	**0.9261**	**0.8808**
ViT	0.8824	0.4412	0.5000	0.4688

ISBN NR: 978-625-5694-92-8

20. RESULTS AND DISCUSSION

In this section, we present the dataset, evaluation metrics, and experimental results obtained from the evaluated architectures on the RadGenome-ChestCT dataset. The results are analyzed to examine the performance differences between convolutional neural networks and transformer-based architectures for binary pleural effusion classification.

20.1. Dataset

Experiments are conducted using the RadGenome-ChestCT dataset, which contains 25,692 non-contrast chest CT volumes collected from 21,304 unique patients. The dataset includes structured disease annotations provided by the CT-RATE annotation layer. These annotations contain binary labels for multiple thoracic conditions. For this study, the pleural effusion label is extracted to formulate a binary classification problem. Each CT volume is assigned either a positive label (presence of pleural effusion) or a negative label (absence of pleural effusion). The dataset is divided into training, validation, and test sets according to the official data partition. Patient-level separation is preserved to prevent overlap between splits. The test set contains 3,618 CT volumes.

20.2. Evaluation Metrics

All architecture performance is evaluated using four standard classification metrics: accuracy, precision, recall, and F1 score. Accuracy measures the proportion of correctly classified samples:

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}} \tag{8}$$

Precision represents the proportion of predicted positive samples that correspond to true positives:

$$\frac{\text{TP}}{\text{TP}+\text{FP}} \tag{9}$$

Recall (Sensitivity) measures the proportion of true positive samples that are correctly identified:

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}} \tag{10}$$

The F1 score represents the harmonic mean of precision and recall:

$$\text{F1} = \frac{2 \cdot \text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}} \tag{11}$$

These metrics provide complementary perspectives for evaluating binary classification performance.

20.3. Experimental Results

Error! Reference source not found. presents the performance of the evaluated architectures on the test set. DenseNet121 achieves the highest accuracy and F1 score among the architectures, indicating a balanced relationship between precision and recall. ResNet18 achieves the highest recall value, suggesting stronger detection of positive samples. ResNet50 produces the highest precision, indicating fewer false positive predictions. The Vision Transformer shows lower performance compared with the convolutional architectures. Table 33 reports the best validation results observed during training. The validation results follow a similar pattern to the test set results. DenseNet121 achieves the highest values across all

evaluation metrics, indicating consistent architecture behavior across different data splits. The experimental results indicate that convolutional architectures consistently achieve higher performance than the transformer-based architecture for this task. All CNN-based architectures obtain accuracy values above 93% and F1 scores above 0.84, while the Vision Transformer produces lower recall and F1 score values under the same experimental conditions. Among the evaluated convolutional architectures, DenseNet121 provides the most balanced performance across the evaluated metrics. The dense connectivity structure enables feature reuse across layers and supports stable gradient propagation during training. ResNet18 achieves slightly higher recall than ResNet50, whereas ResNet50 produces higher precision. This observation suggests that increased network depth does not necessarily provide additional benefits for this binary classification task. The Vision Transformer exhibits lower performance in this experimental setting. Transformer architecture typically requires larger training datasets or pretrained initialization in order to learn spatial relationships effectively. The relatively short token sequence derived from the 96 × 96 × 96 volumetric input may also limit the advantages of global self-attention mechanisms. Overall, the results indicate that DenseNet121 provides the most balanced classification performance for pleural effusion detection from chest CT volumes under the evaluated experimental conditions.

21. CONCLUSION

In this paper, a comparative evaluation of four deep learning architectures for binary pleural effusion classification from chest CT volumes was presented. Experiments conducted on the RadGenome-ChestCT dataset showed that convolutional neural network architectures achieved higher performance than the transformer-based architecture when trained from scratch under identical experimental conditions. Among the evaluated architectures, DenseNet121 obtained the highest accuracy and F1 score, demonstrating a balanced relationship between precision and recall. The dense connectivity structure facilitates feature reuse across layers and enables stable feature propagation during training. The Vision Transformer produced lower performance compared with the convolutional architectures. This observation indicates that transformer-based architectures may require larger datasets or pretrained initialization in order to learn effective spatial representations in volumetric medical imaging tasks. Future research will investigate several directions. First, the impact of volumetric pretraining strategies on transformer-based architectures will be examined, including self-supervised pretraining using large-scale unlabeled CT datasets. Second, the proposed binary classification framework can be extended to additional thoracic conditions such as pericardial effusion and pneumothorax. Third, architecture generalization across different clinical institutions and scanner manufacturers will be evaluated. In addition, ensemble approaches combining multiple convolutional architectures may provide improved robustness. Finally, future studies may incorporate severity estimation mechanisms that quantify pleural effusion volume and categorize cases into multiple clinical severity levels for more detailed decision support.

ACKNOWLEDGEMENTS

This study was supported by Scientific and Technological Research Council of Turkey (TUBITAK) under the Grant Number 325S593 and TUBITAK 2209-B Research Project Support Programme for Undergraduate Students (Project No: 1139B412402748). The authors

thank to TUBITAK for their supports.

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ISBN NR: 978-625-5694-92-8

PERSONALIZED AND SEASON-AWARE GLUCOSE PREDICTION USING WEARABLE SENSOR DATA WITH HYBRID KALMAN FILTER AND Q-LEARNING

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ABSTRACT

Accurate glucose prediction is critical for managing type 1 diabetes and preventing hypoglycemic and hyperglycemic events in daily life. While continuous glucose monitoring (CGM) systems enable real-time tracking of glucose levels, they lack the ability to predict future glucose fluctuations. Recent machine learning approaches have shown outstanding performance; however, existing approaches commonly require manual input of metabolic variables such as insulin doses and carbohydrate intake, limiting long-term usability in free-living conditions. Moreover, fixed-parameter models fail to capture both individual physiological differences and seasonal variability in metabolic dynamics. To address these limitations, this study proposes a hybrid system that integrates the Kalman filter (KF) with Q-learning (QL), where QL dynamically adapts filter noise parameters based on user-specific physiological characteristics and seasonal conditions, enabling personalized and season-aware glucose prediction from wearable sensor data. Experiments on the GlucoWear-T1DM dataset, comprising wearable sensor recordings from type 1 diabetes patients across summer and winter conditions, show that season-specific KF+QL models outperform both fixed-parameter and combined-season baselines, with the optimal physiological parameter configuration differing between seasons. These findings demonstrate the effectiveness of adaptive, season-aware modeling for personalized glucose prediction in wearable health systems.

Keywords: Kalman Filter, Q-Learning, Reinforcement Learning, Wearable Sensor, Glucose Prediction.

1. INTRODUCTION

Diabetes mellitus has become a significant global public health concern due to its steadily increasing prevalence [1]. The chronic nature of the disease and the lifelong requirement for glucose management necessitate regular and systematic monitoring of glucose levels. Acute fluctuations in glucose—both rapid rises and drops—increase the risk of short-term complications, while sustained dysregulation can lead to long-term microvascular and macrovascular damage. For decades, fingertip blood measurements served as the primary glucose monitoring method. However, their invasive nature and limited measurement frequency prevent them from capturing rapid intraday glucose fluctuations. To address this

limitation, continuous glucose monitoring (CGM) systems have been developed, and clinical studies have demonstrated that CGM use significantly improves glycemic control in type 1 diabetes patients [2].

Nevertheless, CGM systems lack the ability to predict future glucose changes, which is particularly critical for the early detection of hypoglycemic and hyperglycemic events [3]. In recent years, machine learning-based glucose prediction models have attracted considerable attention [4]. A substantial portion of these studies combine CGM data with manually entered information such as insulin doses and carbohydrate intake [5]. However, this reliance on manual data entry introduces user errors, missing records, and declining long-term adherence, which can adversely affect model performance [6]. These limitations have directed research toward user-independent data sources. In this context, physiological data obtained from wearable sensors—including heart rate, blood pressure, step count, and body temperature—have gained increasing importance for glucose prediction, as they can be recorded continuously and automatically without user intervention [7]. Bogue-Jimenez et al. demonstrated that clinically acceptable glucose predictions can be achieved using wrist-worn wearable sensor data without manual insulin or carbohydrate inputs [8]. Similarly, Karunarathna and Liang developed a multivariate glucose prediction model by pairing heart rate, electrodermal activity, physical activity, and sleep data collected via wearable sensors with approximately 26,000 CGM measurements under free-living conditions [9].

Despite the promise of wearable sensor-based approaches, the physiological parameters they capture exhibit significant variability depending not only on daily activity levels and sleep patterns but also on individual metabolic characteristics and seasonal environmental conditions [10]. This variability complicates glucose prediction with fixed, one-size-fits-all models. Specifically, temperature fluctuations, physical activity levels, and metabolic responses can differ substantially across seasons and individuals, directly affecting sensor measurement accuracy and glucose dynamics over time [11]. Consequently, the seasonal and individual variability observed in wearable sensor data limits the performance of fixed-parameter models and highlights the need for user-specific, adaptive, and flexible prediction models [9]. Kalman filter (KF) techniques offer a principled framework for state estimation in noisy sequential data [12]. However, their fixed process noise (Q) and measurement noise (R) covariance parameters limit adaptability to nonlinear and time-varying physiological dynamics. In contrast, reinforcement learning approaches, such as Q-learning (QL), offer adaptive capabilities with low computational overhead [13]. However, QL alone suffers from data inefficiency, high variance, and instability in exploration–exploitation balance. To overcome these challenges, our previous studies proposed a hybrid approach integrating QL with KF for glucose prediction using the OhioT1DM dataset [14], [15], [16]. These studies demonstrated that QL-enhanced hybrid models achieve superior prediction accuracy, particularly for medium- and long-term prediction horizons, by dynamically adapting filter parameters.

Building upon these findings, this study extends the hybrid KF+QL framework to wearable sensor data and investigates the impact of seasonal variability on glucose prediction performance. The proposed approach evaluates the KF+QL hybrid model across summer,

ISBN NR: 978-625-5694-92-8

winter, and combined seasonal datasets collected from wearable sensors, identifying the optimal physiological parameter combination for each season.

The rest of the paper is structured as follows: Section 2 provides comprehensive details on the proposed hybrid KF+QL approach, including the KF variants and QL integration. The experimental evaluations and comparison of the models are presented in Section 3. Finally, concluding remarks are given in Section 4.

2. METHOD

This section describes the components of the proposed hybrid prediction framework. The system integrates KF-based state estimation with QL-based adaptive parameter optimization, where separate models are trained for each seasonal period to enable season-specific filter parameter convergence.

2.1. Kalman Filter

The Kalman filter (KF) family includes three main variants: the standard KF, the extended Kalman filter, and the unscented Kalman filter [12]. The standard KF is a recursive state estimation algorithm designed for linear systems. It operates through two phases: in the prediction phase, the current state estimate and error covariance are projected forward using a linear state-transition model; in the update phase, the prediction is corrected based on the incoming measurement and the Kalman gain. The extended Kalman filter relaxes the linearity assumption by linearizing nonlinear state-transition and observation functions around the current estimate using Jacobian matrices [15], whereas the unscented Kalman filter avoids linearization altogether by propagating a set of deterministically chosen sigma points through the true nonlinear functions [17]. Although these advanced variants can capture nonlinear dynamics more accurately, they introduce additional computational complexity. In this study, the standard KF is used, as the prediction targets involve short-term glucose dynamics that exhibit predominantly linear behavior.

2.2. Q-Learning

Q-learning (QL) is a reinforcement learning algorithm that learns an optimal action-selection policy by iteratively updating a Q-table [13]. The Q-table stores the expected cumulative reward for each state–action pair. At each time step, the agent observes the current state s(t), selects an action a(t), receives a reward r(t), and transitions to the next state s(t+1). The Q-value is updated according to the Bellman equation as given in Eq. (1):

$$Q(s,a) \leftarrow Q(s,a) + \alpha[r + \gamma \cdot \max Q(s',a') - Q(s,a)] \quad (1)$$

where Q(s, a) is the expected cumulative reward for state–action pair (s, a), α is the learning rate, r is the immediate reward, γ is the discount factor, s′ denotes the next state, a′ denotes the next action, and max Q(s′, a′) represents the maximum expected future reward over all possible actions in the next state.

The reward function is designed to provide feedback based on prediction accuracy, as formulated in Eq. (2):

$$r(t) = 15 - 15 \cdot |e(t)| + 3 \cdot (|e(t-1)| - |e(t)|) \quad (2)$$

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where r(t) is the reward at time step t, e(t) is the prediction error at time t, and e(t−1) is the prediction error at the previous time step. The constant 15 serves as both the baseline reward and the error penalty scaling factor, while the constant 3 weights the improvement bonus. The first term establishes an inverse relationship between reward and absolute error, while the second term rewards error reduction over consecutive time steps, encouraging continuous improvement.

2.3. Proposed Hybrid Approach

The core insight of the proposed hybrid approach is that the process noise covariance (Q) and measurement noise covariance (R) parameters in KF-based models are conventionally set as fixed values, which limits their ability to adapt to time-varying and user-specific physiological dynamics. By integrating QL with KF variants, these parameters are dynamically optimized through a learning process rather than remaining static throughout prediction.

At each prediction step, the hybrid system operates as follows: (i) the KF variant produces a glucose prediction using the current Q and R values; (ii) the prediction error is computed and the current state is defined based on the error magnitude; (iii) the QL agent selects optimal Q and R values from the Q-table based on the current state; (iv) a new prediction is made with the updated parameters; (v) the reward is computed using Eq. (2); and (vi) the Q-table is updated according to Eq. (1). This iterative process creates a more robust and adaptive glucose prediction system that can personalize its behavior for each user by maintaining individual Q-tables.

A key contribution of this study is the seasonal evaluation strategy. Rather than training a single model on combined data, the proposed system evaluates the KF+QL hybrid model separately for each seasonal period—summer, winter, and combined—to determine whether season-specific models yield higher prediction accuracy than a unified approach. Furthermore, the optimal physiological parameter combination is selected dynamically based on the prediction horizon and seasonal context [18].

3. EXPERIMENTAL EVALUATIONS

3.1. Dataset and Performance Metrics

The GlucoWear-T1DM dataset, collected from type 1 diabetes patients using wearable smartwatches under clinical supervision, was used in this study. The dataset comprises multivariate physiological parameters including glucose, heart rate, step count, sleep duration, body temperature, blood oxygen saturation (SpO_2), and blood pressure, recorded at regular intervals during daily living conditions. To capture seasonal variability, data were collected in two periods: winter (November 2023–February 2024) from 13 patients and summer (May 2024–July 2024) from 14 patients. After removing patients with excessive missing measurements, 11 patients were retained for analysis. Three dataset configurations were evaluated: summer, winter, and summer+winter (combined).

The prediction performance was evaluated using the root mean square error (RMSE), as defined in Eq. (3).

ISBN NR: 978-625-5694-92-8

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(z_i - \hat{z}_i)^2} \quad (3)$$

In this formulation, n denotes the total number of prediction samples, z_i represents the actual measured glucose value at time step i, and $\hat{z}_i$ is the corresponding predicted value. A 5-minute

Table 1. Filter comparison results for 3 datasets at 5-min prediction horizon

DATASET	METHOD	1 PAR.	2 PAR.	3 PAR.	4 PAR.	5 PAR.
SUMMER	**KF**	12.84	14.87	14.07	13.59	16.98
	KF+QL	**9.14**	**4.71**	**5.51**	**7.10**	**7.94**
WİNTER	**KF**	12.43	13.97	13.94	13.10	19.10
	KF+QL	**7.48**	**7.48**	**8.29**	**7.91**	**11.90**
COMBİNED	**KF**	**13.05**	15.06	**14.45**	**13.74**	18.19
	KF+QL	14.44	**14.18**	14.73	18.54	**15.92**

prediction horizon was selected to capture short-term glucose dynamics relevant to immediate clinical decision-making. Two approaches—baseline KF and the hybrid KF+QL model—were compared across 15 configurations per approach: 3 datasets × 5 parameter counts (1 to 5 physiological input parameters). The parameter count indicates how many physiological input features are used, ranging from 1 parameter (glucose only) to multivariate configurations (up to 5 parameters).

3.2. Results and Discussion

The comparative results for the summer, winter, and combined datasets are presented in Table 1. All results are reported as average RMSE values computed using Eq. (3) across 11 patients.

In the summer dataset, the baseline KF produced an RMSE of 12.84 with 1 parameter (glucose only). The KF+QL hybrid model substantially improved prediction accuracy across most parameter configurations: the best performance was achieved with 2 parameters (glucose and systolic blood pressure), yielding an RMSE of 4.71. KF+QL also outperformed pure KF with 3 parameters (glucose, systolic blood pressure, and diastolic blood pressure; RMSE 5.51), 4 parameters (glucose, temperature, pulse, and systolic blood pressure; RMSE 7.10), and 5 parameters (glucose, temperature, pulse, pulse lag, and systolic blood pressure; RMSE 7.94). Even with 1 parameter, KF+QL reduced the error from 12.84 to 9.14. These results indicate that QL-based adaptive parameter tuning is highly effective for summer glucose dynamics, and that the inclusion of systolic blood pressure as an additional input feature provides the greatest complementary benefit. Notably, systolic blood pressure appeared in every top-performing configuration (2 through 5 parameters), underscoring its central role in summer glucose prediction.

In the winter dataset, the baseline KF achieved an RMSE of 12.43 with 1 parameter (glucose only). The KF+QL hybrid model improved prediction accuracy across most configurations: the best performance was achieved with 1 and 2 parameters (glucose only; and glucose with pulse), both yielding an RMSE of 7.48. KF+QL also outperformed pure KF with 4 parameters (glucose, temperature, pulse, and systolic blood pressure; RMSE 7.91) and 3 parameters (glucose, pulse, and systolic blood pressure; RMSE 8.29). With 5 parameters, KF+QL reduced the error from

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19.10 to 11.90. Unlike the summer dataset where systolic blood pressure was the dominant secondary parameter, winter results indicate that pulse provides the greatest complementary benefit, appearing in the top-performing 2-parameter configuration.

When summer and winter data were combined, the results exhibited markedly different characteristics compared to the seasonal datasets. The baseline KF produced an RMSE of 13.05 with 1 parameter (glucose only), which was the lowest KF score across all configurations. Unlike the seasonal datasets, KF+QL did not outperform the pure KF in the combined setting. Across all configurations, KF+QL yielded: 1 parameter (glucose only; RMSE 14.44), 2 parameters (glucose and pulse lag; RMSE 14.18), 3 parameters (glucose, pulse, and pulse lag; RMSE 14.73), 4 parameters (glucose, temperature, pulse, and systolic blood pressure; RMSE 18.54), and 5 parameters (glucose, temperature, pulse, systolic blood pressure, and pulse lag; RMSE 15.92). The best KF+QL result of 14.18 exceeded the KF baseline of 13.05, and none of the configurations improved upon the corresponding KF baselines. These results can be explained through the Q-table convergence mechanism: in season-specific datasets, the Q-table receives consistent reward signals from homogeneous physiological dynamics, enabling it to converge toward optimal process noise (Q) and measurement noise (R) parameters for that particular season. However, in the combined dataset, the Q-table simultaneously receives training signals from two fundamentally different seasonal contexts. Because physiological parameters such as blood pressure, heart rate, and metabolic activity vary systematically between summer and winter periods, parameter adjustments that are rewarded during summer episodes are penalized during winter episodes, and vice versa. This conflicting reward structure prevents the Q-table from converging to a stable parameter policy, resulting in continuous oscillation of the learned Q and R values and ultimately degrading prediction performance below the pure KF baseline. Critically, the QL agent does not merely fail to improve KF performance — it actively degrades it, because the non-converged Q-table effectively applies Q and R values calibrated for one season to data from the other season. This cross-season miscalibration is analogous to using summer-tuned filter parameters on winter data: the resulting parameter settings are not just suboptimal but systematically mismatched to the current physiological dynamics, producing predictions that are worse than those of a fixed-parameter KF that at least maintains consistent, if imperfect, calibration.

The QL-based agent maintained individual Q-tables for each patient, enabling user-specific parameter updates. This per-patient design allows the QL agent to learn personalized Q and R tuning policies that reflect each individual's unique metabolic characteristics, rather than applying a single population-level policy. In the seasonal datasets, this personalization contributed to consistent improvements across all parameter configurations, as the Q-table for each patient converged toward individually optimal filter parameters. In the combined dataset, however, even per-patient Q-tables could not overcome the conflicting seasonal dynamics described above, confirming that the seasonal signal mismatch operates at a fundamental level that individual calibration alone cannot resolve.

Beyond the performance differences across datasets, a cross-seasonal analysis of the optimal parameter configurations reveals an important pattern. Each dataset favors a different optimal secondary parameter: systolic blood pressure for summer, pulse for winter, and pulse lag for

the combined dataset. Moreover, the inclusion of temperature generally degrades prediction accuracy across all three datasets (e.g., summer 4-parameter RMSE of 7.10 vs. 3-parameter RMSE of 5.51; winter 5-parameter RMSE of 11.90 vs. 4-parameter RMSE of 7.91), suggesting that body temperature does not carry meaningful predictive information for short-term glucose dynamics. This season-dependent variation in the optimal secondary parameter provides further evidence that a single mixed-season model cannot capture the distinct physiological relationships present in each season, reinforcing the necessity of training separate models for each seasonal period, in which both the Q-table policy and the physiological parameter configuration are optimized independently.

4. CONCLUSION

This study presented a comparative analysis of KF and KF+QL for seasonal and personalized glucose prediction using wearable sensor data. The two approaches were evaluated across summer, winter, and combined seasonal datasets collected from the GlucoWear-T1DM wearable sensor recordings of 11 type 1 diabetes patients, using 1 to 5 physiological parameter configurations. The results demonstrated that KF+QL substantially improves prediction accuracy in season-specific datasets—achieving the best RMSE of 4.71 in summer with 2 parameters (glucose and systolic blood pressure) and 7.48 in winter with 1 and 2 parameters (glucose only, and glucose with pulse)—but does not outperform the pure KF baseline of 13.05 when summer and winter data are combined. The optimal secondary parameter varies by season—systolic blood pressure in summer versus pulse in winter—underscoring that both the filter parameters and the physiological input configuration must be optimized separately for each season. The consistently lower errors of season-specific models confirm that training separate KF+QL models per seasonal period is essential for accurate glucose prediction. Future work will focus on evaluating nonlinear filtering approaches such as the extended Kalman filter and unscented Kalman filter, as well as expanding the study with broader patient cohorts, clinical validation, and hybrid deep learning models.

ACKNOWLEDGEMENTS

This study was supported by the Scientific and Technological Research Council of Turkey (TUBITAK) under project no. 1919B012400965, the Health Institutes of Turkey (TUSEB) under project no. 43858, and the scientific research projects coordination unit of Izmir Katip Celebi University. The authors thank TUBITAK, TUSEB, and Izmir Katip Celebi University for their support.

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ISBN NR: 978-625-5694-92-8

NONLINEAR PEAK DECONVOLUTION OF MIXED ELECTROCHEMICAL SIGNALS USING MACHINE LEARNING FOR ACCURATE DOPAMINE QUANTIFICATION

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ABSTRACT

Nonlinear peak deconvolution under chemically coupled conditions remains a fundamental challenge in electrochemical signal analysis. When multiple electroactive species coexist, their mutual interactions induce concentration-dependent peak overlap, distortion, and nonlinear shifts that invalidate conventional linear calibration and peak-based separation methods. Dopamine (DA) quantification in the presence of hydroquinone (HQ) provides a challenging and practically relevant benchmark for nonlinear peak deconvolution under chemically coupled conditions. This study introduces a physics-guided, data-driven framework for nonlinear peak deconvolution and selective DA quantification in mixed electrochemical systems. Voltammetric signals are first represented using a compact Fourier-based formulation to obtain a continuous and morphologically interpretable description of signal behavior. Nonlinear interaction effects across the DA–HQ concentration space are modeled via two-dimensional interpolation, enabling reconstruction of mixed signals under coupled conditions. The reconstructed signals are subsequently parameterized using Gaussian peak models to extract DA-specific characteristics, including concentration, peak center, width, and amplitude. Random Forest regression is employed to estimate DA peak parameters directly from mixed-signal descriptors, enabling nonlinear deconvolution without reliance on explicit linear calibration. Model robustness is assessed using group-wise cross-validation across DA concentration levels to ensure generalization to unseen interference scenarios. Experimental results demonstrate reliable DA peak recovery and accurate quantification under strong HQ interference. The proposed framework is implemented as an integrated desktop application, *DopamineFinder*, providing real-time signal synthesis, nonlinear deconvolution, and interactive visualization capabilities.

Keywords: Nonlinear Peak Deconvolution, Dopamine Quantification, Electrochemical Sensing, Voltammetric Signal Analysis, Machine Learning

1. INTRODUCTION

Dopamine (DA, 3,4-dihydroxyphenethylamine) is a key catecholaminergic neurotransmitter that plays a fundamental role in the regulation of motor activity, reward processing, learning, and higher cognitive functions within the mammalian central nervous

ISBN NR: 978-625-5694-92-8

system [1], [2]. Alterations in dopaminergic signaling have been strongly implicated in a broad spectrum of neurological and psychiatric disorders, including Parkinson's disease, schizophrenia, and addiction, reflecting the central role of DA in both motor and cognitive brain functions [3], [4]. Accurate and reliable quantification of DA in biological and chemical environments therefore represents a critical requirement for both clinical diagnostics and fundamental neuroscience research [5], [6].

Electrochemical sensing techniques have been widely adopted for DA detection owing to their high analytical sensitivity, rapid temporal response, low instrumentation cost, and inherent compatibility with miniaturized and portable sensor platforms [7], [8]. Among the available electrochemical methodologies, differential pulse voltammetry (DPV) has emerged as a particularly effective approach for DA analysis. By combining pulsed excitation with differential current sampling, DPV selectively enhances faradaic responses while suppressing capacitive background contributions, yielding an improved signal-to-noise ratio that enables reliable detection of electroactive species at low concentration levels [9]. These analytical advantages make DPV especially well-suited for neurotransmitter sensing; however, the technique faces significant challenges when target analytes coexist with electrochemically similar interferents in complex sample matrices.

Despite these advantages, electrochemical DA sensing in complex matrices remains challenging due to the presence of coexisting electroactive species — such as ascorbic acid, uric acid, and hydroquinone — whose oxidation potentials closely overlap with DA [10], [11]. Among these interferents, hydroquinone (HQ, 1,4-dihydroxybenzene) poses a particularly severe challenge [12], [13]. HQ is frequently encountered in environmental, pharmaceutical, and industrial samples and exhibits redox activity at potentials that strongly coincide with those of DA and structurally related phenolic compounds [14], [15]. Experimental studies based on differential pulse and cyclic voltammetry have shown that HQ generates oxidation peaks that are nearly inseparable from those of DA, precluding reliable quantification through simple peak height or area measurements [12]. More critically, the presence of HQ does not merely produce additive signal overlap; it induces pronounced nonlinear distortion effects on the apparent DA response, including peak shifting, broadening, and amplitude modulation. These effects arise from coupled electrochemical interactions rather than linear superposition, rendering conventional calibration and peak-separation strategies fundamentally inadequate in mixed sensing environments. This distinction — between additive overlap and interaction-driven nonlinear distortion — motivates the development of model-based and data-driven deconvolution approaches capable of recovering analyte-specific information from complex voltammetric signals. These observations are supported by recent experimental evidence. Giordano et al. demonstrated that the simultaneous detection of DA and interfering compounds produces severe peak overlap that renders conventional linear separation and calibration approaches unreliable [14]. Similarly, Doménech-Carbó et al. reported that matrix effects and nonlinear electrochemical interactions inherent to voltammetric systems cannot be adequately captured by linear calibration models [15]. These findings confirm that traditional signal processing methods based on linear peak superposition are fundamentally limited in mixed-analyte environments where coupled redox processes govern signal morphology.

ISBN NR: 978-625-5694-92-8

Addressing this challenge requires modeling frameworks that explicitly account for nonlinear peak interactions and leverage physically interpretable signal representations to resolve overlapping electrochemical responses.

To address this issue, a nonlinear peak deconvolution framework is presented that integrates Fourier-based signal representation, two-dimensional interpolation over DA and HQ concentration axes, Gaussian peak parameterization, and Random Forest regression (RFR). Rather than relying on direct concentration calibration, the framework learns nonlinear mappings between mixed-signal descriptors and DA-specific peak characteristics. This formulation enables robust DA quantification under coupled interference conditions where conventional linear methods fail. Framework performance is validated on both experimentally acquired DPV measurements and systematically generated interpolated datasets, with group-wise cross-validation ensuring generalization to unseen DA concentration levels.

The remainder of this paper is organized as follows. Section 2 presents the proposed nonlinear peak deconvolution, covering experimental data acquisition, Fourier-based signal representation, nonlinear peak parameter extraction, feature construction, RFR, and the developed desktop application. Section 3 reports the experimental evaluation, including dataset construction, evaluation metrics, and results. Section 4 concludes the paper and outlines directions for future work.

2. METHOD

The proposed framework consists of four main stages: (i) signal acquisition and Fourier-based representation, (ii) nonlinear peak parameter extraction via Gaussian fitting and dataset expansion through two-dimensional interpolation, (iii) feature construction and RFR for DA peak deconvolution, and (iv) integration into an interactive desktop application. Figure 28 provides an overview of the complete processing pipeline.

2.1. Signal Acquisition and Fourier-Based Representation

The proposed framework operates on DPV measurements acquired under controlled experimental conditions across systematic DA–HQ concentration combinations. All signals were recorded using screen-printed carbon electrodes (SPCEs) with an integrated Ag/AgCl reference electrode in 0.1 M phosphate-buffered saline (PBS, pH 7.4), with a potential window of −0.6 to +0.6 V (vs. Ag/AgCl) and a pulse amplitude of 50 mV. Each measurement was stored together with its corresponding concentration pair. A standardized preprocessing pipeline was applied to suppress noise and baseline drift while preserving analyte-dependent peak characteristics. Preprocessed signals were aligned onto a common potential axis and normalized for comparability prior to subsequent Fourier-based representation. Preprocessed voltammetric signals were represented using a Fourier series expansion to obtain a smooth, compact, and fixed-dimensional parametric description of the electrochemical response. An eighth-order Fourier series (Fourier8) was adopted, as it was empirically determined to provide an effective balance between representational accuracy and model complexity. Lower-order representations were insufficient to capture subtle peak distortions observed in voltammetric responses, while higher-order expansions introduced high-frequency components that predominantly reflect

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noise rather than electrochemical information [9], [16]. Increasing model order beyond the

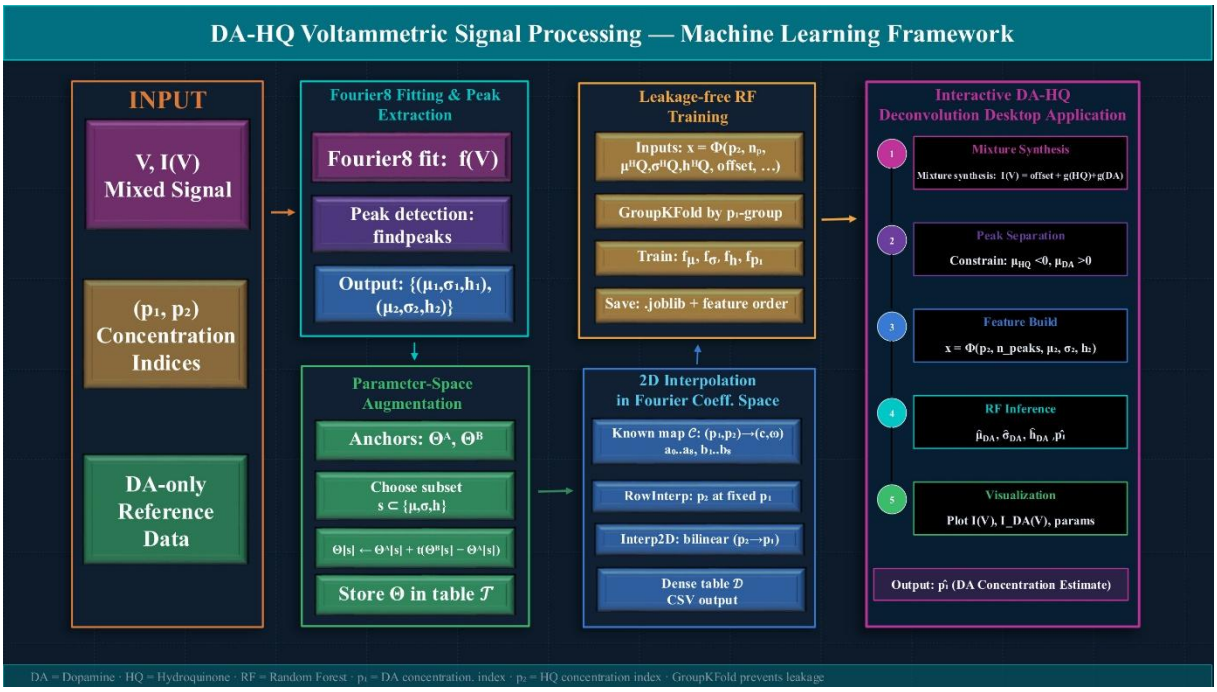

Figure 28. Proposed DA--HQ voltammetric signal processing and machine learning framework. The pipeline includes (i) Fourier8-based signal fitting and peak extraction, (ii) parameter-space augmentation via anchor interpolation, (iii) leakage-free Random Forest training using GroupKFold splitting, (iv) two-dimensional interpolation in Fourier coefficient space, and (v) interactive desktop-based DA--HQ deconvolution and concentration estimation.

intrinsic signal complexity leads to overfitting [17].

The Fourier-based signal model is defined as:

$$f(x) = a_0 + \sum_{k=1}^{8} [a_k \cos(kwx) + b_k \sin(kwx)] \tag{1}$$

where x denotes the applied potential (V), f (x) represents the measured current response, and ω is the fundamental angular frequency. The coefficient a_0 corresponds to the constant (DC) component of the signal and represents the baseline current level, while a_k and b_k are the cosine and sine coefficients associated with the k-th harmonic, respectively. Collectively, these coefficients encode both the global signal morphology and localized peak-related variations.

2.2. Nonlinear Peak Parameter Extraction and Dataset Expansion

Reconstructed voltammetric signals were analyzed to extract DA-related peak parameters, as illustrated in Figure 29. Signals reconstructed in the potential domain were modeled using a Gaussian peak formulation. Each peak was modeled as:

$$g(x) = e^{\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)} h \tag{2}$$

where μ denotes the peak center potential, σ the peak width, and h the peak amplitude. These

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parameters describe the position, dispersion, and intensity of the oxidation response and constitute the primary regression targets.

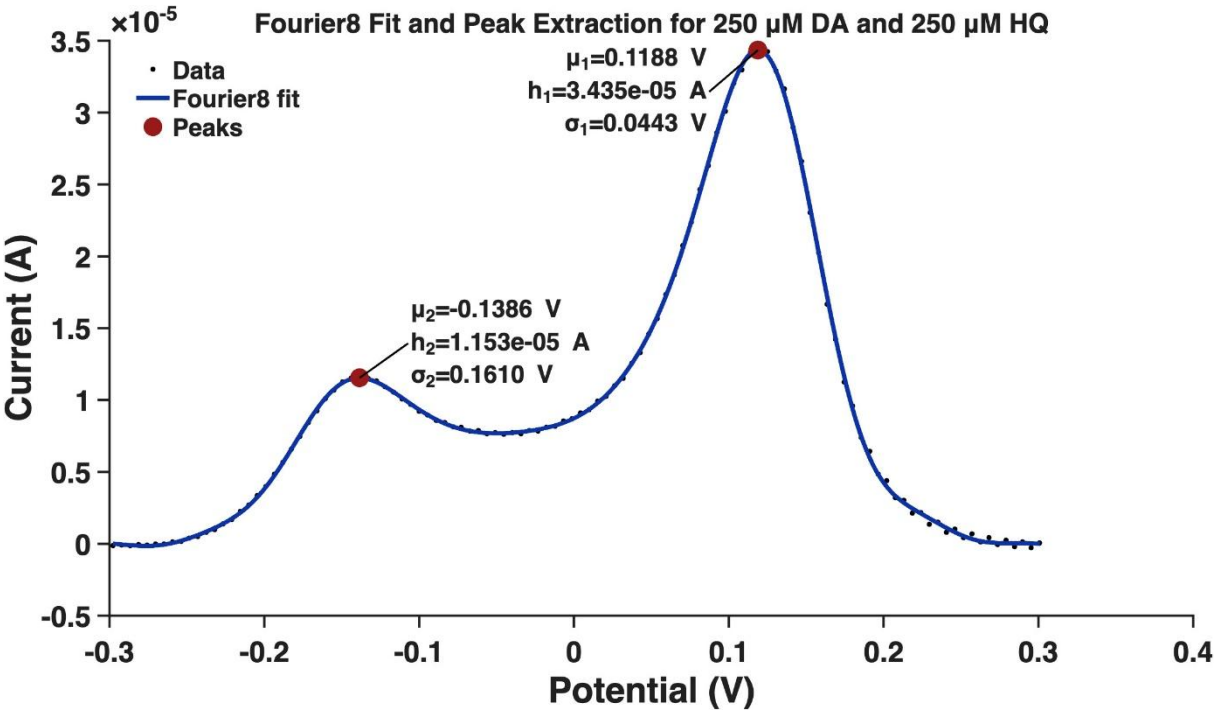

Figure 29. Gaussian peak detection and parameter extraction from a reconstructed mixed DA–HQ voltammetric signal. The dominant and secondary peaks are identified, and the corresponding parameters (μ, σ, h) are estimated for nonlinear modeling.

In mixed DA-HQ signals, candidate peak regions were identified using prominence-based peak detection, followed by nonlinear least-squares optimization to refine the Gaussian parameters. Two-dimensional interpolation of Fourier coefficients across DA and HQ concentration axes produces reconstructed signals with smoothly varying peak morphology, yielding Gaussian parameters that vary continuously across the concentration space.

2.3. Feature Construction and Random Forest Regression

For each DA concentration level, two signal types were considered: (i) a mixed DA–HQ response, and (ii) a DA-only reference signal acquired at the same DA concentration without HQ. Gaussian peak fitting was applied to the mixed signal to extract apparent peak parameters, which serve as regression inputs. The DA-only signal provides ground-truth peak parameters — center μ_{DA}, width σ_{DA}, and amplitude h_{DA}— that serve as regression targets. The learning task consists of mapping distorted mixed-signal descriptors to intrinsic DA peak characteristics.

Two concentration indices, p_1 (DA) and p_2 (HQ), encode nominal concentration levels and support group-wise validation. The number of detected peaks, n_{peaks}, distinguishes single-peak DA-dominant responses from multi-peak DA–HQ mixtures. Gaussian parameters (μ_1, σ_1, h_1) and (μ_2, σ_2, h_2) were extracted for the dominant and secondary peaks, respectively. Secondary parameters were set to zero when only one peak was detected.

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A baseline offset,

$$\text{offset} = \min_{x}\{f(x)\} \tag{3}$$

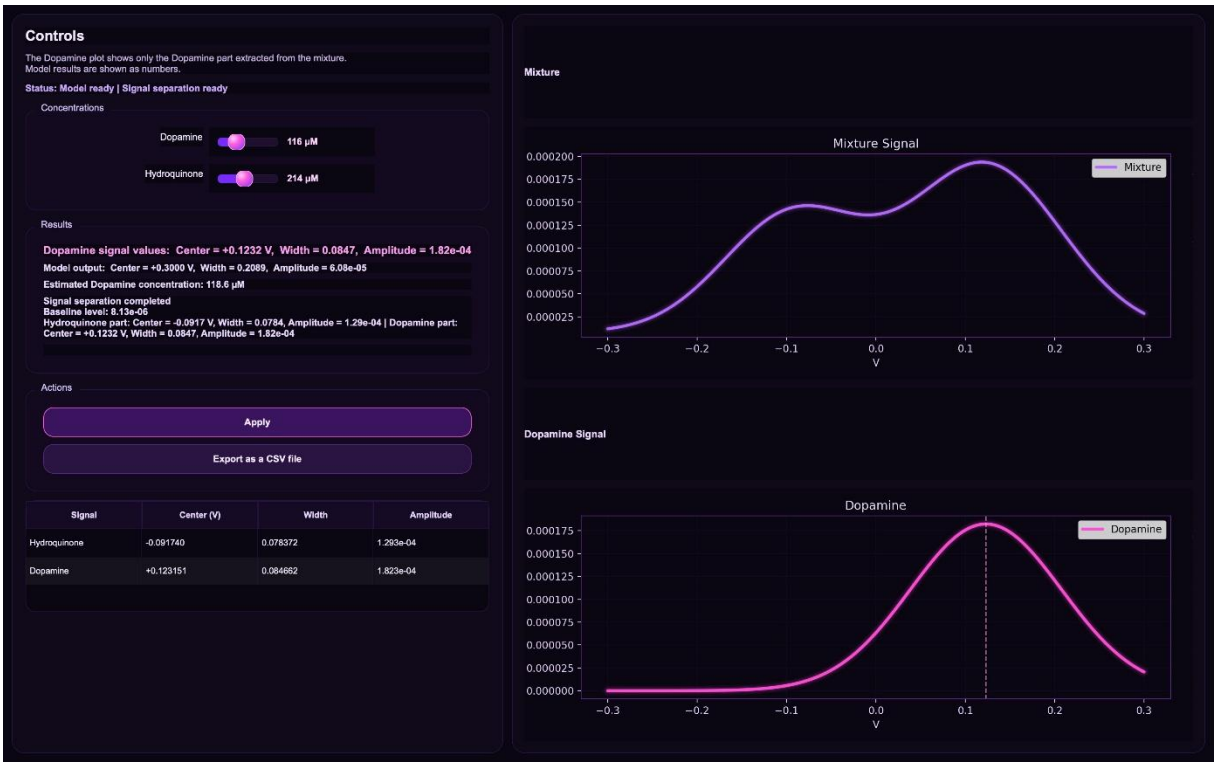

Figure 30. DopamineFinder interface illustrating the predicted DA peak parameters extracted from mixed DA-HQ signals.

accounts for residual background current. The complete feature vector for each sample is defined as:

$$\mathbf{x} = [p_1, p_2, n_{peaks}, \mu_1, \sigma_1, h_1, \mu_2, \sigma_2, h_2, \text{offset}]. \tag{4}$$

RFR was employed for nonlinear peak deconvolution owing to its ability to model complex nonlinear relationships without explicit parametric assumptions and its robustness to multicollinearity in structured feature spaces. Rather than directly predicting DA concentration, the model infers intrinsic DA peak parameters from mixed-signal descriptors, thereby decoupling signal deconvolution from concentration estimation. The input feature vector **x** is constructed excluding the DA concentration index p_1. The regression targets are the ground-truth DA peak parameters (μ_{DA}, σ_{DA}, h_{DA}) obtained from DA-only reference measurements. Excluding p_1 from the input prevents trivial memorization and forces the model to learn deconvolution solely from peak morphology and interference patterns.

Four independent RFR models were trained:

$$\hat{\mu}_{DA} = f_\mu(\mathbf{x}), \hat{\sigma}_{DA} = f_\sigma(\mathbf{x}), \hat{h}_{DA} = f_h(\mathbf{x}), \hat{p}_1 = f_{p_1}(\mathbf{x}) \tag{5}$$

where three models estimate DA peak parameters and a fourth predicts the DA concentration index p_1 directly from mixed-signal features, enabling simultaneous peak recovery and

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concentration estimation.

Group-wise cross-validation was employed using the DA concentration index p_1 as the grouping variable. G denotes the set of unique DA concentration groups. For each fold,

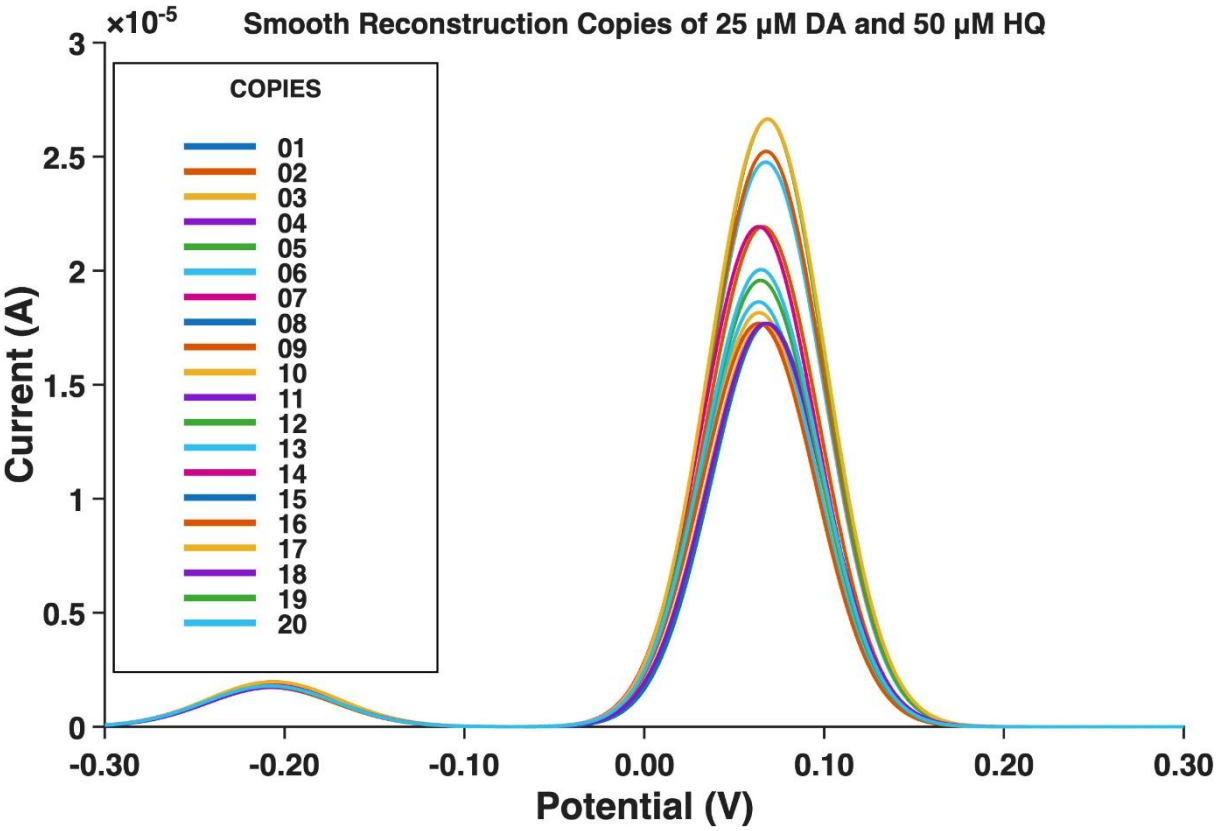

Figure 31. Multiple reconstructed signal copies generated for identical (p_1, p_2) concentration pairs. The signals exhibit coherent peak morphology with controlled variations in amplitude and width, demonstrating reconstruction consistency under fixed concentration conditions.

training uses samples from $G \backslash G_{test}$ while testing is restricted to the held-out group G_{test}. This ensures that DA concentration levels encountered during testing are strictly unseen during training, so that reported performance reflects genuine deconvolution capability rather than memorization. Each decision tree in the ensemble partitions the feature space through threshold-based splits on physically interpretable quantities such as peak widths, amplitudes, and baseline offsets. The final prediction is obtained by averaging the outputs of all trees:

$$\hat{\theta}(\mathbf{x}) = \frac{1}{T}\sum_{t=1}^{T} f_t(\mathbf{x}) \tag{6}$$

where T denotes the number of trees, $f_t(\mathbf{x})$ is the prediction of the t-th tree, and $\hat{\theta}$ estimates $\theta \in \{\mu_{DA}, \sigma_{DA}, h_{DA}, p_1\}$. Agreement between predicted and reference DA peak parameters on held-out concentration groups confirms that the model captures nonlinear interference effects rather than memorizing training patterns.

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2.4. PyQt5 Desktop Application: *DopamineFinder*

A desktop application, *DopamineFinder*, was developed using PyQt5 to provide an interactive interface for the proposed framework [18], [19]. Users specify DA and HQ concentration levels through continuous controls, upon which the application generates a synthetic mixture signal using parametric Gaussian peak models constrained by experimentally observed trends. The mixture is processed by the trained RFR models to estimate DA-specific peak parameters, and the reconstructed DA-only signal is visualized alongside the original mixture (Figure 30). This side-by-side comparison enables direct qualitative assessment of deconvolution performance. *DopamineFinder* also provides numerical parameter outputs and supports result export for offline analysis.

Table 34. Dopamine (DA) and hydroquinone (HQ) concentration levels used in the real electrochemical dataset. All possible DA--HQ concentration combinations were experimentally measured except the (25 µM, 25 µM) pair, resulting in 24 real measurements.

Analyte Concentration Levels (µM)					
Analyte	**25**	**50**	**100**	**250**	**500**
DA	25	50	100	250	500
HQ	25	50	100	250	500
Total: 24 real experimental measurements					

3. EXPERIMENTAL EVALUATION

3.1. Dataset Construction

The dataset combines experimentally acquired DPV measurements with synthetically generated samples obtained through Fourier-domain interpolation. Real signals provide physically grounded reference behavior, while interpolated samples enable denser coverage of the DA–HQ concentration space.

All real measurements were acquired using DPV under identical electrochemical conditions [9]. Voltammetric signals were recorded systematically for multiple DA–HQ concentration pairs. The concentration combinations included in the dataset are summarized in Table 34. DA concentrations were selected as 25, 50, 100, 250, and 500 µM. For each DA level, HQ concentrations were independently varied over a comparable range, resulting in a total of 24 mixed DA-HQ measurements. A separate DA-only dataset consisting of five measurements at the same DA concentrations provides ground-truth peak parameters in the absence of HQ interference. To obtain denser coverage of the DA–HQ concentration space beyond the 24 experimental combinations, an interpolation-based augmentation strategy was employed. Rather than interpolating in the raw signal domain, interpolation was performed on the Fourier coefficient vectors described in Section 2.1. For each experimental concentration pair (p_1, p_2), the corresponding coefficient vector $\mathbf{c}(p_1, p_2)$ was used as the interpolation input.

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A sequential two-dimensional interpolation was applied: first along the HQ axis for fixed DA levels, then along the DA axis using the newly generated intermediate coefficients. This coupled procedure ensures that the synthetic signals preserve the nonlinear influence of HQ on DA peak morphology across the full concentration plane. Inverse Fourier reconstruction yields synthetic signals in the original potential domain. Reconstruction consistency was verified by generating multiple instances for identical (p_1, p_2) pairs; as shown in Figure 31, the reconstructed signals exhibit coherent peak morphology with controlled

Table 35. Random Forest Regression performance for dopamine-related parameter prediction.

Random Forest Regression Results					
Target	**RMSE**	**MAE**	**NRMSE (%)**	**NMAE (%)**	**Range**
Dopamine concentration (p_1)	23.175	14.958	$\mathbf{4.94}$	3.19	$25 - 500$
Peak center (μ_{DA})	0.0439	0.0289	$\mathbf{28.45}$	18.72	$0.34559 - 0.49993$
Peak width (σ_{DA})	0.0696	0.0455	$\mathbf{27.54}$	18.00	$0.00010 - 0.25591$
Peak amplitude (h_{DA})	8.0×10^{-6}	5.0×10^{-6}	$\mathbf{7.26}$	4.63	$2.7 \times 10^{-5} - 1.44 \times 10^{-4}$
5-fold cross validation with group-wise splitting by p_1.					

variability, confirming that the augmentation preserves physically meaningful electrochemical structure.

3.2. Evaluation Metrics

Model performance was assessed using standard regression metrics. Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) are defined as:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \tag{7}$$

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i| \tag{8}$$

where n denotes the number of samples, y_i is the ground-truth value, and $\hat{y}_i$ is the prediction. RMSE is sensitive to large deviations through squared residuals, whereas MAE reflects average error magnitude without disproportionately weighting outliers. Since the target parameters span different physical units and scales, range-normalized counterparts were additionally computed as:

$$\mathrm{NRMSE} = \frac{\mathrm{RMSE}}{y_{max} - y_{min}} \times 100\% \tag{9}$$

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$$\mathrm{NMAE} = \frac{\mathrm{NMAE}}{y_{\max} - y_{\min}} \times 100\% \tag{10}$$

where $y_{\max}$ and $y_{\min}$ denote the observed extremes of the target variable, enabling scale-independent comparison across heterogeneous regression targets [20].

All metrics were computed using k k-fold group-wise cross-validation ($k = 5$), where samples sharing the same DA concentration level (p_1) were assigned exclusively to either the training or test set, preventing concentration-level information leakage.

3.3. Results and Discussion

Table 35 summarizes the regression performance of the RFR. Normalized metrics are emphasized, as the target parameters differ substantially in scale. For DA concentration prediction (p_1), the model achieves an NRMSE of 4.94% and an NMAE of 3.19% (RMSE = 23.17 over the 25–500 µM range), indicating robust DA quantification under strong HQ interference. μ_{DA} is predicted with an NRMSE of 28.45% (NMAE 18.72%), with an absolute RMSE of only 0.0439 V. The relatively high normalized error reflects the narrow dynamic range of the peak center (0.346–0.500 V). Similarly, σ_{DA} yields an NRMSE of 27.54% (RMSE = 0.0696); both parameters operate within narrow ranges where small absolute errors translate to elevated normalized values. In contrast, h_{DA} is recovered with NRMSE of 7.26 (NMAE 4.63%), consistent with amplitude being more directly linked to analyte concentration and less sensitive to subtle peak-shape distortions. Overall, the results confirm that the proposed framework successfully decouples nonlinear peak deconvolution from explicit physical modeling. The Random Forest models learn complex interference-induced dependencies directly from interpretable peak descriptors, enabling accurate DA quantification and reliable peak recovery under realistic mixed-signal conditions.

4. CONCLUSION

This study presented a data-driven framework for nonlinear peak deconvolution and selective DA quantification under HQ interference, addressing distortion and overlap effects that invalidate conventional linear approaches. By combining Fourier-based signal encoding, two-dimensional interpolation in the coefficient domain, Gaussian peak parameterization, and RFR, the framework operates entirely on physically interpretable descriptors rather than raw signal values. Group-wise cross-validation across DA concentration levels confirmed that the model generalizes to unseen conditions, with NRMSE values of 4.94% for DA concentration and 7.26% for peak amplitude, demonstrating that the learned mappings capture genuine interference-driven relationships rather than concentration memorization. The accompanying desktop application, *DopamineFinder*, provides interactive signal synthesis, deconvolution, and visualization, facilitating practical validation and experimental use. Future work will extend the framework to multi-analyte scenarios involving three or more overlapping species and investigate deep learning architectures to improve deconvolution under more complex interference conditions.

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ISBN NR: 978-625-5694-92-8

KAHRAMANMARAŞ DEPREMLERİ: ZEMİN DAVRANIŞI VE YAPI ETKİLEŞİMİ ÜZERİNE TEKNİK BİR İNCELEME

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ÖZET

6 Şubat 2023 tarihinde Kahramanmaraş merkezli meydana gelen ve "Asrın Felaketi" olarak nitelendirilen deprem serisi, Doğu Anadolu Fay Hattı üzerindeki sismik hareketliliğin yapısal ve zemin mekaniği açısından yıkıcı etkilerini bir kez daha ortaya koymuştur. Bu bildiri, söz konusu depremlerin oluşum mekanizmalarını, mühendislik parametrelerini ve bölgedeki yapı stokunda meydana gelen hasarların teknik nedenlerini kapsamlı bir şekilde incelemektedir. Çalışmanın temel odağını, sismik verilerin analizi ile yapısal hasar tahminleme modellerinin karşılaştırılması oluşturmaktadır. Araştırma kapsamında öncelikle sismoloji literatüründeki temel parametreler; pik yer ivmesi (PGA), pik yer hızı (PGV) ve spektral ivme değerleri, Kahramanmaraş depremleri özelinde dijital verilerle analiz edilmiştir. Saha gözlemlerinde, özellikle alüvyon zeminlerde gözlemlenen zemin sıvılaşması fenomeninin, üst yapı tasarımı yönetmeliklere uygun olsa dahi temel sistemlerinde meydana getirdiği stabilite kayıpları detaylandırılmıştır. Mühendislik açısından yapılan incelemeler; yetersiz beton dayanımı, donatı detaylandırma hataları, yumuşak kat düzensizliği ve komşu binalar arasındaki çekiçleme etkisi gibi kronik sorunların, toptan göçme mekanizmalarındaki rolünü kanıtlamaktadır.

Anahtar Kelimeler: Kahramanmaraş Depremleri, Yapısal Hasar Analizi, Zemin Sıvılaşması, Sismik Risk Değerlendirmesi

1. GİRİŞ

Kahramanmaraş Depremleri, geniş bir coğrafyada etkili olan ve çok sayıda yerleşim alanında ağır yapısal hasara yol açan büyük ölçekli bir deprem afetidir. Bu olay, depremlerin yalnızca doğal bir jeolojik süreç değil, aynı zamanda mühendislik, planlama ve denetim boyutlarıyla ele alınması gereken karmaşık bir risk olgusu olduğunu bir kez daha ortaya koymuştur. Deprem sonrasında gözlenen yapısal performans farklılıkları; taşıyıcı sistem tasarımı, malzeme kalitesi, yapım teknikleri, zemin koşulları ve mevcut yapı stokunun yaşı gibi birçok parametrenin bir arada değerlendirilmesini zorunlu kılmaktadır. Özellikle betonarme yapı davranışı, düzensizlikler, yumuşak kat oluşumu, yetersiz detaylandırma ve uygulama hataları gibi mühendislik problemleri, hasarın boyutunu belirleyen temel unsurlar arasında yer almıştır.

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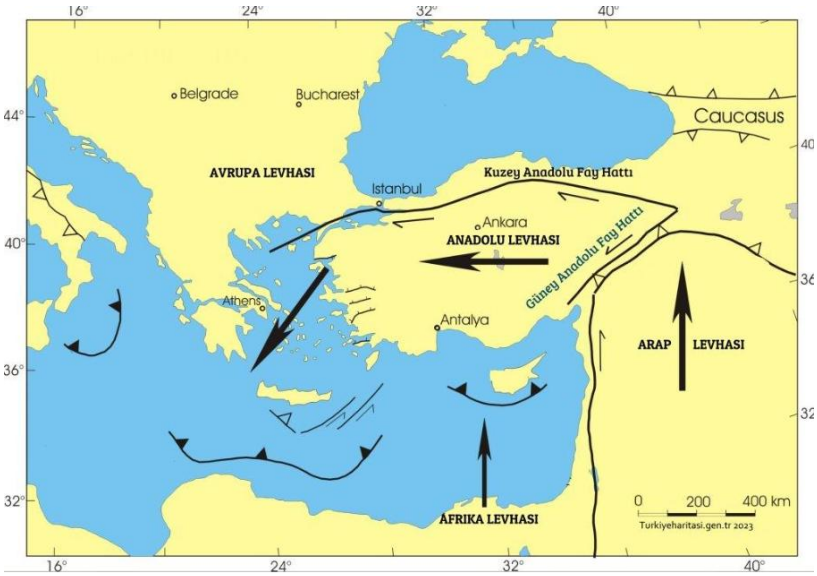
Bu depremler, performans esaslı tasarım yaklaşımının önemini, mevcut yapıların güçlendirilmesi gerekliliğini ve yapı denetim mekanizmalarının etkinliğini yeniden gündeme taşımıştır. Aktif fay hatları üzerinde yer alan Balkan coğrafyası açısından değerlendirildiğinde, bu afetin teknik ve mühendislik boyutlarının analiz edilmesi; bölgesel sismik tehlike değerlendirmeleri, yapı tasarım standartlarının geliştirilmesi ve dayanıklı kentleşme stratejilerinin güçlendirilmesi bakımından önemli çıkarımlar sunmaktadır. Bu çalışma, söz konusu depremleri mühendislik perspektifinden ele alarak yapısal davranış, tasarım ilkeleri ve uygulama süreçleri çerçevesinde genel bir değerlendirme sunmayı amaçlamaktadır.

2. DEPREM VE PARAMETRELERİ

Yerkabuğu içindeki kırılmalar nedeniyle ani olarak ortaya çıkan titreşimlerin dalgalar halinde yayılarak geçtikleri ortamları ve yer yüzeyini sarsma olayına "deprem" denir. Ülkemizde ve balkanlarda en çok görülen ve Kahramanmaraş depremlerinin de türü olan deprem türü, tektonik depremlerdir.

Kahramanmaraş Depremleri Anadolu, Arap ve Afrika levhaları arasındaki üçlü eklemin yakınında gerçekleşmiştir. Türkiye'nin jeolojik yapısı incelendiğinde (Görsel 1); Kızıldeniz genç bir okyanustur ve büyümeye devam ettiği için hareketli olan Arabistan levhasını kuzeye doğru itmektedir. Arap ve Avrasya levhası arasında kalan Anadolu levhası, bu iki levha tarafından sıkıştırılmaktadır. Bu sıkıştırma Anadolu plakasının batıya doğru faylar boyunca kayma yüzeyinde hareketine sebep olmaktadır [1]. Bu, batıya doğruyu kaymayı engelleyen Helen kuşağıdır. Helen yayı batma zonlu çalışan bir yaydır.



Görsel 1.Türkiye'de bulunan levhaların haritası [2]

Fay, yer kabuğunu oluşturan levhaların hareketleri sonucu oluşan gerilme ve sıkışmalar olup, yer kabuğunun bazı bölümlerinde yüzyıllar boyunca enerji birikimine neden olmaktadır.[3] Bu enerjiler zaman zaman ortaya çıkmakatadır. Yer kabuğundaki bu hareketli kesimlere fay adı verilmektedir. Ters fay, yanal atılımlı fay ve normal fay olmak üzere üçe ayrılmaktadır [4].

Cisim dalgaları olan P ve S dalgaları en hızlı dalgalar olup, P dalgası S dalgasından daha yüksek hıza sahiptir. Yüzeye ilk ulaşan dalgalar bunlardır. P dalgaları her türlü maddede hareket ederken, S dalgaları yalnızca katı maddelerde hareket etmektedir. Yüzey Dalgaları olan

ISBN NR: 978-625-5694-92-8

Love dalgası ve Rayleight dalgası, cisim dalgalarına göre daha yavaştır [5]. Genlikleri daha büyük olduğundan yıkıcılıkları da yüksektir. Genelde depremlerde hissettiğimiz Rayleight dalgasıdır.

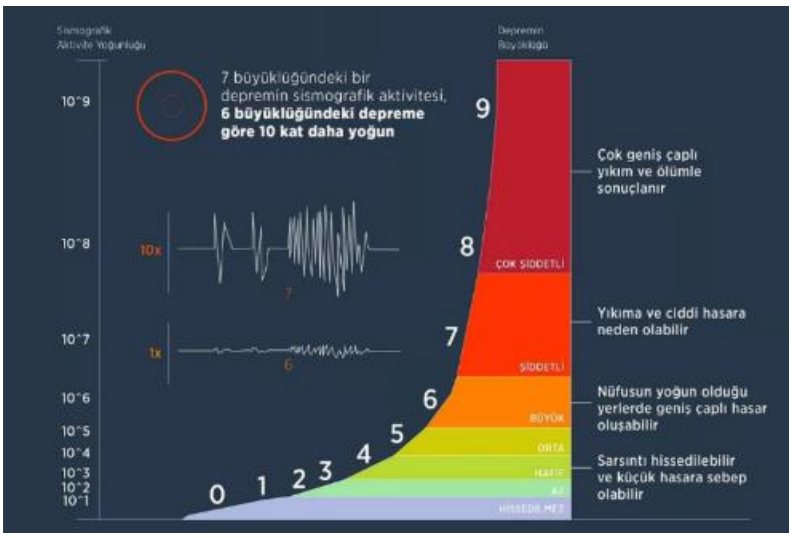
3. KAHRAMANMARAŞ DEPREMLERİ

6 Şubat 2023 de meydana gelen Kahramanmaraş depremlerinin bilgileri aşağıdaki şekildedir. 6 Şubat 2023 tarihinde meydana gelen Kahramanmaraş depremlerinden ilki, saat 04:17'de merkez üssü Pazarcık olan bölgede gerçekleşmiştir. Yaklaşık 100 saniye süren depremin büyüklüğü 7.7 M_w olarak ölçülmüş [6], derinliği ise 8,6 kilometre olarak belirlenmiştir.

- Merkez üssü: Pazarcık
- Saat: 04:17
- Süre:100 sn
- Şiddet: X-XI
- Büyüklük: 7.7 m_w
- Derinlik: 8.6 km
- Etkilenen ülkeler: Türkiye, Suriye

Merkez üssü Elbistan olan ve birinci depremden sadece 9 saat sonra gerçekleşen ikinci deprem saat 13:24 de meydana gelmiş olup, yaklaşık 45 saniye sürmüştür. Büyüklüğü AFAD verilerine göre 7.6 olarak kaydedilen [6] deprem yer yüzeyinin 7 kilometre derinliğinde gerçekleşmiştir. Bu iki deprem 10 saatlik periyotun altında art arda gerçekleşen en yıkıcı deprem ikilisi olarak tarihe geçmiştir. İki depremde hem Türkiye hem Suriye'yi etkilemiş olup, şiddeti X-XI 'dır (Görsel 2).

- Merkez üssü: Elbistan
- Saat: 13:24
- Süre:45 sn
- Şiddet: X-XI
- Büyüklük: 7.6 m_w
- Derinlik: 7 km
- Etkilenen ülkeler: Türkiye, Suriye



Görsel 2. Richter ölçeği [7]

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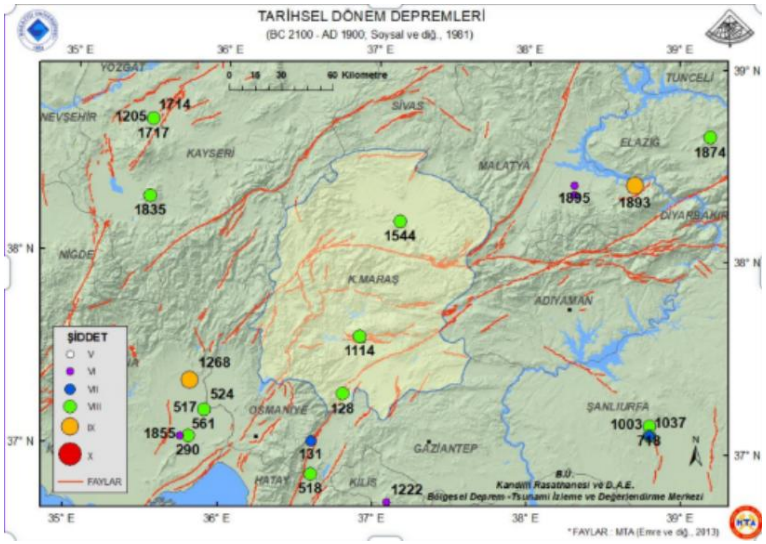
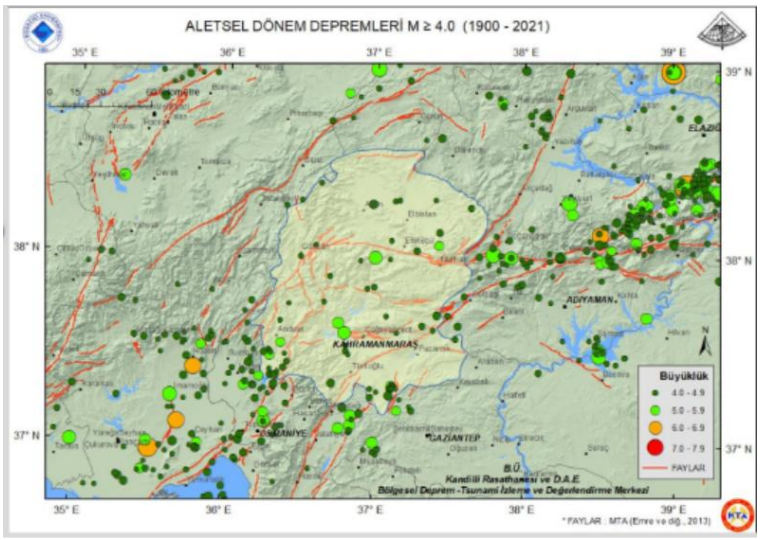
Kahramanmaraş depremlerinin her ikisi de Doğu Anadolu Fay Hattı üzerinde gerçekleşmiştir. Merkez üssü Pazarcık olan ilk deprem, sol yanal doğru atılımlı fayda Gölbaşı segmentinin Narlı fayı kolunda meydana gelmiştir. Merkez üssü Elbistan olan ikinci deprem ise Çardak fayı kolunda meydana gelmiştir [8].

Türkiye, bilindiği üzere deprem riskini en üst seviyede taşıyan ülkelerden birisidir. Kahramanmaraş depremleri bahsedilen üç fayın çakıştığı üçlü eklemin üzerinde bulunmaktadır ve fay hatları içinde yüzyıllar boyunca biriken bir enerji mevcuttur. Bu enerji deprem vasıtasıyla yer yüzeyine çıkmakta ve sönümlenmektedir [3]. Depremlerin bir periyodu vardır ve yapılan çalışmalar bunu göstermektedir. Tarihsel veriler, bu deprem dizisi sırasında kırılan fay bölümlerinin, en az 500 yıldır tektonik gerilme biriktiren sismik boşluklar olduğunu göstermektedir [9]. Kahramanmaraş ili ve çevresinde 29 Kasım 1114'te Kilikya Ermeni Krallığı'nda meydana gelen 7.4 büyüklüğündeki deprem (Görsel 3), 28 Mart 1513 tarihinde Dulkadiroğulları Beyliği sınırları içinde gerçekleşen 7.4 büyüklüğündeki deprem (Görsel 4), 6 Şubat 2023'te Türkiye'de meydana gelen 7.7 ve 7.6 büyüklüklerindeki iki deprem sıkışan enerjinin deprem periyodu ile tutarlı bir şekilde deprem oluşturduğunun kanıtı niteliğindedir.



Görsel 3. Tarihsel dönemde Kahramanmaraş ili ve çevresinde meydana gelen depremler [10]



Görsel 4. Aletsel dönemde Kahramanmaraş ili ve çevresinde meydana gelen depremler [10]

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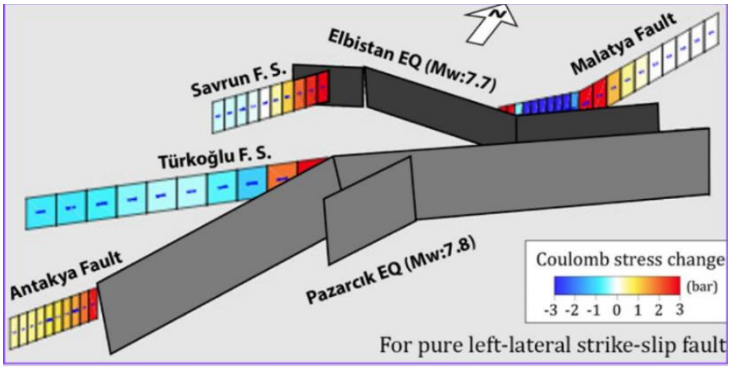
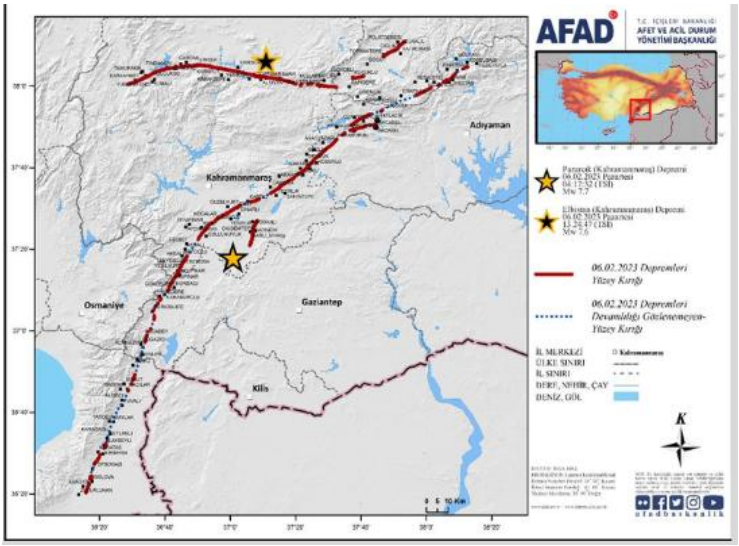
Tarih boyunca Kahramanmaraş ili ve çevresinde gerçekleşen depremler yukarıdaki haritalarda verilmiştir. Kahramanmaraş bölgesinde 6 Şubat- 6 Mayıs arasında en büyüğü ana sarsıntıdan yaklaşık 11 dakika sonra meydana gelen 6.7 M_w büyüklüğünde olan yaklaşık 38.000 artçı sarsıntı meydana gelmiştir. Kahramanmaraş depremlerinin stres değişimi, Coulomb Stres çizelgesinde (Görsel 5) görülmektedir [11].



Görsel 5. Coulomb stres çizelgesi [12]



Görsel 6.Kahramanmaraş depremleri sonrasındaki yüzey kırığı haritası [13]

Yüzey kırılması (zemin kırılması ya da zeminin yer değiştirmesi), sismolojide, bir fay boyunca bir deprem yırtılması, Dünya yüzeyini etkilediğinde zemin yüzeyinin görünür kaymasıdır. Kahramanmaraş depreminden sonra birçok bölgede yüzey kırığı tespit edilmiştir (Görsel 6).

4. YAPISAL HASARLARA YÖNELİK SAHA ÇALIŞMALARI

Söz konusu depremler sonrasında bazı yerleşim bölgelerinde, ciddi yüzey bozulmaları tespit edilmiştir [6]. Bu bozulmalar yumuşak zeminlerde daha da belirgin hal alarak geniş yarıklar şeklinde ortaya çıkmıştır. Aşağıda aynı zemin koşullarında hasar gören ve görmeyen yapılara örnekler verilmiştir (Görsel 7).

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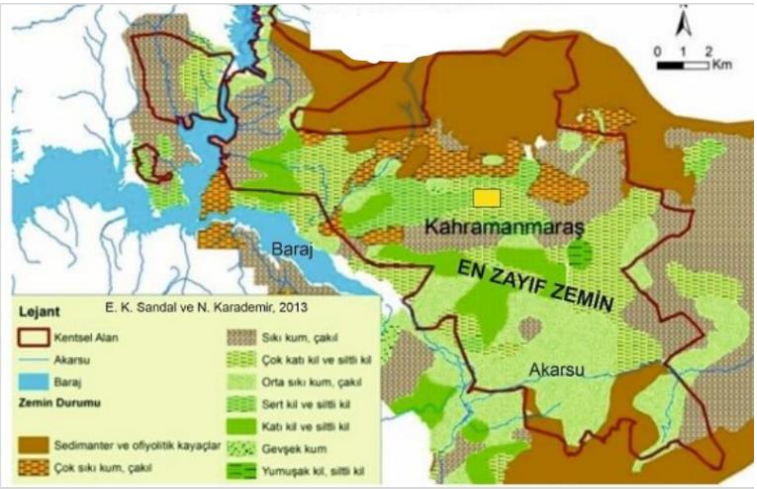
Görsel 7. a) Kahramanmaraş b) Malatya c) Gaziantep d) Adıyaman [13]

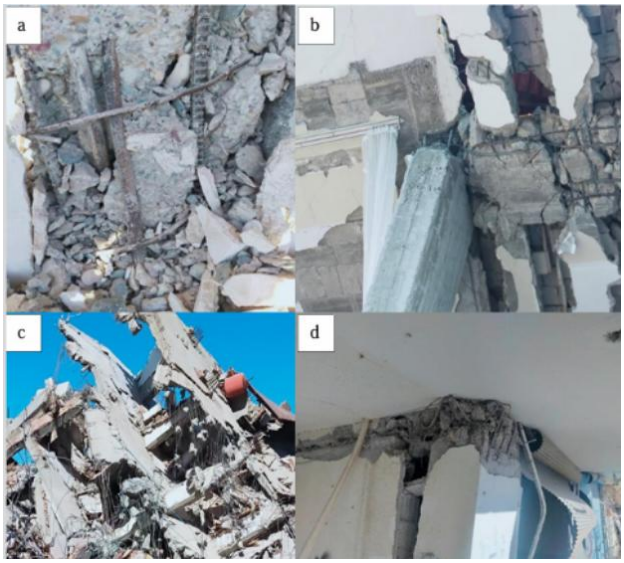
Zemin Sıvılaşması, deprem anında yer şiddetle sarsılırken zeminin dayanıklılığını kaybederek katı yerine sıvı gibi davranması durumudur [14]. Kahramanmaraş depreminde zemin sıvılaşması görülmüş olup (Görsel 8), zemin kaynaklı hasarların çoğunun nedeni zemin sıvılaşması olmuştur. Zemin sıvılaşması suya doygun, kohezyonsuz, yer altı suyunun fazla derinde olmadığı zeminlerde karşımıza çıkmaktadır [15].



Görsel 8. Kahramanmaraş zemin sıvılaşma durumu [16]

Taşıyıcı sistem ile deprem kuvvetlerini karşılayan dolgu duvarların herhangi bir katta kaldırılması ve asma katlarda kolonların kiriş ve dolgu duvarlarla tam olarak desteklenmemesi durumunda yapıda ani rijitlik değişimi meydana gelmekte ve genellikle yıkım buradan başlamaktadır. Yapılan incelemelerde birleşim bölgelerindeki etriyelerin yetersiz ve boyuna donatıyı tutmayacak şekilde bağlantıların yapıldığı gözlemlenmiştir. Kolon, kiriş ve perdelerde düz donatının kullanıldığı, perdelerde çiroz kullanılmadığı, boyuna donatı boylarının kısa tutulduğu bu nedenle de birleşim bölgelerinde sıyrılmaların yaşandığı ve bu hassas bölgelerde iri çakıl ve tahta gibi yabancı unsurlara rastlanılmasının betonun gevrekliğinin artmasına neden olduğu belirlenmiştir. Kahramanmaraş depremlerindeki binaların genelinde, kolon-kiriş birleşim bölgelerindeki etriyelerin yetersiz ve boyuna donatıyı tutamayacak şekilde olduğu görülmüştür [6]. Kolon, kiriş, perdede düz donatı kullanılması, boyuna donatıların kısa tutulduğu perdelerde çiroz olmaması, birleşim bölgelerinde sıyrılmalara neden olmuştur (Görsel 9). Ayrıca Kahramanmaraş'ta betonun gevrekliğini arttıran yabancı cisimlere (tahta, iri agrega, çakıl gibi) rastlanmıştır. Yönetmelik deprem bölgelerinde C30 beton sınıfını önermektedir [17]. Bu beton sınıfı beton durabilitesi açısından asgari değerlerdir.

ISBN NR: 978-625-5694-92-8



Görsel 9. Kusurlu beton ve hasarlarına yönelik örnekler a) Kahramanmaraş b) Malatya c) Adıyaman d) Gaziantep [13]

Binaların doğal bir periyodu vardır. Dolgu duvarlar binanın yatay rijitliğini artırarak doğal periyodu azaltmakata [18] ve binanın deprem talebinin artmasına sebep olmaktadır. Binayı çözümlerken planlanan kesme kuvveti ve momentten daha fazla ivme kesme kuvveti ve momente maruz kalması binanın deprem talebinin artması demektir. Kahramanmaraş'ta meydana gelen depremlerde dolgu duvar hasarına sıkça rastlanmıştır (Görsel 10).

Görsel 10. Dolgu duvar hasarlarına örnekler a) Kahramanmaraş b) Hatay c) Gaziantep d) Malatya [13]

Donatıların paslanmış olması, sıvaların kalın olması gibi hataların meydana getirdiği hasarlar da mevcuttur. Kesme kuvveti artarken, etkili boyun kısalması ile eğilme momenti düşük kalmaktadır. Bunun sonucunda gevrek güç tükenmesi (yorulma) ortaya çıkmaktadır [19]. Hiç beklenmeyen güç tükenmesi yıkıma sebep olmaktadır. Genellikle kırsal yaşam alanlarında, köylerde, halkın kendi çabasıyla ortaya koyduğu yapılarda görülmektedir. Bu durum yıkımlara sebep olmaktadır.

ISBN NR: 978-625-5694-92-8

5.KAHRAMANMARAŞ DEPREMİNDE SEMBOLİKLEŞMİŞ YERLEŞİM YERLERİ

5.1.Ebrar Sitesi

Ebrar Sitesi, Kahramanmaraş'ta 6 Şubat 2023 depremlerinde 22 bloktan 18'i yıkılan (Görsel 11), yaklaşık 1400 kişinin öldüğü bir sitedir. Bu çevreden daha önceden küçük derelerin geçtiği tespit edilmiştir [20].

Görsel 11. Kahramanmaraş depremi sonrası Ebrar Sitesine ait görsel [20]

5.2.Rönesans Rezidans

Deprem sonucunda Rönesans Rezidansın yıkıldığı (Görsel 12), 269 kişinin hayatını kaybettiği ve 13 kişinin de yaralandığı tespit edilmiştir [21]. Bodrum katında yeraltı suyuna rastlanmış olup, zemin sıvılaşması olduğunu belirlenmiştir. Ayrıca bodrum katında, pencere türü açıklıklar bırakılmış, bu durum da kısa kolon etkisi yaratmıştır. Etriyelerin 135 derece yerine 90 derece büküldüğü de görülmüştür [22].

Görsel 12. Kahramanmaraş depremi sonrası Rönesans Rezidansa ait görsel [22]

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Görsel 13. Kahramanmaraş depremi öncesi ve sonrasına ait görsel [23]

5.3. Konteyner Kent

Kahramanmaraş depreminden sonra evleri yıkılan insanlar için konteyner kentler oluşturulmuştur (Görsel 14). Depremin ilk gününden bu yana yaklaşık 707.000 depremzede konteyner kentlerde barınma ihtiyacını karşılamıştır. Ocak 2025 itibariyle toplamda yaklaşık 651.958 kişi konteynerlerde hayatını devam ettirmektedir [24]. Yarısı kentte, yarısı kırsaldaki konteyner kentlerde yaşayan Kahramanmaraş'ta ise toplamda yaklaşık 107.896 kişi bu barınma merkezlerinde yaşamını sürdürmektedir [24].

Görsel 14. Kahramanmaraş'ta bulunan konteyner kent [25]

5.4. Büyük Yıkım ve Ekonomik Kayıp

Depremler, 120 bin kilometrekarelik bir alanda 14 milyondan fazla insanı etkilemiştir [18].53.737 kişi hayatını kaybetmiş, 107.213 kişi yaralanmış ve 3,5 milyondan fazla insan bölgeden tahliye edilmek zorunda kalmıştır [26]. 2.337.455 binadan 39.466'sı tamamen yıkılmış olup, 21.175 bina acil yıkım gerektirecek durumda, 199.967 bina ağır hasarlı ve 43.698

bina orta hasarlı olarak tespit edilmiştir [27]. Depremlerin Türkiye ekonomisine maliyeti 103,6 milyar dolar olarak hesaplanmıştır. Bu kayıpları telafi etmek için 75 milyar dolarlık kamu harcaması yapılmıştır [28].

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ISBN NR: 978-625-5694-92-8

ASSESSMENT OF LIQUEFACTION POTENTIAL BASED ON SPT DATA IN KARSIYAKA, IZMIR

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ABSTRACT

The province of Izmir and its surroundings are located in a seismically hazardous area under the influence of active fault systems in Western Anatolia. The prevalence of young alluvial soils, particularly in developed settlements along the coastal strip, highlights the need for a more detailed investigation of soil movements and behavior that may occur during earthquakes. This study aims to determine the liquefaction risk potential of soils in Bahariye Neighborhood, Karşıyaka District. The study is based on data obtained from Standard Penetration Test (SPT) results conducted in the field. The groundwater level was measured at approximately 1.96 meters in the field. According to the test results, low plasticity clay layers were observed in the near-surface sections, while sandy, silty sandy, and gravelly soil layers were found at deeper sections. Among these soil layers, the continuity of the soil layers containing silty sand is particularly noteworthy. The analyses were performed based on the requirements of the current earthquake regulations, and the safety factors against liquefaction were determined using the corrected blow values obtained from the raw blow values after the test. The findings obtained from the analyses revealed that liquefaction risk is higher in soil layers close to the groundwater level and with low blow counts obtained from the Standard Penetration Test (SPT). After the analyses, it was seen that the safety factor approached critical values at some depths and fell below this value in places. This situation poses a risk of settlement or horizontal deformation on the surface during an earthquake. Consequently, it is of high importance for safety to evaluate the soil conditions in detail for the new structures planned in the coastal areas of Karşıyaka and, if deemed necessary, to plan and implement soil improvement measures. The study aims to reveal the effect of local soil characteristics on earthquake performance and to contribute to regional risk reduction efforts.

Keywords: Liquefaction potential, Standard Penetration Test (SPT), groundwater level, factor of safety

1. INTRODUCTION

The Western Anatolia Region has an expansive tectonic regime controlled by active normal faults developed within the Aegean graben system. This tectonic structure places Izmir and its surroundings among the settlement areas at high seismic risk. Young alluvial deposits commonly observed around the Gulf of İzmir cause ground behavior to become critically important during earthquakes. Especially in coastal areas where the groundwater level is close to the surface, loose to moderately dense granular soils are likely to exhibit liquefaction

ISBN NR: 978-625-5694-92-8

potential. Liquefaction is defined as the decrease in effective stress and the temporary loss of shear strength of the soil due to an increase in pore water pressure during seismic loading [1], [4]. This situation can lead to significant engineering problems such as surface settlements, loss of bearing capacity, foundation rotations, and lateral spreading. The ground behavior observed in the coastal areas of Izmir following the 2020 Aegean Sea Earthquake has once again highlighted the importance of assessing liquefaction potential at the local scale.

Although various methods have been developed in the literature for liquefaction assessment, semi-empirical approaches based on Standard Penetration Test (SPT) data are widely used in engineering applications. These methods are based on comparing the cyclic stress ratio (CSR) with the cyclic resistance ratio (CRR) and enable the determination of the safety factor (FS) against liquefaction. Within the scope of this study, the liquefaction potential of soils was evaluated in detail using SPT data obtained in the Bahariye neighborhood of Karşıyaka district [1], [2], [3], [7].

2. WORK AREA AND GEOTECHNICAL CHARACTERISTICS

The work area is located within the boundaries of Bahariye Neighborhood, Karşıyaka District, İzmir Province, and is situated on the northern shore of the Gulf of İzmir. The region has generally developed on young alluvial units and has a heterogeneous ground structure where marine and terrestrial sediments are found in alternating layers. These alluvial units were deposited under low-slope coastal plain conditions and exhibit variability in terms of their engineering properties. Given its proximity to the coastal zone, the proximity of the groundwater level to the surface, and the dense development character, it is important to examine the ground conditions in the region in detail in terms of earthquake behavior. Furthermore, differences in stratification within the ground profile can directly affect the stress distribution that may occur during an earthquake.

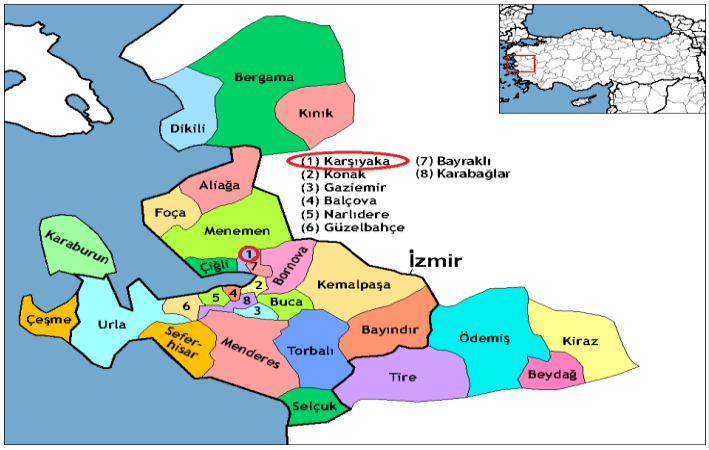

Figure 1. Location map of the work area. [10]

During the drilling conducted as part of the field studies, low-plasticity clay units were identified at near-surface levels, and silt-sand and sand layers were observed beneath these units. Gravelly levels were also detected in the profile in places. The presence of granular units under saturated conditions has been assessed as a situation that could increase the potential for

ISBN NR: 978-625-5694-92-8

strength loss under cyclic loading [1], [4]. Groundwater level measurements were determined at a depth of approximately 1.96 m, and this was considered a decisive parameter in liquefaction analyses.

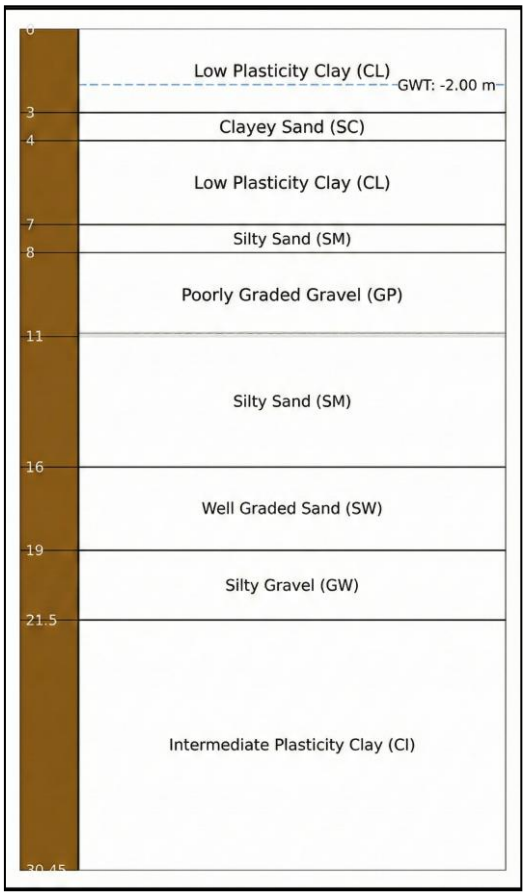

Figure 2. Bahariye Neighborhood Ground Profile.

Upon examination of the ground profile, it was determined that layers containing silty sand exhibit continuity at specific depth intervals and that these units could form critical zones in terms of liquefaction. In particular, granular units that begin just below the groundwater level may be more susceptible to strength loss under cyclic loading.

3. LIQUEFACTION EVALUATION METHOD

In this study, a simplified method based on SPT data was used to determine liquefaction potential, in accordance with the principles of the Turkish Building Code (TBDY, 2018) [9]. In the literature, liquefaction assessment methods based on shear wave velocity (V_s) have been developed as alternatives to SPT-based approaches, and empirical relationships have been proposed, particularly within the scope of NCEER workshops [5], [6]. Since the shear wave velocity (V_s) data for this study is not available, the Vs-based liquefaction assessment approach has not been applied in this study. In the first stage, the raw impact counts obtained in the field were normalized by applying energy correction, cover stress correction [2], [3], and other necessary coefficients. In this context, the energy ratio associated with the test equipment, the drill diameter correction, and the rod length effect were taken into account; then, the cover

ISBN NR: 978-625-5694-92-8

stress correction based on the effective vertical stress was applied. The $(N_1)_{60}$ values obtained as a result of this process were used as the basic parameter in determining the cyclic bearing capacity of the soils. Taking into account the effect of fine grain content, correction factors were applied where necessary, and representative strength parameters for granular units were obtained.

The cyclic stress ratio (CSR) has been calculated as the ratio of the effective vertical stress to the shear stress acting on the ground during an earthquake [1]. The maximum ground acceleration, earthquake magnitude, total and effective stresses, and depth-dependent stress reduction factor were taken into account in the calculations. The cyclic resistance ratio (CRR) has been determined using normalized impact counts through empirical relationships [3], [7]. The final CRR value was obtained by applying the scaling factor based on the magnitude of the earthquake. In the final stage, the safety factor against liquefaction was calculated using the relationship FS = CRR / CSR [1]. These evaluations are based on raw SPT results obtained directly from the field, and separate analyses were performed for each depth interval.

Table 1. SPT Test Results. [11]

Test Depth (m)	SK-1	SK-2	SK-3	SK-4	SK-5
1.5	4	7	6	5	8
3	3	2	4	5	8
4.5	3	3	4	4	6
6	3	4	2	4	2
7.5	14	9	5	6	4
9	17	15	21	14	22
10.5	2	16	14	14	8
12	8	5	6	7	4
13.5	8	9	5	5	21
15	10	10	7	8	11
16.5	11	11	11	11	8
18	22	7	8	5	5
19.5	3	5	11	10	9
21	50	47	48	41	21
22.5	12	41	50	10	20
24	42	20	13	13	14
25.5	11	32	15	33	21
27	23	6	63	58	13
28.5	15	30	36	50	14
30	14	35	9	11	8
Average	14	16	16	16	11

The calculated safety factors were used to determine whether the soil layers were safe or critical in terms of liquefaction. An FS value below 1 indicates the potential for liquefaction in the relevant depth range [1], [3].

4. FINDINGS AND DISCUSSION

The analyses revealed that the safety factor decreased, particularly in soil layers close to the groundwater level and with relatively low normalized impact values. It has been observed that FS values approach the critical threshold at certain depth intervals and occasionally fall below this value. This situation indicates that there may be a risk of deformation due to liquefaction

ISBN NR: 978-625-5694-92-8

under the effects of an earthquake. The clay and gravel layers in the ground profile have shown higher safety factor values at certain depth intervals. However, it has been assessed that liquefaction potential increases in zones where silty sand and sand units are continuous. This finding reveals that soil heterogeneity is a determining factor in liquefaction behavior.

Project Name	BAHARIYE NEIGHBORHOOD, KARSIYAKA, IZMIR																							
Borehole No:	Groundwater Level		Energy Rate		Hammer Type		Local Soil Class		DTS		M_w				S_{DS}		P.G.A.							
SK-1	2,0M		60%		Safety Hammer		ZF		DTS-2		7.5				1.123		0,45g							
Data obtained from field and laboratory tests.								Correction of raw SPT blow counts (N-values)								Calculation of liquefaction resistance			Earthquake shear stress			Safety condition against liquefact.		
Depth (m)	SPTN-30	Soil type (USCS)	Plasticity index-PI	Clay content (%)	γ_n (kN/m^3)	γ' (kN/m^3)	Fine content (%)	Total Stress σ_{vo} (kN/m^2)	Effective stress σ'_{vo} (kN/m^2)	C_n Overburden load correct.	C_r Correction for load length	C_s Sampler correction	C_b Correction for borehole	C_e Correction for hamer efficiency	$N_{1,60}$ Corrected SPTN for field	$N_{1,60f}$ Corrected SPTN for fine	$CRR_{M=7.5}$ Moment magnitude	C_M Moment mag.correct.ion	t_R Liquefaction resistance	r_d Stress reduction factor	t_{Eq} Shear stress due to EQ	F_{SL}	$FS=t_R/t_{EQ}$ ≥1.1	
1.5	4	CL	21		18.5	19.5	73.8	27.8	27.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	3	CL	16		18.5	19.5	73.8	56.5	46.7	1.43	0.85	1.00	1.00	1.00	4	9	-	-	-	-	-	-	-	No Liquefaction
4.5	3	SC	18	39.6	18.5	19.5	34.9	85.8	61.2	1.25	0.85	1.00	1.00	1.00	3	9	-	-	-	-	-	-	-	No Liquefaction
6	3	CL			18.5	19.5	73.8	115.0	75.8	1.12	0.95	1.00	1.00	1.00	3	9	0.103	1.00	7.81	0.95	32.04	**0.24**		Liquefaction Zone
7.5	14	SM			18.5	19.5	18.3	144.3	90.3	1.03	0.95	1.00	1.00	1.00	14	18	0.191	1.00	17.23	0.94	39.70	**0.43**		Liquefaction Zone
9	17	GP			18.5	19.5	10.6	173.5	104.8	0.96	1.00	1.00	1.00	1.00	16	18	0.189	1.00	19.76	0.93	47.17	**0.42**		Liquefaction Zone
10.5	2	GP			18.5	19.5	10.6	202.8	119.4	0.90	1.00	1.00	1.00	1.00	2	3	0.058	1.00	6.90	0.89	52.90	**0.13**		Liquefaction Zone
12	8	SM			18.5	19.5	18.3	232.0	133.9	0.85	1.00	1.00	1.00	1.00	7	11	0.118	1.00	15.76	0.85	57.82	**0.27**		Liquefaction Zone
13.5	8	SM			18.5	19.5	18.8	261.3	148.4	0.80	1.00	1.00	1.00	1.00	6	10	0.116	1.00	17.14	0.81	62.06	**0.28**		Liquefaction Zone
15	1	SM			18.5	19.5	18.8	290.5	163.0	0.77	1.00	1.00	1.00	1.00	1	4	0.066	1.00	10.81	0.77	65.61	**0.16**		Liquefaction Zone
16.5	11	SW			18.5	19.5	3.4	319.8	177.5	0.73	1.00	1.00	1.00	1.00	8	8	0.097	1.00	17.13	0.73	68.48	**0.25**		Liquefaction Zone
18	22	SW			18.5	19.5	3.4	349.0	192.0	0.71	1.00	1.00	1.00	1.00	16	16	0.165	1.00	31.75	0.69	70.66	**0.45**		Liquefaction Zone
19.5	3	SW			18.5	19.5	16.7	378.3	206.6	0.68	1.00	1.00	1.00	1.00	2	5	0.073	1.00	15.04	0.65	72.16	**0.21**		Liquefaction Zone

Figure 3. Liquefaction Analysis Results.

When examining the change in liquefaction potential with depth based on the data obtained after liquefaction analysis using the specified calculation methods, it is observed that liquefaction risk does not occur at every depth but is concentrated in specific zones. This situation necessitates a detailed assessment of the behavior of the local soil layer in terms of liquefaction in the engineering design for structural and life safety. In addition to the safety factor, comprehensive parameters such as the Liquefaction Potential Index (LPI) can also be used to quantitatively express the liquefaction risk at a regional scale [8].

5. EVALUATION FROM AN ENGINEERING PERSPECTIVE

The results obtained highlight the importance of conducting detailed geotechnical studies for new developments planned in the Karşıyaka coastal area. The proximity of the groundwater level to the surface and the continuity of granular soil layers have been identified as the main parameters that increase the risk of liquefaction. In this context, it is recommended to evaluate ground improvement methods, select the appropriate foundation system, and opt for deep foundation solutions if necessary. Considering the effects of settlement and horizontal deformation that may occur after liquefaction on structural performance, adopting deformation-based approaches during the design phase will yield safer results.

6. RESULTS

Liquefaction analyses conducted in Bahariye as part of this study revealed that alluvial soils in the region may exhibit liquefaction potential at certain depth intervals under seismic effects. It has been determined that the safety factor approaches critical values in layers located close to the groundwater level and exhibiting low to medium granular properties, and in some levels, this value falls below the critical level. This situation indicates that effective stress loss may occur due to the increase in pore water pressure during an earthquake, and consequently, a decrease in strength may occur. The heterogeneous structure of the ground profile, the irregularity of interlayer transitions, and the discontinuous distribution of granular units cause the safety factor to vary with depth. Therefore, liquefaction behavior does not occur uniformly throughout the entire profile, but rather tends to concentrate in specific zones.

The proximity of the groundwater level to the surface is a key parameter in the increased risk of liquefaction. It has been assessed that under low effective stress conditions, the cyclic loading effect may lead to a faster increase in pore water pressure, which in turn may increase the liquefaction potential. In this context, considering hydrogeological conditions and soil stratification together is important for regional risk assessment.

As a result, detailed assessment of local ground conditions is required for new developments planned in the Karşıyaka coastal area. In structures where shallow foundation systems are preferred, the potential effects of settlement and differential deformation caused by liquefaction on structural performance should be considered. Where deemed necessary, the application of ground improvement methods, the redesign of the foundation system, or the evaluation of deep foundation solutions will be an important engineering approach in terms of reducing the risk of earthquake-induced damage. This study highlights the necessity of integrating local ground behavior into the design process and contributes to risk reduction strategies at the regional scale.

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ISBN NR: 978-625-5694-92-8

DOĞRUSAL OLMAYAN YAPI ANALİZİNDE DEPREM ÖLÇEKLENDİRME FAKTÖRLERİNİN SONUÇLAR ÜZERİNDEKİ ETKİLERİ

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ÖZET

Bu çalışma kapsamında iki katlı bir betonarme yapı modelinden seçilen 2 boyutlu çerçeveler üzerinde doğrusal olmayan dinamik analizler gerçekleştirilmiştir. Yapı modelinde doğrusal olmayan davranış malzeme kaynaklı olarak yansıtılmıştır. Analizi yapılan yapının, yeterli mühendislik hizmeti almamış, görece eski bir yapı olduğu kabul edilmiştir. Depremselliğin ise orta seviyede olduğu kabul edilmiştir. Çalışma kapsamında, çeşitli yönetmeliklerce tavsiye edilen yer hareketi ölçeklendirme yöntemlerinden birisi olan 0.2T-1.5T aralığında yer hareketi ölçeklendirme yöntemi seçilmiştir. Bu yöntem üç farklı kritere göre ölçeklendirme yapılmasında temel olarak kullanılmıştır: (i)İlk yöntemde seçilen yer hareketi kayıtlarının seçilen periyot aralığında (0.2T-1.5) tasarım ivme spektrumuna minimum hata ile uyum sağlaması, (ii) ikinci yöntemde seçilen yer hareketi kayıtlarının seçilen periyot aralığında tasarım ivme spektrumunun üzerinde kalması, (iii) üçüncü yöntemde ise seçilen yer hareketi kayıtlarının, seçilen periyot aralığında tasarım ivme spektrumunun %90'ının üzerinde kalması sağlanmıştır. Uygulanılan ölçeklendirme yöntemi için tasarım ivme spektrumu ile en iyi uyum sağlayan 20 adet yer hareketi kaydı geniş bir yer hareketi kaydı havuzundan, tasarım ivme spetrumuna uyum dikkate alınarak, seçilmiştir. Seçilen yer hareketi kayıtları kullanılarak her bir ölçeklendirme durumu için ayrı ayrı doğrusal olmayan dinamik analizler yapılmıştır. Daha sonra bu analizlerin sonuçları katlar arası göreli deplasman sonuçları üzerinden incelenmiştir. Göreli değerleri kat yüksekliğinin %aşan sonuçlar göçme olarak değerlendirilmiş ve ilgili durumda göreli ötelenme değeri kat yükseliğinin yüzde ikisi olarak işaretlenmiştir. Analizler sonucunda, kullanılan ölçeklendirme yöntemine göre, ortalama göreli kat deplasmanlarının birinci önemli ölçüde değiştiği görülmüştür. Bu sonuçlar, analiz süreçlerinde kullanılan ölçeklendirme kriterlerinin karar mekanizmasını etkileyebileceğini ortaya çıkarmıştır. Bu

[1] Sorumlu Yazar

ISBN NR: 978-625-5694-92-8

çalışma Ayşe Çelik'in yüksek lisans tez kapsamında yaptığı çalışmalardan üretilmiştir.

Anahtar Kelimeler: Dinamik analiz, Betonarme çerçeve, Ölçeklendirme

ISBN NR: 978-625-5694-92-8

INVESTIGATION OF EARTHQUAKE GROUND MOTIONS RECORDED ON DIFFERENT SITE CONDITIONS

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ABSTRACT

The softness or stiffness of the soil through which seismic waves propagate plays an important role in shaping the characteristics of ground motions recorded at different site conditions. Therefore, soil properties are key factors that directly influence the level of structural damage during earthquakes. Structural design depends on the soil type in the seismic design codes. There are five soil types accepted in the seismic codes worldwide. In this study, the ground motion records from three types of soils, such as rock (B), very dense soil and soft rock (C) and stiff soil (D), have been selected and investigated through their frequency characteristics. The decomposition of signals has been performed by discrete wavelet transform to obtain low-frequency energy of the earthquakes. In the discrete wavelet transform, high frequency pass detail and low-frequency pass approximation signals are obtained. In this study approximation signals have been focused to acquire low-frequency contents of earthquakes because of the importance of low-frequency contents to structural resonance and displacement demand. The analysis results indicate noticeable differences in the frequency characteristics of earthquake records obtained from different site conditions. Ground motions recorded on soft soil sites have exhibited stronger low-frequency components compared to those recorded on rock or stiff soil sites. These components are more clearly captured in the lower-level approximations of the decomposition results. In contrast, records obtained from rock sites generally contain relatively higher-frequency components. The comparison results demonstrate that site conditions play a significant role in shaping the frequency characteristics of earthquake ground motions.

Keywords : different soil types, frequency content, ground motions, approximations.

ISBN NR: 978-625-5694-92-8

1. INTRODUCTION

Earthquake waves travel through different soil types and eventually transmit their seismic energy to structures. The responses of these structures vary, mostly due to the types of soil on which they are built and, of course, their structural characteristics. Soils have different shear wave velocities in the first 30 meters (V_{s30}) depending on whether they are soft or stiff. Low shear wave velocity indicates soft soil (V_{s30}<180 m/s), and therefore significant structural damage; while higher values (V_{s30}>180 m/s) indicate stiff soil and cause less structural damage. Therefore, knowledge of soil properties is essential in the design of structures.

In this study different earthquake accelerations recorded on different soil types has been investigated. The ground motion records taken form the B (rock), C (very dense soil and soft rock) and D (stiff soil), defined in FEMA440 [1], have been analyzed through discrete wavelet transform. Discrete wavelet transform decomposes an earthquake signal into approximation and detail components at different scales, allowing the identification of its time–frequency characteristics. Three sets of earthquakes, each containing three earthquakes, were analyzed under five-level decomposition. Approximation signals have been taken into account since they are representative for low-frequency components. The mother waveform function was taken as Daubechies 4, consistent with the literature. The aim of this study is to compare the frequency content of earthquake records from different soil types and to present which decomposition level is similar to the real record.

2. EARTHQUAKE RECORDS AND DECOMPOSED SIGNALS

Three sets of earthquake records corresponding to B, C and D type soils have been selected [2]. The records have been obtained from PEER ground motion database. The component, magnitude (Mw) and peak ground acceleration (PGA) properties are given in Table 1.

Table 36 Ground motions selected

Earthquake	Station	Component	Mw	PGA (cm/s^2)	NEHRP Site Class
1994 Northridge	LA, Wonderland Ave.	185	6.8	168.7	B
1979 Imperial Valley	Superstition Mountain	135	6.8	198.2	B

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1992 Landers	Twentynine Palms Park Maintenance Bldg.	0	7.5	78.7	B
1989 Loma Prieta	Saratoga, Aloha Ave.	0	7.1	494.5	C
1984 Morgan Hill	Gilroy #6, San Ysidro Microwave Site	90	6.1	280.4	C
1994 Northridge	Castaic, Old Ridge Route	360	6.8	504.2	C
1994 Northridge	Santa Monica City Hall	90	6.8	866.2	D
1979 Imperial Valley	Calexico	225	6.6	269.6	D
1999 Kocaeli	Duzce	270	7.5	390.1	D

Discrete wavelet transform decomposes time series into approximation and detail signals. Approximations are obtained by applying high-pass filter and resulting in low-frequency contents. Details are referred as high-frequency signals. Low-frequency components of earthquake accelerations are of particular importance, as they can significantly influence the response of structures. In each decomposition the number of data points in the signal is halved.

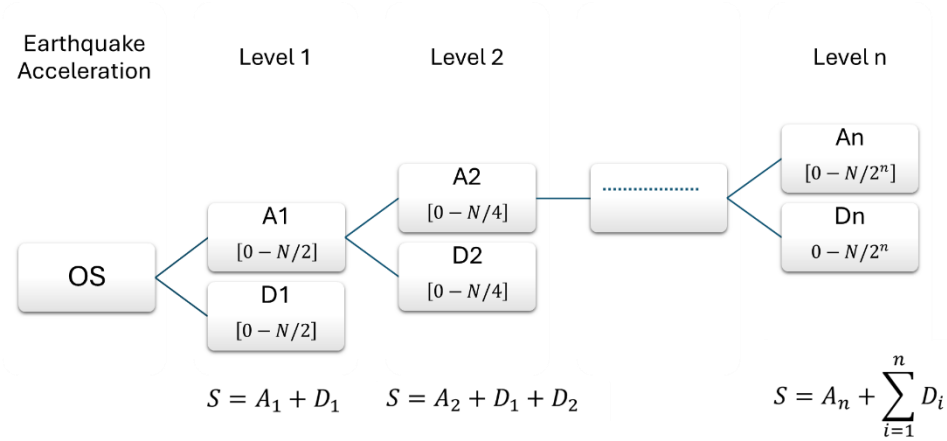

Figure 1. Schematic of DWT

3. RESULTS

In this section, the results have been presented to clarify the applicability discrete wavelet transform in earthquake ground motions recorded in different soil types. The earthquakes recorded on B-type soil gives similar signals at first-level decomposition (A1) as given in Figure

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2. However 1992 Landers earthquake contains more high-frequency components since its approximation at higher levels distorted.

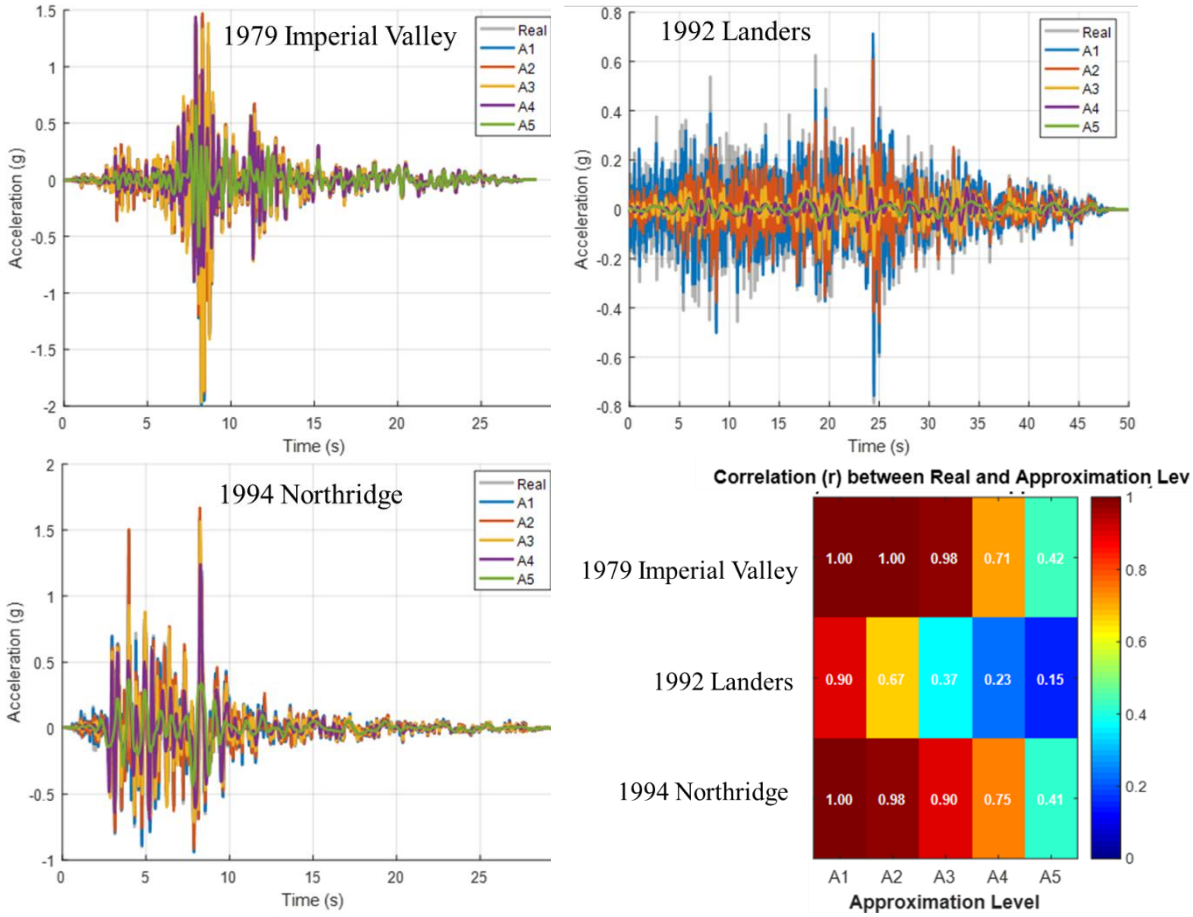

Figure 2. Approximations and corresponding correlation coefficient of the earthquakes recorded on B-type soil

For the earthquakes recorded on C-type soil, the signals decomposed up to second-level approximation closely represent the real acceleration as given in Figure 3. 1984 Morgan Hill earthquake is more suitable for decomposition using wavelet because it shows a good agreement with the real record, even at high levels (up to A4).

ISBN NR: 978-625-5694-92-8

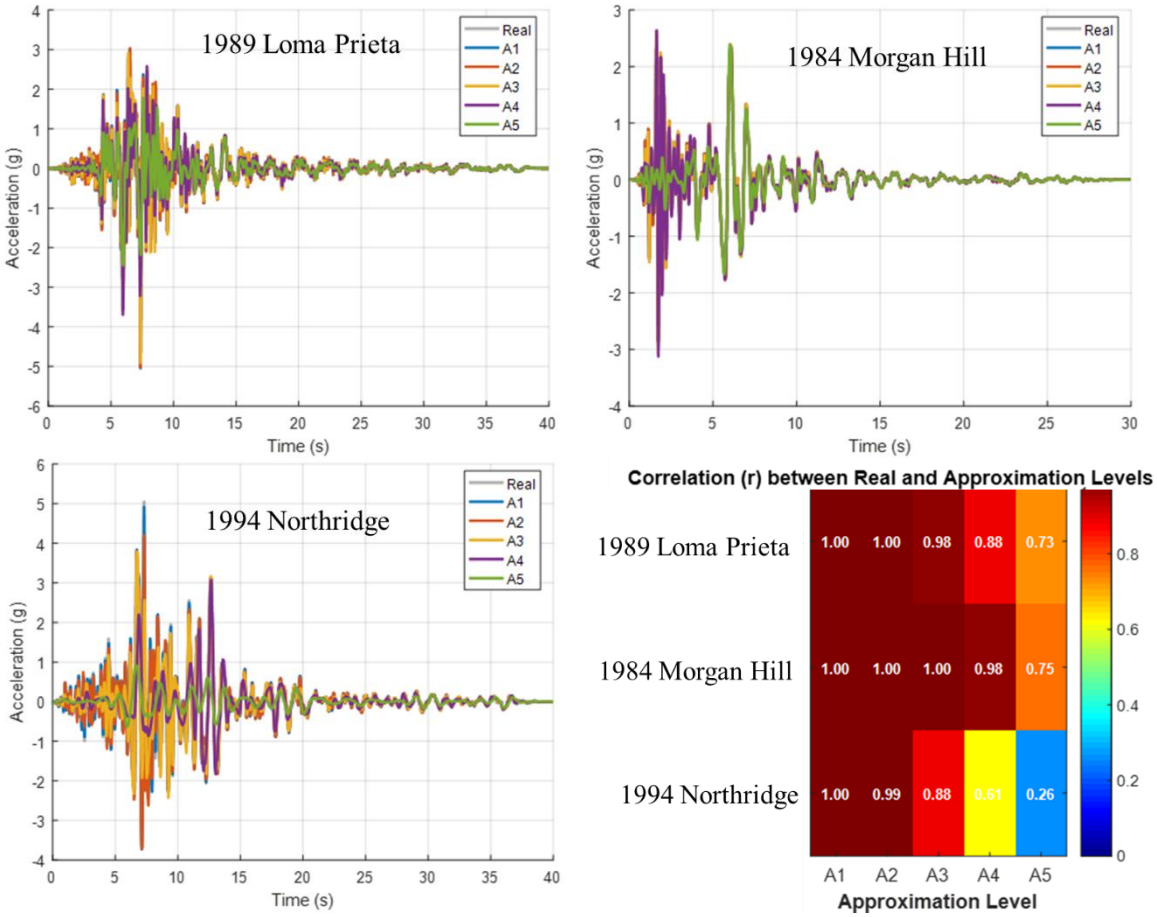

Figure 3. Approximations and corresponding correlation coefficient of the earthquakes recorded on C-type soil

As shown in Figure 4, earthquakes recorded on D-type soil contain stronger low-frequency components. Although the Northridge record slightly deviates from this general trend, it is still well represented up to the A2 approximation level.

ISBN NR: 978-625-5694-92-8

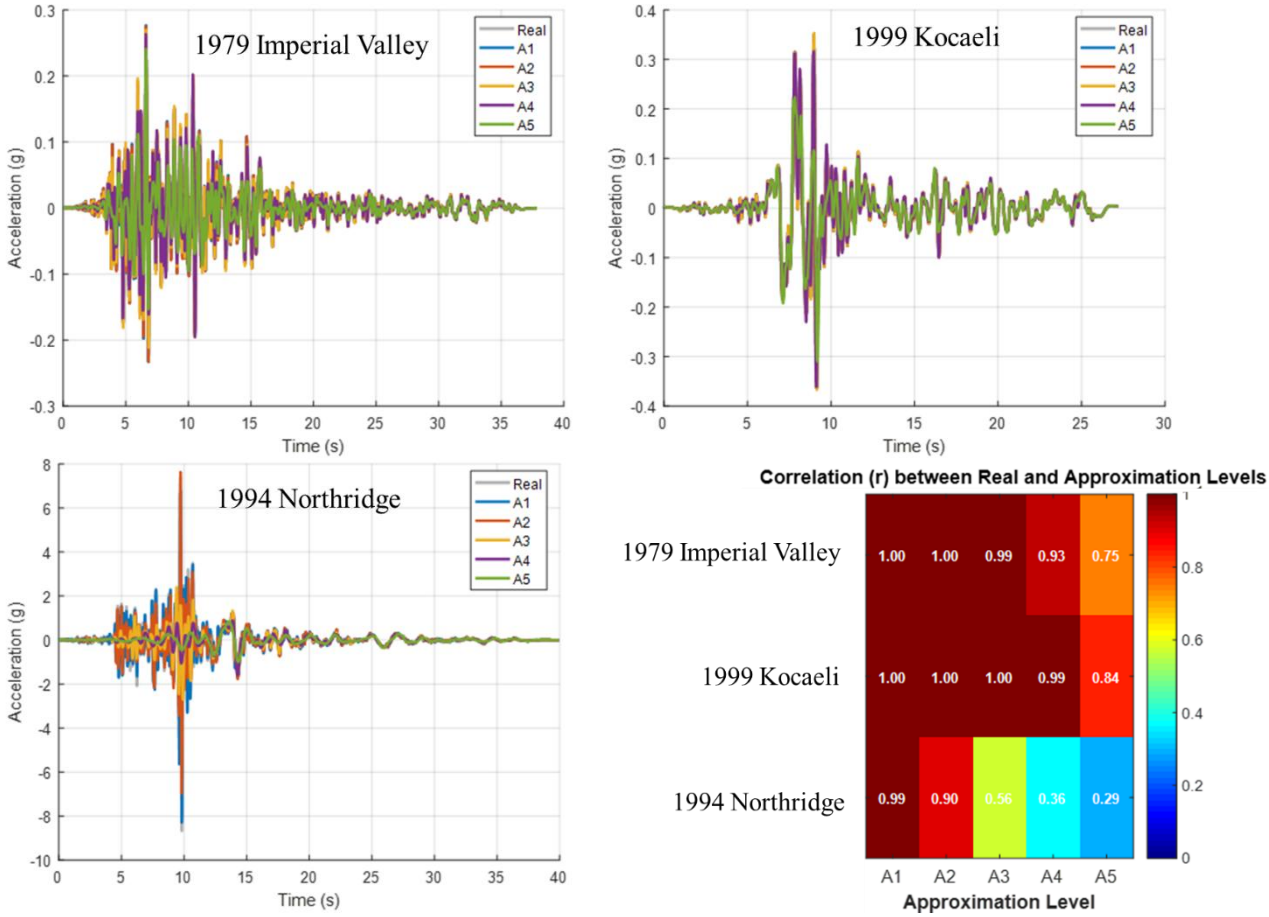

Figure 4. Approximations and corresponding correlation coefficient of the earthquakes recorded on D-type soil

4. CONCLUSIONS

This study evaluated earthquake ground motion records obtained from different soil types using discrete wavelet signal decomposition techniques. The correlation results between the actual acceleration records and the approximate levels show that the first and second approximate levels (A1 and A2) represent the original signals very well, with correlation coefficients close to one. However, as the decomposition level increases, the correlation between the approximate signals and the original records gradually decreases. Differences in correlation patterns can be observed among soil types. Ground motions recorded in softer soils tend to preserve low-frequency components more strongly. Although there are some differences between individual records, the overall results show that lower approximate levels provide a more reliable representation of earthquake accelerations.

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ISBN NR: 978-625-5694-92-8

EVALUATION OF EARTHQUAKE GROUND MOTIONS ON DIFFERENT SOILS USING VARIOUS SIGNAL DECOMPOSITION FUNCTIONS

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ABSTRACT

Definition of wavelet is done by mother wavelets and scaling functions. This allows the signal to be decomposed according to its frequency component and time, ultimately yielding high and low frequency components called approximation and detail, respectively. Low-frequency components of earthquakes are of great importance in structural design because of structural resonance and displacement demand. Therefore, emphasis was placed on approximation signals in this paper. On the other hand, different mother wavelet functions have been investigated and compared to reveal the appropriate one which is best to represent real records. The ground motions have been selected from the acceleration signals recorded on different soil types. Ground motion records from soft (D), stiff (C) and rock (B) site conditions were chosen to represent a wide range of soil properties. The aim of the study is to acquire suitable mother wavelet according to the soil type. Each record was decomposed into three approximation levels using discrete wavelet analysis, allowing the identification of dominant frequency components associated with different soil types. Mother wavelet function of Haar, Daubechies 4 and biorthogonal 3.3 which are mostly used in seismicity related studies have been preferred to compare. The results reveal that low-frequency components are more pronounced in motions recorded on soft soils, whereas rock site motions exhibit higher-frequency content. Comparisons across wavelet functions indicate that the choice of wavelet influences the clarity and resolution of the decomposition, though general trends remain consistent across methods.

Keywords : earthquake acceleration, mother wavelet function, different soil types.

1. INTRODUCTION

Discrete wavelet transform is defined by mother wavelet and scaling functions. Different wavelet function result in different interpretation of time series. Therefore, finding and studying

ISBN NR: 978-625-5694-92-8

with the correct functions are of great importance. In this study, mother functions of Haar, Daubechies 4 and biorthogonal 3.3 which are mostly used in seismic engineering, have been applied to ground motions recorded on different soil sites. The ground motion records taken form the B (rock), C (very dense soil and soft rock) and D (stiff soil), defined in FEMA440 [1], have been analyzed through discrete wavelet transform. Discrete wavelet transform decomposes an earthquake signal into approximation and detail components at different scales, allowing the identification of its time–frequency characteristics. Three sets of earthquakes, each containing three earthquakes, were analyzed under three-level decomposition. Approximation signals have been taken into account since they are representative for low-frequency components. The mother waveform function was taken as Daubechies 4, consistent with the literature. The aim of this study is to compare the frequency content of earthquake records from different soil types and to present which mother wavelet presents best similar signals to the real record.

2. SELECTED EARTHQUAKE RECORDS AND MOTHER WAVELETS

Three sets of earthquake records corresponding to B, C and D type soils have been selected [2]. The records have been obtained from PEER ground motion database. The component, magnitude (Mw) and peak ground acceleration (PGA) properties are given in Table 1.

Table 37 Ground motions selected

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1984 Morgan Hill	Gilroy #6, San Ysidro Microwave Site	90	6.1	280.4	C
1994 Northridge	Castaic, Old Ridge Route	360	6.8	504.2	C
1994 Northridge	Santa Monica City Hall	90	6.8	866.2	D
1979 Imperial Valley	Calexico	225	6.6	269.6	D
1999 Kocaeli	Duzce	270	7.5	390.1	D

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Mother wavelets differ in their shapes, and this difference affects how well they can represent various characteristics of a time series. Some wavelets are better at detecting sharp discontinuities, while others are suited for smooth oscillations.

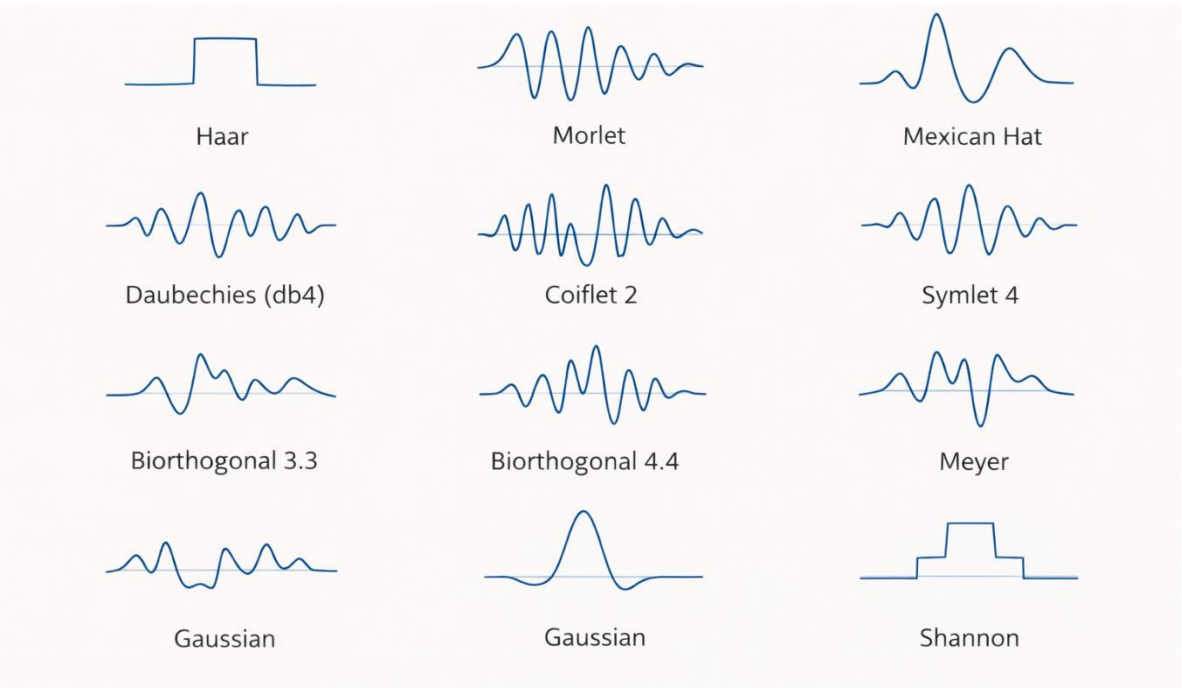

Figure 2. Different mother wavelet functions

3. RESULTS

The correlation coefficients between original record and corresponding approximations are presented in this section. The numerical results have been calculated by Pearson correlation formula due to its capability in showing the difference between the time series. In Figure 3, correlation coefficients for the earthquakes recorded at B-type soil is given. The mother wavelets Haar, Db4 and bior3.3 has been used and corresponding approximations have been compared. As for B-type soil, the high-frequency contents in the ground motions are dominant as can be understood from the figures. Especially, 1992 Landers earthquake, even for the first-level decomposition (A1), the correlation between real record and A1 is lower than 1.

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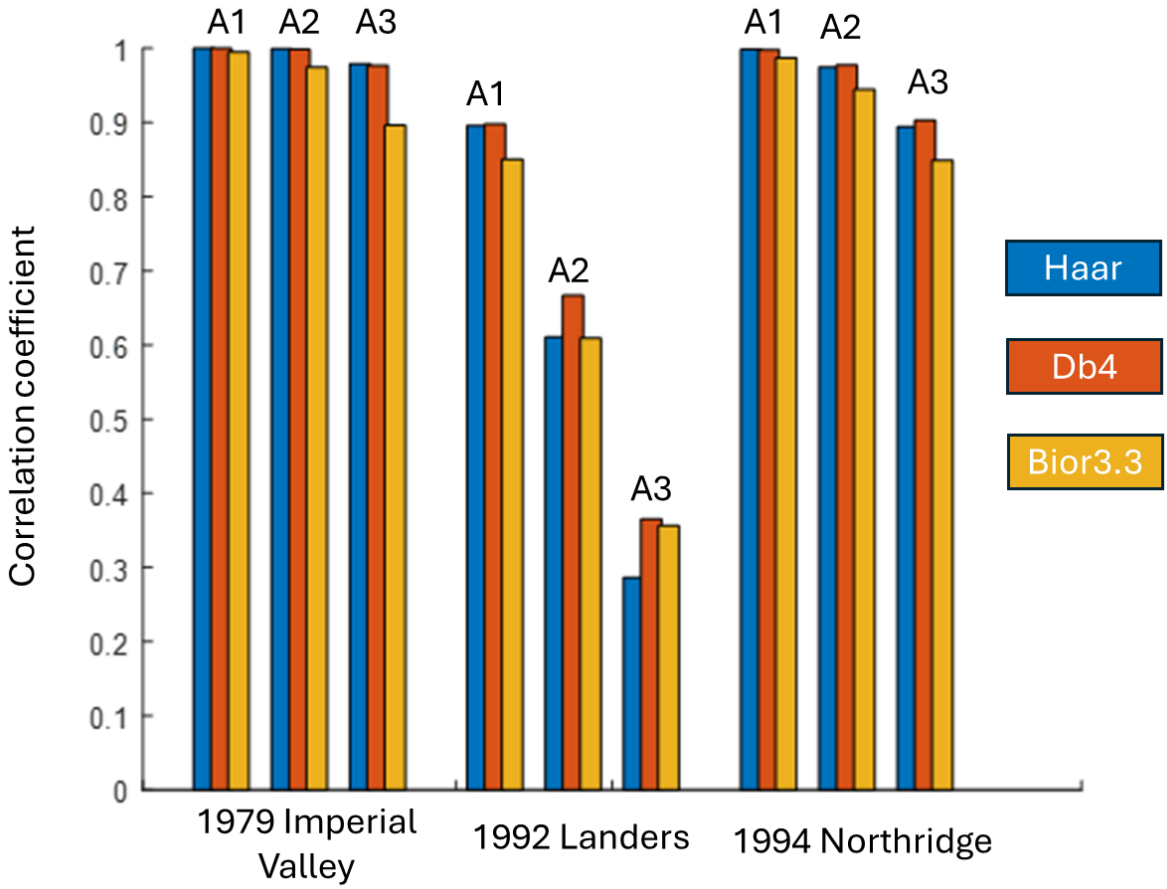

Figure 3. Correlation coefficient for B-type soil

Table 38 Correlation coefficient for B-type soil

Record	**Level**	**Haar (RMSE / Corr)**	**db4 (RMSE / Corr)**	**bior3.3 (RMSE / Corr)**
ImpVal_Supers135.mat	A1	0.02181 / 0.99478	0.00274 / 0.99992	0.00245 / 0.99993
	A2	0.04809 / 0.97436	0.01155 / 0.99854	0.00925 / 0.99907
	A3	0.09489 / 0.89603	0.04554 / 0.97703	0.04368 / 0.97905
LandersPalms0.mat	A1	0.06348 / 0.85069	0.05315 / 0.89794	0.05367 / 0.89581
	A2	0.09579 / 0.60889	0.09000 / 0.66674	0.09579 / 0.61040
	A3	0.11284 / 0.35622	0.11242 / 0.36514	0.11727 / 0.28642
NorthridgeWon185.mat	A1	0.03310 / 0.98707	0.01300 / 0.99802	0.01160 / 0.99842
	A2	0.06799 / 0.94425	0.04376 / 0.97729	0.04617 / 0.97471
	A3	0.10912 / 0.84899	0.08885 / 0.90271	0.09258 / 0.89393

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For the C-type soil, the correlation coefficients show similarity of the approximations to the original record as shown in Figure 3. This means that the ground motions recorded on C-type soil contain significant low frequency contents.

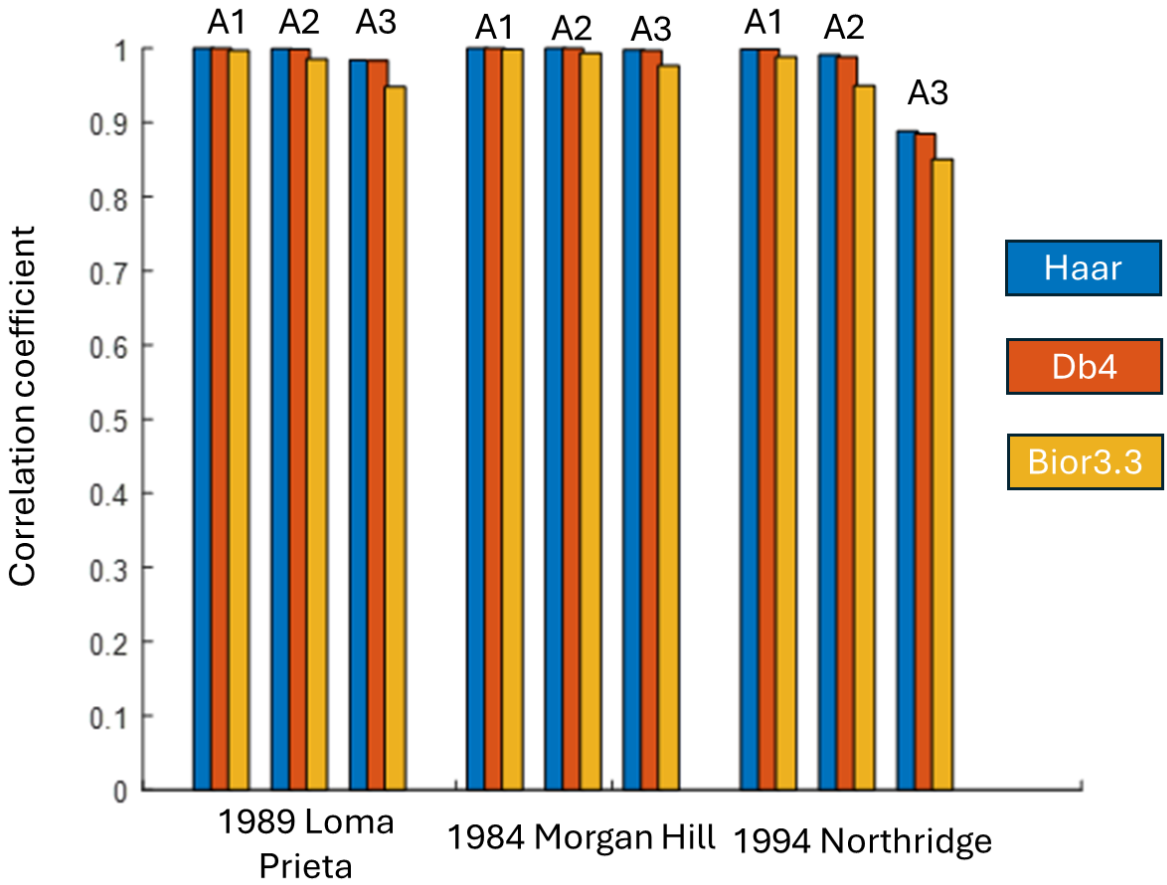

Figure 3. Correlation coefficient for C-type soil

Table 39 Correlation coefficient for C-type soil

Record	Level	Haar (RMSE / Corr)	db4 (RMSE / Corr)	bior3.3 (RMSE / Corr)
Loma_Aloha0.mat	A1	0.03687 / 0.99702	0.00360 / 0.99997	0.00297 / 0.99998
	A2	0.08048 / 0.98571	0.02135 / 0.99900	0.01650 / 0.99941
	A3	0.15201 / 0.94805	0.08601 / 0.98367	0.08501 / 0.98409
Morgan_Gilroy6_90.mat	A1	0.02142 / 0.99874	0.00078 / 1.00000	0.00063 / 1.00000
	A2	0.04743 / 0.99380	0.00548 / 0.99992	0.00457 / 0.99994
	A3	0.09119 / 0.97689	0.03077 / 0.99740	0.02645 / 0.99809
Northridge_Castaic360.mat	A1	0.10605 / 0.98855	0.03311 / 0.99889	0.03151 / 0.99899
	A2	0.22068 / 0.94942	0.10677 / 0.98839	0.09308 / 0.99122
	A3	0.36939 / 0.85070	0.32795 / 0.88443	0.32365 / 0.88820

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For the D-type soil, the correlation coefficients show great similarity of the approximations to the original record as shown in Figure 4. This indicates that the low-frequency components of the ground motion are well preserved, particularly at lower approximation levels.

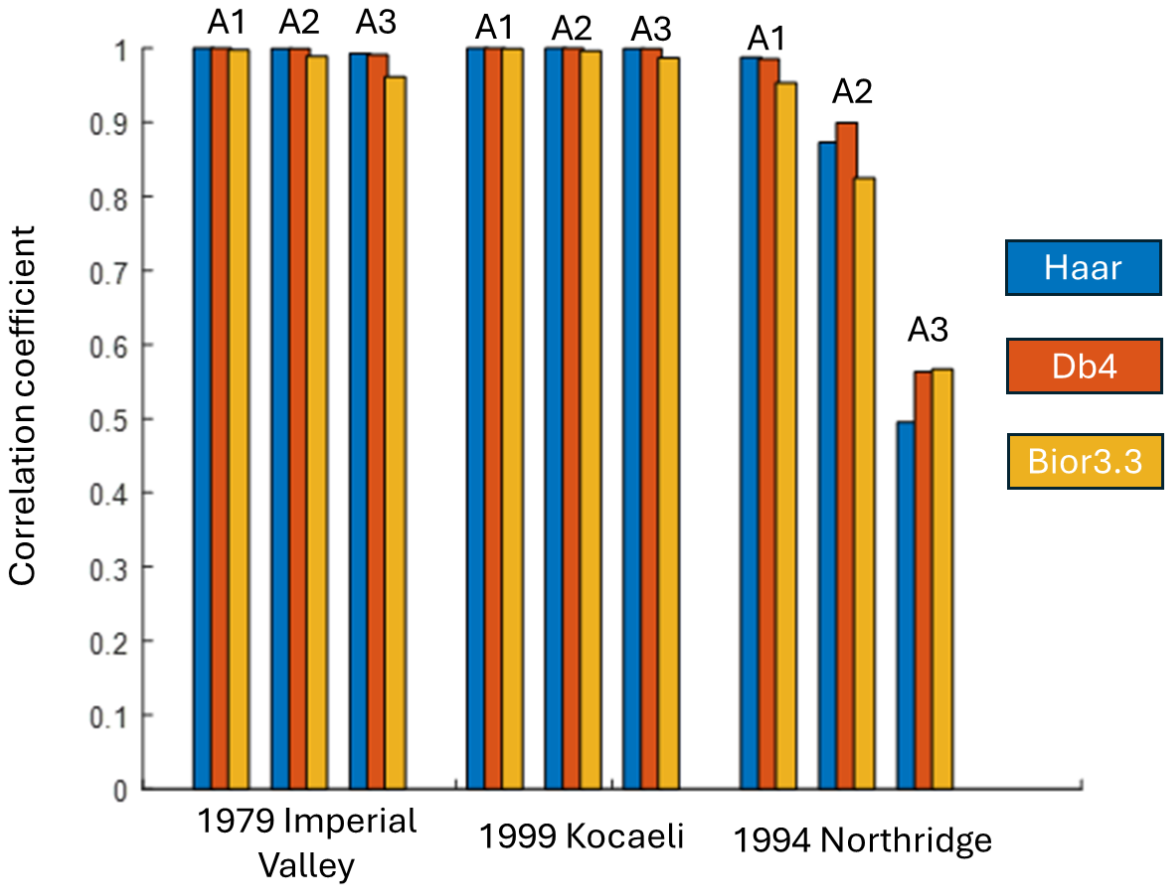

Figure 3. Correlation coefficient for D-type soil

Table 40 Correlation coefficient for D-type soil

Record	**Level**	**Haar (RMSE / Corr)**	**db4 (RMSE / Corr)**	**bior3.3 (RMSE / Corr)**
ImpVal_Calex225.mat	A1	0.00251 / 0.99786	0.00032 / 0.99997	0.00029 / 0.99997
	A2	0.00556 / 0.98945	0.00125 / 0.99947	0.00108 / 0.99961
	A3	0.01057 / 0.96133	0.00511 / 0.99109	0.00470 / 0.99251
Kocaeli270.mat	A1	0.00201 / 0.99936	0.00003 / 1.00000	0.00003 / 1.00000
	A2	0.00448 / 0.99684	0.00022 / 0.99999	0.00013 / 1.00000
	A3	0.00906 / 0.98703	0.00166 / 0.99957	0.00132 / 0.99973
Northridge_Santa90.mat	A1	0.20133 / 0.95329	0.11353 / 0.98539	0.10491 / 0.98761
	A2	0.37674 / 0.82494	0.29115 / 0.89956	0.32533 / 0.87280
	A3	0.54925 / 0.56656	0.55076 / 0.56324	0.59635 / 0.49525

ISBN NR: 978-625-5694-92-8

4. CONCLUSIONS

Decomposition of earthquake ground motions allows the identification of dominant frequency components and facilitates the comparison of signals recorded on different soil types. This study focuses on the analysis of earthquake acceleration records obtained from different soil conditions (B, C, and D) by applying a multi-level signal decomposition technique. The results show that the first two approximation levels (A1 and A2) are generally sufficient to represent the original ground motion with high accuracy, as reflected by the strong correlation values. However, as the decomposition level increases, a gradual reduction in similarity is observed, mainly due to the elimination of higher-frequency components.

For B-type soils, the results reveal a more noticeable decrease in correlation at higher levels, particularly for certain records, indicating a more complex signal structure. In contrast, records from C-type soils tend to preserve their similarity to the original signal even at higher approximation levels, suggesting a more stable frequency distribution. On the other hand, D-type soils exhibit a clearer decline in correlation at A3, which highlights the dominant role of low-frequency components in these records.

The findings suggest that soil conditions have a significant influence on the frequency content of earthquake records, and that low-frequency components are particularly important for representing ground motion behavior. The study also emphasizes that the choice of decomposition approach plays an important role in achieving reliable results.

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ISBN NR: 978-625-5694-92-8

TEK PİLONLU BETONARME KABLO ASKILI BİR KÖPRÜDE KİRİŞ DERİNLİĞİNİN DÜŞEY YER DEĞİŞTİRME DAVRANIŞI ÜZERİNE ETKİSİ

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ÖZET

Kablo askılı köprüler, geniş açıklıkları ekonomik ve estetik biçimde geçebilme avantajları nedeniyle modern köprü mühendisliğinde yaygın olarak tercih edilmektedir. Bu çalışmada, tek pilonlu ve betonarme kutu kesitli bir kablo askılı köprü modelinde, ana taşıyıcı kiriş derinliğinin düşey yer değiştirme davranışı üzerindeki etkisi incelenmiştir. Çalışma kapsamında CSI Bridge programı kullanılarak 1.8 m ile 2.2 m arasında değişen beş farklı kiriş derinliği için sonlu elemanlar modelleri oluşturulmuş ve servis yükleri altında doğrusal elastik analizler gerçekleştirilmiştir. Analiz sonuçları, kiriş derinliğinin 1.8 m'den 2.2 m'ye çıkarılmasıyla, orta açıklıkta oluşan maksimum düşey yer değiştirmelerde yaklaşık %15–20 aralığında bir azalma sağlandığını göstermektedir. Elde edilen bulgular, kiriş derinliğindeki artışın tabliye rijitliğini sistematik olarak yükselttiğini ve köprü tabliyesinin servis yükleri altındaki sehimlerinin hedeflenen sınırlar içinde kalmasına önemli ölçüde katkı sunduğunu ortaya koymaktadır. Çalışma sonucunda, yapısal güvenlik ile malzeme ekonomisi arasındaki dengenin gözetildiği, tasarım sürecinde mühendisler için yol gösterici nitelikte bir kiriş derinliği aralığı önerilmektedir.

Anahtar Kelimeler: Kablo askılı köprü, kiriş derinliği, düşey yer değiştirme, sonlu elemanlar analizi, yapısal rijitlik

1. GİRİŞ

Kablo askılı köprüler, 200 m ile 1000 m arasındaki açıklıkları ekonomik olarak geçebilme kapasiteleri nedeniyle modern köprü mühendisliğinde önemli bir yere sahiptir [1]. Bu köprü tipinde, tabliye ağırlığı ve hareketli yükler, pilondan tabliyeye uzanan kablolar aracılığıyla taşınmaktadır. Tabliye, genellikle çelik veya betonarme

kutu kesit olarak tasarlanmakta ve yüksek burulma rijitliği ile aerodinamik stabilite sağlamaktadır [2]. Kablo askılı köprülerde tabliye tasarımında en kritik parametrelerden biri, ana taşıyıcı kiriş derinliğidir. Kiriş derinliği, yapının rijitliğini, düşey yer değiştirme davranışını, gerilme dağılımını ve malzeme tüketimini doğrudan etkilemektedir [3].

Literatürde, uzun açıklıklı köprüler (>500 m) için kiriş derinliği optimizasyonu üzerine çalışmalar bulunmakla birlikte [4,5], orta açıklıklı (200-300 m) tek pilonlu köprüler için sistematik parametrik çalışmalar sınırlıdır. Geleneksel tasarım yaklaşımlarında, kiriş derinliği genellikle açıklık/derinlik (L/h) oranına göre belirlenmektedir. AASHTO LRFD [6], kablo askılı köprüler için L/h oranının 100 ile 150 arasında olmasını önermektedir. Bu çalışmanın amacı, 260 m ana açıklıklı tek pilonlu betonarme kablo askılı bir köprüde, kiriş derinliğinin 1.8 m ile 2.2 m arasında değiştiği beş farklı senaryonun düşey yer değiştirme davranışı üzerindeki etkisini sistematik olarak incelemektir.

2. MATERYAL VE YÖNTEM

2.1. Köprü Modeli ve Geometrik Özellikler

Çalışmada, 260 m ana açıklıklı tek pilonlu kablo askılı bir köprü modeli oluşturulmuştur. Pilon yüksekliği 60 m olarak belirlenmiş ve L/Hpilon oranı yaklaşık 4.33 olarak hesaplanmıştır. Tabliye genişliği 12.0 m olup, iki trafik şeridi ve yaya yolu için yeterli genişliği sağlamaktadır. Tabliye, üç gözlü betonarme kutu kesit olarak tasarlanmıştır. Kablolar, fan tipi düzende yerleştirilmiştir. Pilon üzerinde 2.0 m, tabliye üzerinde 10.0 m aralıklarla ankraj edilmiştir. Kablo malzemesi olarak 1860 MPa çekme dayanımına sahip yüksek mukavemetli çelik kullanılmıştır. Tabliye malzemesi C28 beton (fck = 28 MPa) olarak belirlenmiştir.

2.2. Parametrik İnceleme Kapsamı

Kiriş derinliğinin düşey yer değiştirme davranışı üzerindeki etkisini sistematik olarak incelemek amacıyla, beş farklı kiriş derinliği senaryosu oluşturulmuştur: 1.8 m (L/h=144), 1.9 m (L/h=137), 2.0 m (L/h=130), 2.1 m (L/h=124) ve 2.2 m (L/h=118). Her senaryoda, kutu kesit genişliği ve plak kalınlıkları sabit tutulmuş, sadece kiriş derinliği değiştirilmiştir.

2.3. Yük Kombinasyonları ve Analiz Yöntemi

Analizlerde AASHTO LRFD [6] standartlarına göre üç farklı yük kombinasyonu kullanılmıştır: (1) DEAD - Sadece ölü yük, (2) SERV 1 - Servis yük kombinasyonu (ölü yük + hareketli yük), (3) STR 1 - Dayanım yük kombinasyonu (1.25×ölü yük + 1.75×hareketli yük). Hareketli yük olarak AASHTO HL-93 tasarım

ISBN NR: 978-625-5694-92-8

kamyonu kullanılmıştır. Sonlu elemanlar analizleri CSI Bridge v23 programı kullanılarak gerçekleştirilmiştir.

3. BULGULAR VE TARTIŞMA

3.1. Düşey Yer Değiştirme Sonuçları

SERV 1 yük kombinasyonu altında elde edilen maksimum düşey yer değiştirme değerleri Çizelge 1'de sunulmuştur. 1.8 m kiriş derinliğinde maksimum sehim -42 mm (L/6190) olarak hesaplanmıştır. Kiriş derinliği 2.0 m'ye çıkarıldığında, sehim -35 mm'ye (L/7429) düşmüş ve %16.7 azalma sağlanmıştır. 2.2 m derinlikte ise sehim -29 mm (L/8965) olarak elde edilmiş ve toplam %31.0 azalma gözlenmiştir. Görsel 1, kiriş derinliği ile düşey yer değiştirme arasındaki ilişkiyi göstermektedir.

Çizelge 1. Farklı Kiriş Derinliklerinde Düşey Yer Değiştirme Sonuçları

Kiriş Derinliği (m)	L/h Oranı	SERV 1 Sehim (mm)	Sehim Oranı
1.8	144	42	L/6190
1.9	136	38	L/6842
2.0	130	35	L/7428
2.1	123	29	L/8965
2.2	118	29	L/8965

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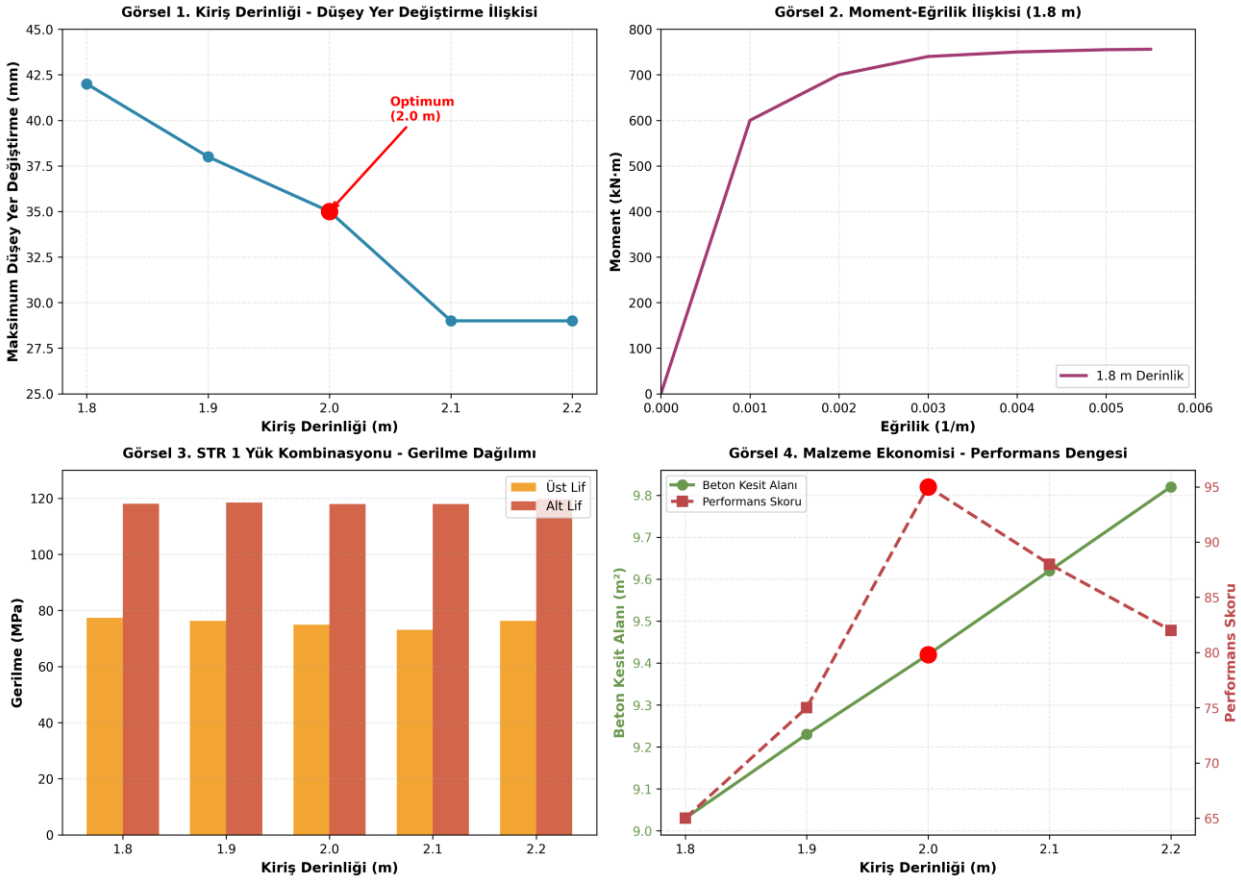

Görsel 1. Kiriş Derinliği - Düşey Yer Değiştirme İlişkisi ve Karşılaştırmalı Analizler

3.2. Gerilme Dağılımı

STR 1 yük kombinasyonu altında kesit içi normal gerilme dağılımları Çizelge 2'de sunulmuştur. 1.8 m derinlikte üst lif gerilmesi -77.4 MPa, alt lif gerilmesi -118.1 MPa olarak hesaplanmıştır. Kiriş derinliği arttıkça gerilmeler sistematik olarak azalmış ve 2.1 m derinlikte minimum değerlere ulaşmıştır (üst lif: -73.1 MPa, alt lif: -117.9 MPa). Ancak, 2.2 m derinlikte gerilmeler tekrar artmıştır. Bu bulgu, belirli bir derinlikten sonra kiriş derinliği artışının, zati ağırlık artışı nedeniyle gerilmeleri yükselttiğini göstermektedir.

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Çizelge 2. STR 1 Yük Kombinasyonu - Gerilme Değerleri

Kiriş Derinliği (m)	Üst Lif Gerilmesi (MPa)	Alt Lif Gerilmesi (MPa)
1.8	77.4	118.1
1.9	76.3	118.5
2.0	74.9	118.0
2.1	73.1	117.9
2.2	76.3	119.7

3.3. Moment Kapasitesi ve Malzeme Ekonomisi

Kesit moment kapasitesi, kiriş derinliği ile doğru orantılı olarak artmıştır. 1.8 m derinlikte 755 kN·m olan moment kapasitesi, 2.0 m'de 820 kN·m'ye (%8.6 artış), 2.2 m'de ise 875 kN·m'ye (%15.9 artış) yükselmiştir. Beton kesit alanı, 1.8 m derinlikte 9.03 m² iken, 2.0 m'de 9.42 m²'ye (%4.3 artış), 2.2 m'de ise 9.82 m²'ye (%8.7 artış) yükselmiştir. Görsel 1'de sunulan malzeme ekonomisi-performans dengesi grafiği, 2.0 m derinliğin optimum noktayı temsil ettiğini göstermektedir.

4. SONUÇLAR VE ÖNERİLER

Bu çalışmada, 260 m ana açıklıklı tek pilonlu betonarme kablo askılı bir köprüde, kiriş derinliğinin düşey yer değiştirme davranışı üzerindeki etkisi sistematik olarak incelenmiştir. Beş farklı kiriş derinliği senaryosu (1.8-2.2 m) CSI Bridge programı kullanılarak analiz edilmiş ve aşağıdaki sonuçlar elde edilmiştir:

(1) Kiriş derinliğinin 1.8 m'den 2.2 m'ye artırılması, servis yükleri altında maksimum düşey yer değiştirmelerde %15-20 azalma sağlamıştır.

(2) 2.0 m kiriş derinliği (L/h=130), yapısal güvenlik ile malzeme ekonomisi arasında optimum dengeyi sağlamıştır.

(3) 2.1 m'den sonra kiriş derinliği artışının marjinal faydası azalmıştır.

(4) Tüm senaryolar AASHTO LRFD sehim sınırlarını fazlasıyla sağlamıştır.

(5) Orta açıklıklı (200-300 m) tek pilonlu köprülerde ön tasarım için L/h=120-140 aralığı önerilmektedir.

Gelecek araştırmalarda, farklı kablo düzenlerinin, çift pilonlu sistemlerin ve çelik-beton kompozit kesitlerin etkisi incelenebilir. Bu çalışma, orta açıklıklı kablo askılı köprüler için literatürde eksik olan sistematik bir veri seti sunmaktadır.

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ISBN NR: 978-625-5694-92-8

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ISBN NR: 978-625-5694-92-8

PHYLOGENETIC COMPARISONS OF FISH BELONGING TO THE GENUS *CAPOETA* IN TURNASUYU STREAM (ORDU, TÜRKİYE)

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ABSTRACT

This study was designed to compare the phylogenetic levels of fish belonging to the genus *Capoeta*, sampled from Turnasuyu Stream (Ordu, Türkiye). Basic morphometric measurements of the fish sampled from Turnasuyu Stream were performed in the laboratory, followed by genomic DNA isolation. Phylogenetic evaluations were carried out using the COI (Cytochrome oxidase I) gene region, commonly used to determine interspecific phylogenetic differences. The isolated DNA samples were amplified by Polymerase Chain Reaction (PCR) using universal primers. Sanger sequencing of the PCR products was performed, and the resulting DNA sequences were processed using various bioinformatics software and made suitable for analysis. For COI-based phylogenetic comparison analyses of *Capoeta*, a sequence dataset for the relevant gene region was created from the NCBI (National Biotechnology Information Center) database. The sequence data obtained from Turnasuyu Stream (Ordu, Türkiye) were also integrated into this set to create phylogenetic trees. Nucleotide sequences of samples belonging to the genus *Capoeta* were aligned, compared, and phylogenetic relationships were determined in detail using MEGA 12 software. In this study, COI sequences of 39 individuals belonging to 14 species of the genus *Capoeta* were evaluated. Neighborhood Join (NJ) and Maximum Likelihood (ML) methods were used to assess the taxonomic position of populations of *Capoeta* species. The study revealed that the fish samples from Turnasuyu Stream (Ordu, Türkiye) belonged to the species *C. banarescui*.

Keywords: *Capoeta*, COI, phylogenetic analysis, bioinformatics

ISBN NR: 978-625-5694-92-8

INTRODUCTION

Türkiye acts as a bridge between Europe and Asia thanks to its location; therefore, Türkiye is one of the richest countries in terms of freshwater fish diversity as a consequence of its diverse bioclimatic areas, spatial heterogeneity, and wide range of endorheic basins and isolated river systems (Giannetto & Innal, 2021). Freshwaters play a relatively significant role in biodiversity owing to their distinct features. Independent and closed inland water systems in Anatolia increase the diversity of fishes by confining gene flow between populations. As a result of taxonomic revisions, the family Cyprinidae currently ranks third in respect of species diversity in Turkish inland waters (Kaya et al., 2026)

The genus *Capoeta* (Valenciennes, 1842), belonging to the family Cyprinidae and widely distributed in Anatolia's freshwater ecosystems, is one of the prime examples (Kaya, 2019). It is distributed within the wide inland waters of the Middle East, the Mediterranean, the Caucasus, and Southwest Asia, including Anatolia (Geldiay & Balık, 2007). Freyhof et al. (2025) reported 27 species in the genus *Capoeta*, of which 15 are distributed in Turkish inland waters (Kaya et al., 2026). In spite of limited economic importance, the algae-scraping cyprinid *Capoeta* are consumed locally in some regions and play a critical role in the freshwater food web. Generally, it prefers moderately flowing streams with a stone and gravel substrate to live. However, it appears in high-velocity streams near the trout zone as well as stagnant lake waters (Kaya, 2019).

Although the genus *Capoeta* is one of the most common and dominant fish groups in the inland waters of both West Asia and Anatolia, it is one of the most controversial groups in terms of taxonomic structure. The members of the genus can mislead researchers in identifications based solely on morphological characters because of the high phenotypic plasticity (Özdemir, 2013; Kaya, 2019). River capture and complex geological history incidents of Anatolia set the stage especially for introgressive hybridization by bringing together different *Capoeta* populations. This complexity leads to discussions on synonymy and taxonomy of *Capoeta* species in the literature. For instance, for many years, the Eastern Black Sea populations classified under the *Capoeta tinca* complex were defined as a new species under the name *Capoeta banarescui* in regard to morphological differences (Turan et al., 2006). Besides the species *C. barroisi*, *C. trutta*, and *C. erhani*, which are known in the literature as the Mesopotamian group, were removed from the genus *Capoeta* and reassigned to the new genus *Paracapoeta* based on current molecular and morphological data (Özdemir, 2013; Turan et al., 2022). Thereby, in cases where morphological data fail to supply adequate resolution or contribute to vague taxonomic conclusions, molecular phylogenetic analyses become indispensable for testing species validity, resolving evolutionary relationships, and building precise biodiversity inventories. The biodiversity in Turkey's freshwater is an important source for both ecological balance and the country's economy. Because of that, these sources need to be identified and observed precisely using molecular methods.

Morphological characteristics, which have underpinned the taxonomy of living organisms for decades, are nowadays inadequate for determining the exact species range in cases of high

phenotypic plasticity, genetic variation, and cryptic species. Molecular methods such as DNA barcoding become obligatory to cope with both these morphological ambiguities and to elucidate evolutionary relatedness with higher resolution (Hebert et al., 2003; Keskin & Atar, 2013). The mitochondrial gene cytochrome c oxidase I (COI) gene sequences are species-specific DNA regions. Diagnostic and phylogenetic problems, which can lead to inadequacy of species identification, are solved by using the COI gene sequencing. In this situation COI gene is widely accepted as a universal species identification tool and the 'gold standard' owing to its optimal evolutionary mutation rate (Briolay et al., 1998; Hebert et al., 2003; Yedier, 2020). Current studies highlight the profound efficacy of the COI gene region in the diagnosis of complicated populations and the detection of cryptic species. As a result, where morphological approaches fail to deliver adequate taxonomic resolution, DNA barcoding facilitates accurate biological classification by supplying statistically verifiable, highly robust, and definitive genetic data (Han et al., 2025; Ullah et al., 2025; Wang et al., 2025).

Despite the abundance of investigations into *Capoeta*, the genus in Turkey's freshwaters, there is a striking paucity of literature on the morphological and molecular qualification of the Turnasuyu Stream populations located in Ordu. To this end, the primary aim of this research is to fulfill an exhaustive morphometric characterization of the *Capoeta* specimens sampled from the Turnasuyu Stream, corroborating conventional taxonomic identification (particularly for *Capoeta banarescui*) through contemporary analytical tools. In this study phylogeny of the *Capoeta* genus was performed by analyzing mitochondrial cytochrome oxidase I gene sequences from 39 individuals representing 14 species. The findings obtained from this inquiry will contribute to shedding light on regional freshwater biodiversity at the molecular level, as well as to resolving the instant taxonomic uncertainties within the genus *Capoeta*.

MATERIALS & METHODS

Specimen Collection and Study Area

In this study, *Capoeta* sp. specimens were collected by electrofishing from Turnasuyu Stream (Ordu, Türkiye). The captured fish were safely transported to the Hydrobiology Laboratory of the Faculty of Arts and Sciences at Ordu University for basic morphometric measurements and preparation of fin tissue samples. Total length (±0.1 cm) and body weight (±0.1 g) measurements were taken from the fish samples. For molecular analysis, tissue fragments were cut from the caudal fin of each specimen and stored in 96% ethanol at -20°C until DNA extraction.

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DNA Extraction and PCR Amplification

Total DNA extraction from the alcohol-maintained dorsal fin tissues was executed following the manufacturer's instructions, utilizing the HibriGen Genomic DNA Isolation Kit. The presence and purity of the isolated DNA were monitored by using 1% agarose gel electrophoresis. The mitochondrial COI gene region was amplified utilizing the universal fish primers (F1 & R1) (Ward et al. 2005).

The PCR thermal cycling was performed with conditions as follows: a first denaturation at 95°C for 2 minutes, subsequently 35 cycles of denaturation at 94°C for 30 seconds, annealing at 54°C for 30 seconds, and extension at 72°C for 1 minute, with a final extension step at 72°C for 10 minutes. The completed PCR products were subjected to bidirectional (forward and reverse) Sanger sequencing through a service contract with Macrogen.

Sequence and Phylogenetic Analyses

Raw DNA sequences, forward and reverse, were visualized and processed utilizing BioEdit (Hall, 1999) and MEGA 12 (Kumar et al., 2024) to generate the accurate consensus sequences by manual trimming misread bases. Multiple sequence alignment was performed using the integrated MUSCLE algorithm in MEGA12. The aligned sequences were compared with the National Center for Biotechnology Information (NCBI) GenBank database using the Basic Local Alignment Search Tool (BLAST) search tool to validate the taxonomic identity of the specimens (Altschul et al., 1997). Interspecific and intraspecific genetic distances were calculated based on the Kimura 2-parameter plus Gamma distribution (K2P+G) evolutionary model, which was declared as the best-fit substitution model for our dataset. COI sequences obtained from *Capoeta* species in the literature were retrieved from the updated GenBank and included in the analysis to accurately evaluate phylogenetic relationships. Phylogenetic tree construction was performed using the Maximum Likelihood (ML) and Neighbor-Joining (NJ) algorithms in MEGA 12, and the topological reliability analysis of the nodes was evaluated through bootstrap analysis based on 1000 replicates.

RESULTS

In this study, 50 fish species were sampled, and the total length and weight of the samples ranged from 9.5-20.0 cm and 7.2-105.7 g, respectively. Within the scope of this research, the mitochondrial DNA COI gene region of *Capoeta* individuals sampled from Turnasuyu Stream in Ordu was examined for the purpose of taxonomic identification and phylogenetic classification. The raw data obtained in the laboratory stage were trimmed and processed using bioinformatics tools, and then it was integrated into a broad comparison matrix encompassing 39 individuals from 14 different *Capoeta* species.

Molecular Diagnostics and BLAST Analysis

The aligned samples from Turnasuyu Stream were compared with over 4.7 billion nucleotide sequences in the NCBI GenBank database. The results of BLAST (Basic Local Alignment

ISBN NR: 978-625-5694-92-8

Search Tool) uncovered that the sequences of haplotype 1 match with *Capoeta banarescui* (Accession no: MH592441.1) GenBank records with 100% identity. The obtained E-value of 0.0 in this analysis demonstrated that this match is non-random and shows the highest level of statistical significance for molecular identification. Moreover, sequences of haplotype 2 matched to *Capoeta banarescui* (Accession no: MH592441.1) GenBank data with 99.69% identity. As shown in Figure 1, an E-value of 0.0 indicates that the sequence identity is statistically significant.

Description	Scientific Name	Max Score	Total Score	Query Cover	E value	Per. Ident	Acc. Len	Accession
Capoeta banarescui haplotype 1 cytochrome oxidase subunit I (COI) gene, partial cds; mitochondrial	Capoeta banare...	1205	1205	97%	0.0	100.00%	652	MH592441.1
Capoeta sp. IHS-2014e cytochrome oxidase subunit I (coxI) gene, partial cds; mitochondrial	Capoeta sp. IHS...	1182	1182	100%	0.0	98.51%	770	KM590418.1
Capoeta banarescui haplotype 2 cytochrome oxidase subunit I (COI) gene, partial cds; mitochondrial	Capoeta banare...	1177	1177	97%	0.0	99.23%	652	MH592442.1
Capoeta sp. IHS-2014d cytochrome oxidase subunit I (coxI) gene, partial cds; mitochondrial	Capoeta sp. IHS...	1177	1177	100%	0.0	98.36%	770	KM590417.1
Capoeta damascina saadii isolate 2293Bakh Yazd cytochrome oxidase subunit I (coxI) gene, partial cds; mitoch...	Capoeta damasc...	1155	1155	100%	0.0	97.76%	770	KM590415.1

Description	Scientific Name	Max Score	Total Score	Query Cover	E value	Per. Ident	Acc. Len	Accession
Capoeta banarescui haplotype 1 cytochrome oxidase subunit I (COI) gene, partial cds; mitochondrial	Capoeta banare...	1194	1194	97%	0.0	99.69%	652	MH592441.1
Capoeta sp. IHS-2014e cytochrome oxidase subunit I (coxI) gene, partial cds; mitochondrial	Capoeta sp. IHS...	1192	1192	100%	0.0	98.52%	770	KM590418.1
Capoeta sp. IHS-2014d cytochrome oxidase subunit I (coxI) gene, partial cds; mitochondrial	Capoeta sp. IHS...	1186	1186	100%	0.0	98.37%	770	KM590417.1
Capoeta banarescui haplotype 2 cytochrome oxidase subunit I (COI) gene, partial cds; mitochondrial	Capoeta banare...	1177	1177	97%	0.0	99.23%	652	MH592442.1
Capoeta damascina saadii isolate 2293Bakh Yazd cytochrome oxidase subunit I (coxI) gene, partial cds; mitoch...	Capoeta damasc...	1164	1164	100%	0.0	97.78%	770	KM590415.1

Figure 1: BLAST Analysis

Phylogenetic Tree and Topology Analysis

Distance and 1,000 bootstrap replications-based Neighbor-Joining (NJ) and probability-based Maximum Likelihood (ML) analysis were performed using MEGA 12 software for phylogenetic reconstruction. The tree building obtained as a result of both algorithms is perfectly consistent with each other in terms of the main evolutionary branching, despite the little variations in the side branches. As shown in Figures 2 and 3, the samples from the Turnasuyu Stream population were placed within the *C. banarescui* lineage, and our specimens (Haplotype 1 and Haplotype 2) were genetically diverged from other *Capoeta* species (e.g., *C. tinca*, *C. capoeta*) in both trees.

ISBN NR: 978-625-5694-92-8

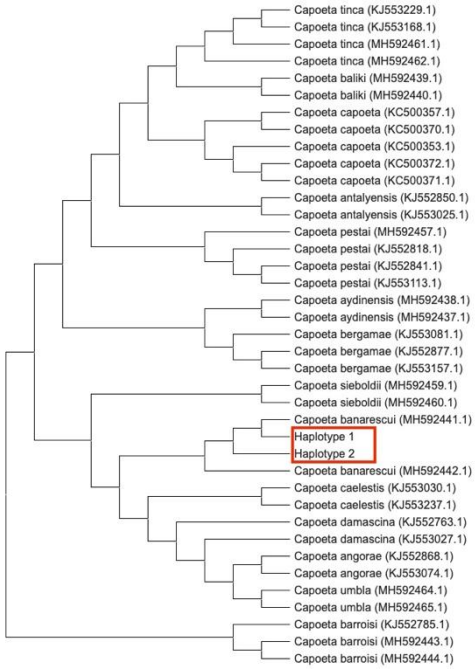

Figure 2: Maximum-Likelihood Tree

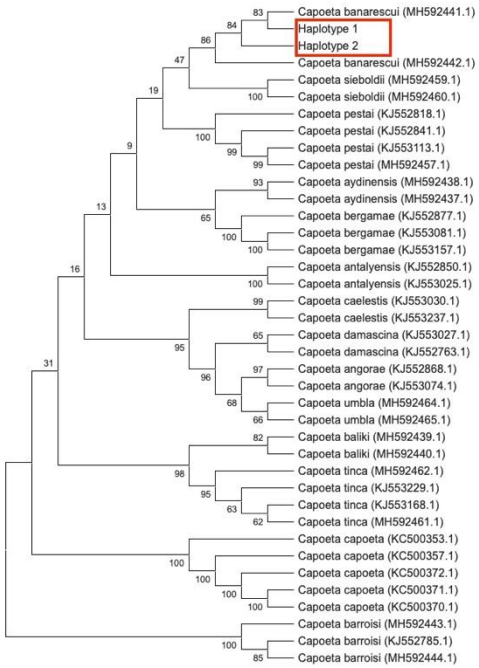

Figure 3: Neighbor-Joining (NJ) Tree

The clustering of Turnasuyu specimens with reference sequence (MH592441.1) at GenBank at the same node and with a small difference between them proves low intraspecific genetic variation for the COI marker. This result shows the reliability of the COI barcoding method in species diagnosis. In this way, it has been verified with certainty that the Turnasuyu population definitively belongs to the species *C. banarescui.*

ISBN NR: 978-625-5694-92-8

DISCUSSION

Capoeta banarescui is a characteristic species of the ruined water flowing into the Black Sea basin. This molecular data obtained from Turnasuyu Stream verified the distribution of the species in Turkey's Northeast Black Sea region and added a critical data point to the biodiversity inventory. The comparisons with the other 14 *Capoeta* species used in the dataset show that the Turnasuyu population. The obtained molecular data conclusively confirmed the *Capoeta* specimens from Turnasuyu Stream as *C. banarescui*. The findings address the problem of morphological similarity and taxonomic confusion and solve it. *Capoeta* species is a group that shows high phenotypic plasticity depending on the environmental considerations. As a consequence of that, the inaccuracy increases merely based on the appearance (morphometric and meristic traits). There are differing opinions in the literature regarding the classification of this genus. However, the mitochondrial COI barcoding method utilized in this study has delivered an exact interspecific genetic line. The success of a 100% rate in BLAST analysis demonstrates that COI gene region has extremely high resolving power for this genus. Molecular findings obtained from this research significantly coincided with literature data shedding light on the taxonomic complexity of the genus *Capoeta* in the Black Sea basin. Turan et al. (2006) presented that the species *C. tinca*, formerly thought to have a broad distribution, consists of three different species, and they defined individuals from the Çoruh River drainage as *Capoeta banarescui*. In this study, the positioning of specimens obtained from Turnasuyu Stream within the *C. banarescui* clade with nearly 100% similarity supports the molecular-level validity of this species, which was morphologically described by Turan et al. (2006).

Özdemir (2013) remarked on both the low genetic distance between *Capoeta* species and the close phylogenetic history of species in the comprehensive revision study. Moreover, the study conducted by Turan et al. (2022) showed that the *Capoeta* taxonomy is a dynamic structure by transferring several scraper species from the Mesopotamia and Levant regions to the genus *Paracapoeta*. In this regard, molecular data obtained from localized populations such as Turnasuyu Stream play a crucial role in the protection and updating of the biodiversity inventory in Turkey’s inland waters of the *Capoeta* genus. Eventually, this examination has proved both the success of the bioinformatics pipeline on local examples and established a molecular reference for freshwater biodiversity in Ordu, Turkey. This genetic basis is indispensable for future studies in population genetics, conservation biology, and evolutionary ecology.

CONCLUSIONS

The molecular analyses conducted on the samples collected from Turnasuyu Stream clearly revealed the placement of the population in this local region. Both BLAST results and phylogenetic reconstructions of our specimens were definitively verified as *Capoeta*

banarescui, exhibiting 100% and %99.69 sequence identity and robust bootstrap support. This subtle genetic variation among the gained individuals proves the presence of natural intraspecific diversity and multiple haplotypes within the Turnasuyu population.

The obtained data shed light on the molecular boundary of the species defined by Turan et al. (2006). Consequently, the high dependability of COI barcoding in resolving morphological uncertainties has been demonstrated, establishing an integral data entry for the faunal inventory of the Eastern Black Sea. This study serves as an essential scientific basis for the conservation and future monitoring of local freshwater ecosystems.

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ISBN NR: 978-625-5694-92-8

CONTROLLED RELEASE BEHAVIOR OF *VIBURNUM OPULUS* L. AND *VACCINIUM MYRTILLUS* L. LOADED CHITOSAN-COATED PCL NANOPARTICLES

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ABSTRACT

Plant-derived bioactive compounds have gained increasing attention due to their wide range of biological activities. However, their direct application is often restricted by limited physicochemical stability, susceptibility to environmental conditions, and uncontrollable release behavior. To overcome these limitations, nanoencapsulation approaches, particularly core–shell nanoparticle systems composed of a polymeric core and functional shell layer, have been widely explored as effective strategies to enhance the stability, protection, and controlled delivery of plant-derived compounds.

In this study, aqueous extracts obtained from *Viburnum opulus* L. (gilaburu-VO) and *Vaccinium myrtillus* L. (bilberry-VM) fruits were encapsulated within poly(ε-caprolactone) (PCL) nanoparticles and further modified by chitosan coating to improve their physicochemical stability and potential biological performance. The nanoparticles were fabricated using an emulsion-solvent evaporation method and subsequently lyophilized. The physicochemical properties of the synthesized nanoparticles were characterized by dynamic light scattering (DLS) for particle size and polydispersity index, zeta potential analysis for surface charge determination, and scanning electron microscopy (SEM) for morphological assessment. *In vitro* release studies were carried out to evaluate the release behavior of the encapsulated extracts under physiological conditions (phosphate-buffered saline, pH 7.4).

DLS, zeta potential, and SEM analyses confirmed the successful formation of the nanoparticles. The *in vitro* release profiles demonstrated that the nanoparticles exhibited different release behaviors depending on the formulation. After 48 hours, the cumulative release percentages reached approximately 53.34% for VO-PCL, 33.09% for chitosan-coated VO-PCL, 48.97% for VM-PCL, and 70.74% for chitosan-coated VM-PCL, indicating that chitosan coating influenced the release characteristics of the encapsulated extracts. In conclusion, the

synthesized nanoparticle formulation provides a controlled release profile and represents a promising carrier platform for the controlled delivery of plant-derived bioactive compounds.

This study is derived from a part of the master's thesis of İrem Akyol, conducted under the supervision of Asst. Prof. Dr. Neslihan Güleç. The authors are grateful to the Scientific and Technological Research Council of Türkiye (TÜBİTAK) under the 2210-A National MSc Scholarship Program for their support.

Keywords: Polymeric nanoparticles, PCL, Chitosan coating, *Viburnum opulus* L., *Vaccinium myrtillus* L., Controlled release.

ISBN NR: 978-625-5694-92-8

IDENTİFİCATİON OF CERTAİN ANTİOXİDANT ACTİVİTİES IN PRUNUS CERASİFERA FRUİT (ROSACEAE)

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ABSTRACT

The main objective of this study was to determine the antioxidant effect of the methanol extract of the fruit Prunus cerasifera, which belongs to the Rosaceae family and is commonly found in Van province and other regions. In addition, this antioxidant effect was compared with other similar fruit studies, and the necessary antioxidant requirement from this fruit was determined. This fruit type is commonly known as green plum among the public. First, freshly harvested Prunus cerasifera fruits were washed and ground into powder, then 10 g of ground fruit puree was homogenized with 100 mL of methanol, centrifuged, and the upper phase was obtained. To determine the antioxidant effect, catalase (CAT) activity, glutathione (GSH), and superoxide dismutase (SOD) levels were measured by spectrophotometry. Prunus cerasifera offers a rich biochemical composition, containing various vitamins, high levels of proteins, and essential mineral elements. The natural antioxidant compounds present in its composition: support the immune system against infectious agents, prevent anemia by suppressing hemolytic processes, inhibit the biosynthesis of carcinogenic compounds, exhibit antithrombotic effects by increasing prostaglandin synthesis, prevent atherosclerotic changes, and reduce the biochemical effects of hepatotoxic oxidant species. Prunus cerasifera has been reported in various studies to exhibit therapeutic and chemopreventive effects on certain types of cancer. In cherry samples, the catalase (CAT) level was determined to be an average of 1.19 U/L protein, the superoxide dismutase (SOD) level was an average of 1.19 U/L protein, and the glutathione (GSH) level was an average of 0.26 mmol/g. Prunus cerasifera exhibits antioxidant activity associated with changes in MDA levels. Therefore, it can be considered a promising source for the development

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ISBN NR: 978-625-5694-92-8

of active pharmaceutical ingredients with antioxidant properties. The findings revealed that Prunus cerasifera exhibits potent antioxidant activity. Accordingly, it was concluded that Prunus cerasifera may play a protective role against oxidative stress-induced cellular damage and, therefore, may be considered a potential antioxidant agent in the prevention of various chronic diseases.

Anahtar Kelimeler: Prunus cerasifera, Antioxidant, Oxidative stress, Free radicals, Human health.

1. INTRODUCTION

Our country holds an important place in terms of genetic diversity for the Prunus cerasifera species. For example, a molecular characterization study conducted on a collection of 66 genotypes in Turkey found that Prunus cerasifera exhibits a high level of polymorphism (morphological diversity, diversity dice = 0.39) [1]. This result shows that the genetic resources within our country are valuable for breeding programs. Therefore, it can be stated that Prunus cerasifera has high potential to be included in this national gene pool, particularly in Van province. In this region, the natural growth of Prunus cerasifera and its mineral richness allow this species to be evaluated for both agricultural/economic and biological research purposes. Genotypes that have adapted to the local climate and land conditions can potentially be used for breeding, as a functional food source, or as a genetic resource. Research conducted in Van Province shows that P. cerasifera is one of the naturally occurring plum species. In a study titled "Nutrient Content of Some Wild Plum Species Growing in Van Ecological Conditions," P. cerasifera Ehrh. was among the plum species growing naturally in the Van ecology [2]. This situation indicates that natural cherry fragments in the Van region can be evaluated as genetic resources. In this context, Geçer et al. (2016) determined in their study that the mineral content (P (282.08 ppm) and Ca (176.91 ppm)) was highest in p. cerasifera fruit. This result shows that the p. cerasifera genotypes growing naturally in Van are rich in minerals and that the region has biochemical potential. Therefore, it can be stated that systematic studies of this kind conducted in Van province are of great importance in terms of more effectively evaluating this genetic resource in the region.

Today, free radicals and reactive oxygen species (ROS) formed during the vital activities of living organisms cause oxidative damage to cell components and play an important role in the development of many degenerative diseases [3]. The main mechanism that balances these harmful effects in the cell is the antioxidant defense system. This system consists of both

ISBN NR: 978-625-5694-92-8

enzymatic (superoxide dismutase, catalase, glutathione peroxidase, etc.) and non-enzymatic (phenolic compounds, flavonoids, vitamins C and E, carotenoids, etc.) components. Oxidative stress resulting from the insufficiency of these systems underlies many pathological processes such as cancer, diabetes, cardiovascular diseases, neurodegenerative diseases, and aging [4]. Plants possess a powerful antioxidant defense network that has evolved to counteract environmental stress conditions. For this reason, plant-based foods are considered the most important source of natural antioxidants in human nutrition [5]. The Rosaceae family, in particular, contains many fruit species (plums, cherries, apricots, peaches, apples, etc.) that stand out for their antioxidant properties. Species belonging to this family are rich in phenolic acids, flavonoids, anthocyanins, and vitamin C [6]. In this regard, Prunus cerasifera Ehrh. (wild cherry-red cherry), a member of the Rosaceae family, originates from Europe and Western Asia and is widely grown in our country, especially in the Mediterranean, Aegean, and Eastern Anatolia regions. P. cerasifera is a species used for both food and medicinal purposes. Its fruit is notable for its high content of phenolic compounds, flavonoids, anthocyanins, and organic acids [7]. These compounds are known to have lipid peroxidation-inhibiting, free radical scavenging, and cell-protective properties [8]. Various studies conducted on Prunus cerasifera have shown that this fruit possesses antioxidant and antimicrobial activities [9]. Studies conducted particularly in the Mediterranean region report that the total phenolic content of the fruit ranges from 136.8 to 583,1 mg GAE/kg, while the FRAP value ranges from 0.123 to 0.835 mmol TE/kg (Korkmaz et al., 2020). A study conducted in China indicates that anthocyanin extracts obtained from P. cerasifera peel have high DPPH radical scavenging activity (78.2%) [8]. However, such studies mostly focus on non-enzymatic antioxidant components, and studies investigating enzymatic antioxidant systems (SOD, CAT, GSH) are limited. The enzymatic components of the antioxidant defense system play a crucial role in understanding the plant's physiological stress response. Superoxide dismutase (SOD) converts superoxide radicals into hydrogen peroxide, while catalase (CAT) and glutathione peroxidase (GPx) reduce this hydrogen peroxide into water and oxygen [10]. Glutathione (GSH) acts both as a direct free radical scavenger and as a cofactor in many enzymatic reactions. Therefore, the activity levels of these enzymes are important indicators of the plant's antioxidant capacity. In this context, the investigation of SOD, CAT, and GSH activities in Prunus cerasifera fruit provides a biochemical-based perspective on the fruit's antioxidant capacity and fills a gap in the existing literature. Furthermore, considering that these enzymatic systems may vary according to

ISBN NR: 978-625-5694-92-8

regional and ecological conditions, comparing samples grown in different geographical regions constitutes an important area of research.

This study is significant as it is one of the few studies evaluating the enzymatic antioxidant activity (SOD, CAT, GSH) of Prunus cerasifera fruit. The study aims to demonstrate that the fruit possesses antioxidant capacity not only due to its phenolic or anthocyanin content but also through its biochemical defense mechanisms. Thus, the data obtained will have scientific and economic value in terms of both functional food development and the identification of natural antioxidant sources.

In conclusion, this study aims to reveal the antioxidant potential of Prunus cerasifera at the enzymatic level and provide a scientific basis for comparing the antioxidant profiles of fruits grown in different regions. In this respect, it is believed that the research will contribute to the identification of natural antioxidant sources and shed light on new applications in the fields of food and health.

2. EXPERIMENTAL

2.1. Sample Collection and Processing

In this study, Prunus cerasifera (Rosaceae) fruits grown in their natural environment in Van province were used. These fruits were carefully selected and collected in Van province according to maturity criteria, being physically sound and free from insects, pests, and disease. The following steps were applied in sequence to extract these fruit samples. First, the fruits were cleaned of stones, leaves, and stem residues, and then the fleshy parts were pureed. A study reported that the conditions of “1% HCl-methanol solution, solid-liquid ratio (1:5), 55 °C temperature, and 80 min” were suitable for the extraction of anthocyanins and phenolic compounds in P. cerasifera samples (especially in the fruit peel) [11].

In this study, 10 g of fruit puree was homogenized with 100 mL of methanol according to the data for Van province, the mixture was centrifuged at 2000 rpm for 15 minutes, then left to stand for approximately 2 hours, and the supernatant formed at the top was carefully separated and stored at -20 °C for analysis. Thus, the phenolic/anthocyanin profile and antioxidant activity of P. cerasifera fruits specific to Van province were determined.

2.2. Determination of reduced glutathione (GSH) levels

200 µL of phosphate buffer (800 µL) was added to the sample. The initial absorbance (A1) was recorded at 412 nm using UV/visible spectra. Ellman's reagent (100 µL) was added to the same tube, and the second absorbance (A2) was obtained. Glutathione concentration (C) was calculated in mmol/g protein units using equation 1 [12]. C/1000 =

ISBN NR: 978-625-5694-92-8

(A2−A1)/13,600×E1×5/2×½ Where: A1 is the initial absorbance at 412 nm before adding DTNB; A2 is the second absorbance at 412 nm after adding DTNB; E1 = 1; 13,600 is the molar extinction coefficient of the yellow color formed during the interaction of GSH and DTNB (5,5-dithiobis-(2-nitrobenzoic acid)); 1000 is the conversion factor to mmol; C is the concentration in mmol/glutathione (mg/dL).

2.3.Determination of Catalase (CAT) Activity

Hydrogen peroxide H_2O_2 (1.4 mL, 30 mM) and 0.1 mL phosphate buffer were added to an empty tube. Then, 1.4 mL of 30 mM H_2O_2 and 0.1 mL of enzyme were added and mixed. Absorbance was measured twice at 240 nm at 30-second intervals. Catalase activity was calculated in U/L using equation 3 [13].

Activity = (2.3/Δx)*(log A1/log A2)

Here, Δx = 30 s; 2.3 is the absorbance of 1 µmol H_2O_2 in 1 cm of light path [14].

2.4.Determination of superoxide dismutase (SOD) activity

A manual method was preferred for determining this value. Accordingly, preparation of the reactive solution: 40 ml of xanthine solution, 20 ml of EDTA solution, 20 ml of NBT solution, 12 ml of Na2CO3 solution, and 6 ml of BSA were mixed and stored in a dark-colored bottle for use. Sixteen microliters of xanthine oxidase (167 u/L) (Sigma X1875) enzyme was dissolved in 1 ml of 2 M $(NH_4)_2SO_4$. 2M $(NH_4)_2SO_4$: 2.643 g $(NH_4)_2SO_4$ was dissolved in 10 ml of distilled water and stored at +4 °C. 0.8 mM $CuCl_2 \cdot 2H_2O$: 13.6 mg $CuCl_2 \cdot 2H_2O$ was prepared and dissolved in 100 ml of distilled water.

Çizelge 1.1. SOD aktivitesi tayin yöntemi.

	Kör	**Örnek**
Reaktif	1.425 µl	1.425 µl
Örnek	-	50 µl
Bidistile	100 µl	-
Ksantin oksidaz	25 µl	25 µl
25˚C'de oda sıcaklığında 20 dakika bekletildi		
$CuCI_2$	50 µl	50 µl

As indicated in Table 1.1, after pipetting, the blank and sample tubes were read against bidistilled water at 560 nm. Following the reading, the inhibition calculation was performed as follows:

% inhibition: [(Blank OD – Sample OD) / Blank OD] x 100,

1 Unit SOD: Enzyme activity that inhibits NBT reduction by 50%. Therefore,

Activity = (% inhibition) / (50 x 0.1), Activity was calculated in U/ml.

ISBN NR: 978-625-5694-92-8

3. DİSCUSSİON AND CONCLUSION

The antioxidant enzyme activities and glutathione levels measured in fruit extracts of Prunus cerasifera adapted to the ecology of Van Province indicate that the species has a significant antioxidant potential. The measured SOD (1.08 U/mg protein) and CAT (1.19 U/mg protein) activities indicate the capacity to play an effective role in the detoxification of intracellular reactive oxygen species. In addition, the GSH level (0.26 µmol/g fresh weight) indicates an antioxidant reserve that could contribute to maintaining cellular redox balance and reducing oxidative stress. In line with these results, the SOD and CAT activities measured in the Prunus cerasifera fruit extract indicate that the genotypes from Van Province effectively activate the antioxidant defense system and possess a protective potential against reactive oxygen species.
The positive level of GSH indicates that fruit extracts may exhibit antioxidant effects at the cellular level and may play a protective role against oxidative damage. Different studies have indicated that there is a positive correlation between enzyme activity (SOD, CAT, and GSH) and total phenolic content/natural organic compound level/high content [15,16]. Therefore, it is stated that in prunus cerasifera samples grown in Van province, the high level of phenolic compounds is related to the measured enzyme activities and GSH levels and that the species has antioxidant capacity. These findings show that Prunus cerasifera fruit has both functional food potential and is a natural antioxidant source [17]. Studies have examined plum genotypes from different regions and found a strong, significant correlation between total phenolic content and total antioxidant capacity, revealing that phenolic content positively affects antioxidant levels. Therefore, it emphasized that there is a strong antioxidant effect in plum varieties from different regions, but that this is also influenced by genotype-maturity and environmental factors [17].
In another study, three different plum species (Prunus domestica L., Prunus cerasifera Ehrh. and Prunus spinosa L. Fruits) were compared based on the highest phenolic compound, highest total antioxidant capacity (TAC), and highest vitamin C values. As a result, it was stated that Prunus spinosa (blackthorn) had the highest value [18]. Therefore, this result confirms that Prunus cerasifera exhibits antioxidant properties, but it may also indicate that it is not always the strongest antioxidant in inter-species comparisons. In this respect, Prunus cerasifera can be said to be a natural antioxidant source, but it can also be stated that this situation varies relatively in other species. The fruit of Prunus cerasifera exhibits a potent antioxidant effect due to its high content of anthocyanins and various phenolic compounds. Therefore, regularly including

ISBN NR: 978-625-5694-92-8

this fruit group in a balanced diet may play a preventive role against various health problems caused by oxidative stress. This study revealed that Prunus cerasifera fruit exhibits a significant antioxidant effect and, thanks to this property, has protective potential against various diseases [19]. In their studies, they stated that Prunus cerasifera fruits have a high total phenolic content and, especially in purple-colored varieties, a high ferric reducing antioxidant power, and therefore the fruit peel can be considered a source of antioxidant activity. Another study indicated that Prunus cerasifera cv. “Pissardii Nigra” fruits contain high levels of phytochemicals such as flavonoids and resveratrol, and that these compounds contribute to antioxidant capacity [20].

When making a general assessment, considering the wide plant diversity in our country, it is believed that such studies are of great importance both in the field of health and in terms of creating economic value. Therefore, the results obtained from this study can form a scientific basis for more comprehensive studies to be conducted in the future.

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ISBN NR: 978-625-5694-92-8

SYNTHESIS OF NANOPARTICLES FROM FUSARIUM SPECIES AND THEIR APPLICATIONS

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ABSTRACT :

The synthesis of nanomaterials has significantly advanced biological research and enabled a wide range of applications across industries such as agriculture, food science, nanomedicine, pharmacology, and environmental remediation.

Currently, the biogenic synthesis of metal nanoparticles is at the forefront of technological development. This environmentally friendly ("green") approach has attracted considerable interest from both academic and industrial sectors due to its sustainability, low toxicity, minimal environmental impact, and cost-effectiveness. In particular, microbial-mediated synthesis of metal nanoparticles—using bacteria, fungi, viruses, yeast, or algae—provides a promising framework for eco-friendly manufacturing processes.

Among these biological agents, *Fusarium* fungal species are notably utilized in a process known as mycosynthesis, serving as an effective model for green chemistry. In this method, *Fusarium* functions as a biological "nanofactory," employing extracellular enzymes and secondary metabolites to facilitate the reduction of metal ions into stabilized nanoparticles.

Furthermore, mycosynthesized nanoparticles have diverse applications across multiple fields. In biomedical contexts, they function as effective antimicrobial agents, promote improved wound healing, and serve as delivery vehicles for targeted cancer therapies.Moreover, in advanced agriculture, nano-agriculture encompasses the development of nanofungicides and nanopesticides. For environmental remediation, biogenic metal nanoparticles act as efficient catalysts in the photocatalytic degradation of complex organic pollutants.

Keywords : *Fusarium* , Mycosynthsied nanoparticles, Biogenc nanoparticles.

1. INTRODUCTION: THE RISE OF GREEN NANOTECHNOLOGY

ISBN NR: 978-625-5694-92-8

Nanotechnology and Nanoparticles (NPs): Nanotechnology is a multidisciplinary field encompassing research and development at the nanoscale. Nanoparticles are microscopic clusters of atoms sized between 1 and 100 nanometers. Examples of nanoparticles include those composed of titanium, magnesium, platinum, silver, gold, and silica oxide.The shift from traditional chemical and physical methods to biological "green" nanofabrication techniques for nanoparticle synthesis is motivated by the limitations associated with older approaches. Chemical and electrochemical methods often require high temperatures, toxic chemicals, and significant capital investment. Bacterial-based methods are environmentally friendly; however, they are not always cost-effective due to the need for expensive specialized equipment for separation and purification (Zielonka A., and Klimek-Ochab M., 2017; Ahmad et al., 2019; Ullah et al., 2025).

The primary objective is to develop environmentally sustainable nanomanufacturing protocols that produce safe, stable, and reliable nanomaterials. While plant-based methods encounter challenges related to reliability and reproducibility, which can be influenced by geographical and seasonal variations (Islam et al., 2021), fungi offer several advantages. Fungi are capable of generating large quantities of metabolites, including enzymes, proteins, peptides, polysaccharides, and other macromolecules. They also provide high yields, are relatively easy to handle, and produce low-toxicity residue by-products. The use of various fungal species and the ability to modify synthesis conditions enable the production of nanoparticles with a range of physicochemical properties (Rahli et al., 2022).

2. THE *FUSARIUM* GENUS: A VERSATILE BIO-FACTORY

Many *Fusarium* species are considered weak pathogens and typically infect plants that are damaged or experiencing stress. However, this genus can also cause a range of serious diseases, including vascular wilt, root rot, foot and stem rot, leaf lesions, fruit rot, head blight in cereals, and post-harvest decay, all of which can lead to decreased yields and economic losses (Tanina et al., 2025)

Gaikwad et al. (2013) conducted a study investigating eleven different *Fusarium* species isolated from various infected plants. The researchers screened these species for their potential to synthesize silver nanoparticles. Each of the eleven species demonstrated the capability to synthesize silver nanoparticles.

Various *Fusarium* species, including *F. oxysporum*, *F. solani*, and *F. acuminatum*, *F. semitectum*, *F. culmorum*, *F. chlamydosp czerw*, *F. equiseti*, *F. tricinctum*, *F. proliferatum*, *F. keratoplasticum* and F. moniliforme have been effectively utilized to synthesize metal nanoparticles such as silver, gold, platinum, as well as a range of metal sulfides and oxides. (Rai et al., 2021)

3.THE MECHANISM OF SYNTHESIS

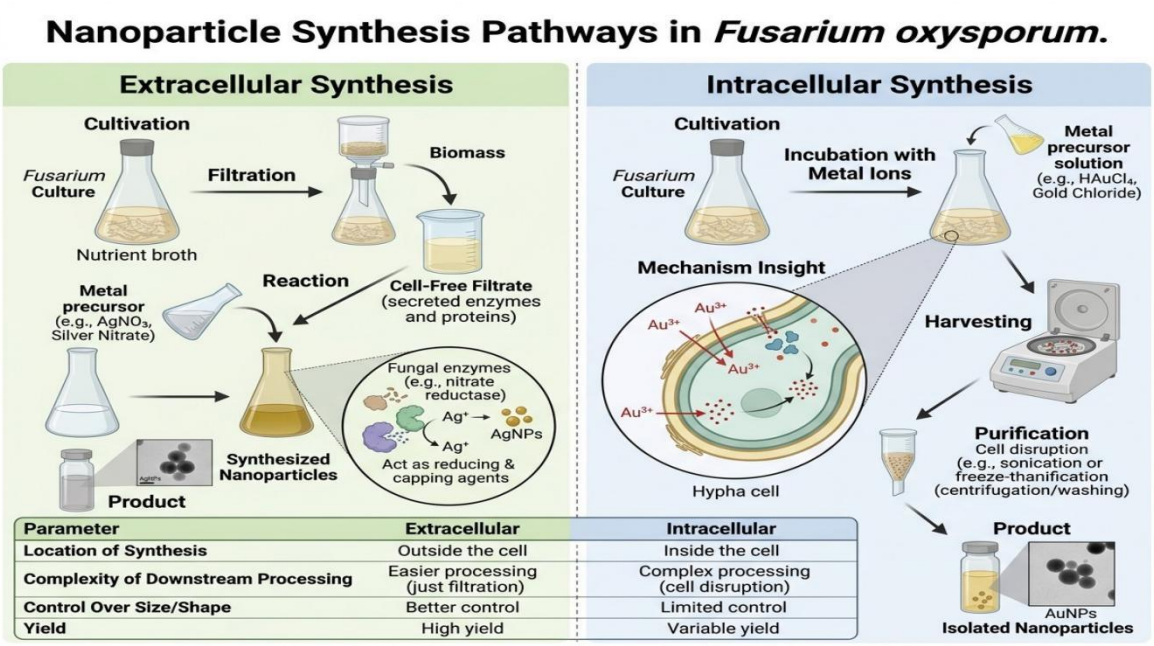
The mechanism involves fungal metabolites, including enzymes, proteins, polysaccharides, flavonoids, and organic acids, which act as reducing and stabilizing agents to facilitate the conversion of metal ions into nanoparticles. This process can take place extracellularly, often mediated by enzymes such as NADPH-dependent nitrate reductase. Secreted by Fusarium

ISBN NR: 978-625-5694-92-8

species, this enzyme primarily facilitates electron transfer to metal ions (such as silver or gold), resulting in the formation of stable nanoparticles (Rai et al., 2021; Ullah et al., 2025).

To stabilize the formed nanoparticles, capping agents derived from fungal proteins adhere to their surface and interact with various functional groups, such as amino, carboxyl, and hydroxyl groups. This adsorption creates a protective layer around the nanoparticles, which helps maintain their small size, uniformity, and stability. Additionally, this organic layer prevents aggregation by acting as a barrier between individual nanoparticles (Bahari et al., 2023)..

Nanoparticles can be formed intracellularly within fungal hyphae. After absorbing metal ions, enzymes facilitate their reduction to metal oxides nanoparticles. This process occurs either in the cytoplasm or within fungal organelles (Slavin & Bach, 2022).



Parameter	Extracellular	Intracellular
Location of Synthesis	Outside the cell	Inside the cell
Complexity of Downstream Processing	Easier processing (just filtration)	Complex processing (cell disruption)
Control Over Size/Shape	Better control	Limited control
Yield	High yield	Variable yield

Figure 32: Nanoparticle Synthesis Pathways in *Fusarium oxysporum*.

4. TYPES OF NANOPARTICLES SYNTHESIZED

Extracellular synthesis of silver nanoparticles using *Fusarium solani* has been documented. Initial visual observation confirmed nanoparticle formation, which was subsequently validated through UV spectrophotometry, revealing an absorption peak around 420 nm characteristic of silver nanoparticles. Fourier Transform Infrared Spectroscopy (FTIR) analysis indicated the presence of proteins acting as capping agents, which likely contributed to the enhanced stability of the synthesized nanoparticles. Transmission Electron Microscopy (TEM) further verified the successful production of silver nanoparticles (Ingle et al., 2009). The smallest silver nanoparticles synthesized by *Fusarium oxysporum* measured approximately 3–25 nm, whereas

ISBN NR: 978-625-5694-92-8

the largest nanoparticles produced by *Fusarium solani* ranged from 3–50 nm (Duran et al., 2005).

Bakhtyar et al. (2025) observed that visual examination can serve as an initial indicator of nanoparticle type. A color change from yellow to dark brown typically suggests the formation of silver nanoparticles, while a shift to dark red indicates the formation of gold nanoparticles. However, additional confirmatory tests are necessary. Various instrumental analyses, such as UV spectroscopy and X-ray diffraction, have been documented in the literature for definitive characterization.

Additionally, emerging research has been conducted on nanoparticles derived from *Fusarium*, including zinc, copper, titanium, palladium, magnetic, and semiconductor variants, with a focus on their potential applications in agriculture and catalysis (Rai et al., 2021).

5. FACTORS INFLUENCING PARTICLE QUALITY

The production of *Fusarium*-derived nanoparticles is influenced by several factors, including reductase enzyme activity and the presence of cofactors, the stability of the protein-based capping agent, and reaction conditions such as concentration, duration of the process, and environmental factors like pH and temperature. All of these variables impact the stability, size, and characterization of the nanoparticles (Guilger-Casagrande & Lima, 2019 ; Loshchinina et al., 2022).

Preferred results are achieved within a temperature range of 25°C to 37°C to ensure acceptable nanoparticle quality (Gericke & Pinches, 2006), based on the hypothesis that this temperature range is effective. Additionally, exceeding an incubation period of 70 hours can significantly influence the size and stability of the product (Ahmad et al., 2003). Furthermore, the incorporation of cofactors such as NADH and quinones, which facilitate the reduction and reduce aggregation process, facilitate nanoparticle formation (Mukherjee et al., 2002; Rai et al., 2021) .

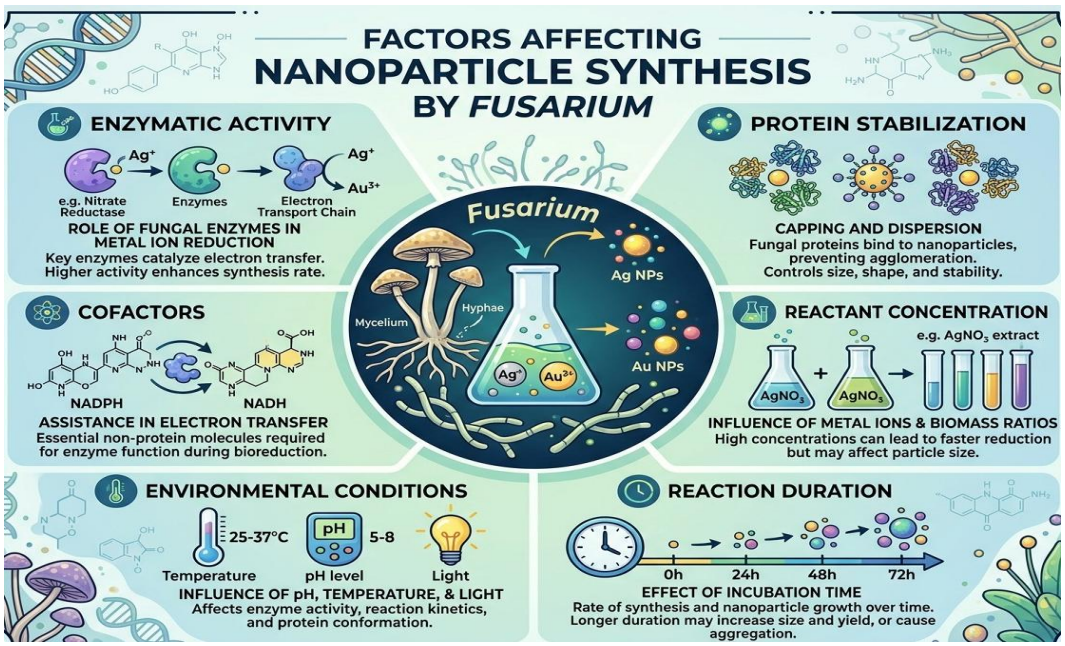


Figure 33: Factors Affecting Nanoparticle Synthesis by *Fusarium*.

ISBN NR: 978-625-5694-92-8

6. APPLICATIONS AND FUTURE PROSPECTS

Fungal nanotechnology offers diverse applications across various industries, including agriculture, healthcare, and manufacturing. In the agricultural sector, it is utilized for plant disease management, crop improvement, biosensing, and the development of environmentally friendly, non-toxic pesticides and fertilizers, promoting sustainable farming practices.

This technology facilitates the controlled delivery of agrochemicals, which can improve crop yields while minimizing chemical usage, thereby supporting environmentally responsible agriculture. (Rai et al., 2021; Panda et al., 2025; Akrivou et al., 2026).

In the medical field, nanoparticles have garnered attention due to their antibacterial, antiviral, anticancer, and antifungal properties. They are effective against various bacteria, such as Escherichia coli and Staphylococcus aureus, as their small size allows them to enter cells and interact with internal cell components, leading to cell death . Furthermore, the generation of oxidative stress enhances their efficacy against fungi such as Candida species. Additionally, these nanoparticles exhibit antiviral activity by preventing virus attachment and reducing the infectivity of viruses such as herpes simplex virus (Rahli et al., 2022).

Nanoparticles produced from Fusarium exhibit cytotoxic effects against cancer cells. In vitro studies utilizing breast cell lines have demonstrated a reduction in cell viability. Additionally, these nanoparticles have been employed in various molecular diagnostic techniques, such as PCR, to facilitate pathogen identification (Rai et al., 2021).

Moreover, Islam et al., (2021) reported that silver/silver oxide nanoparticles serve as catalysts that increase the rate of the dye degradation reaction without being consumed. Due to their nanoscale size, they have a high surface area that provides more active sites for the reaction. breaking down a dye via catalytic degradation involves using a catalyst and a reducing agent to chemically decompose the dye molecules, reducing pollution and toxicity in contaminated water.

7. CONCLUSION:

The significant potential of biological synthesis of nanoparticles is noteworthy. In particular, the utilization of fungi such as *Fusarium* species for nanoparticle production presents a wide array of practical applications. While *Fusarium* is highly efficient, the main challenge remains standardization. Since fungi are living organisms, their output can vary.

Fusarium-derived nanoparticles are versatile tools with promising applications aiming to improve health outcomes and agricultural productivity through eco-friendly and cost-effective means.

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ISBN NR: 978-625-5694-92-8

ANNUAL CHANGES IN TRAFFIC ACCIDENTS AND EVALUATION OF RISK FACTORS IN KONYA PROVINCE

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ABSTRACT

This study aims to analyze the annual changes in traffic accidents and the main risk factors causing these accidents in Konya province between 2015 and 2024. In the research, the Road Traffic Accident Statistics published by the Turkish Statistical Institute (TÜİK) were used as the basis; the temporal changes, spatial distribution, and determining causes of traffic accidents in Konya province were examined in detail. Within the scope of the study, driver faults, pedestrian errors, vehicle defects, passenger behaviors, and road infrastructure-related factors were evaluated using statistical methods.

The findings indicate that the vast majority of traffic accidents in Konya occur in urban areas and on main arteries with heavy traffic flow. It was particularly noted that accident density is significant on the Ankara Ring Road, Adana Ring Road, Istanbul Road, and in the Beyşehir and Karaman corridors. Driver errors account for approximately 89% of traffic accidents, while pedestrian errors occur around 9% and vehicle faults around 1%. In the pandemic year of 2020, a noticeable decline in traffic accidents was observed; however, in the period following 2021, there has been a tendency for accident numbers to increase again.

This study aims to contribute to the development of traffic safety policies for local authorities and relevant institutions by examining long-term traffic accident data specifically for the province of Konya. The results obtained are expected to serve as a guide in the formation of strategies for urban transportation planning and the prevention of traffic accidents.

Keywords: Traffic accidents, Konya, statistical analysis, traffic safety, risk factors

1. INTRODICTION

Traffic accidents, as in the rest of the world, emerge in Turkey as a major public health and traffic safety issue, causing fatalities, injuries, and significant economic costs. According to data from the World Health Organization (WHO), approximately 1.3 million people die annually due to traffic accidents, and tens of millions are injured. This indicates that traffic

ISBN NR: 978-625-5694-92-8

accidents are not only an individual problem but also have multidimensional impacts on health systems, economic sustainability, and social welfare [1-2].

When examining the main causes of traffic accidents in Turkey, it is seen that driver faults clearly have the highest share by far. According to TÜİK data, approximately 90% of fatal and injury-causing traffic accidents are due to driver errors; this is followed by pedestrian errors, vehicle defects, and problems related to road infrastructure. This picture clearly demonstrates that the human factor should be placed at the center of traffic safety policies [3].

Konya province holds a special position in terms of traffic safety due to being the largest province in Turkey in terms of area, its wide and dispersed settlement pattern, and strong agricultural and industrial activities. The province is an important transportation hub in the Central Anatolia Region and has routes with heavy urban and intercity road traffic. Road connections extending to Ankara, Istanbul, Adana, Karaman, and Antalya make Konya a strategic center for transit passages. This situation leads to an increase in the number of motor vehicles and a higher risk of traffic accidents [4].

With Konya having metropolitan status, the population density and vehicle ownership, especially in the districts of Selçuklu, Meram, and Karatay, have increased rapidly. These districts are also regions where commercial activities, educational institutions, and industrial areas are concentrated, and they are among the areas where traffic accidents are spatially clustered. Main urban arteries, ring roads, and intersections stand out as points where traffic accidents frequently occur [2-4].

In recent years, as throughout Turkey, the increase in the number of motor vehicles in Konya has created a significant pressure in terms of traffic safety. However, the restrictions implemented in 2020 due to the COVID-19 pandemic reduced traffic volume, and this led to a temporary decrease in the number of traffic accidents. Nevertheless, with the normalization process, it has been observed that traffic accidents have started to show an increasing trend again in the post-2021 period [5].

This study aims to comprehensively analyze the annual changes, spatial distribution, and main risk factors of traffic accidents that occurred in the province of Konya between 2015 and 2023. Within the scope of the study, the causes of traffic accidents are determined using data from official institutions, primarily TÜİK, and policy recommendations are developed to improve traffic safety specifically in Konya. The findings are intended to serve as a scientific guide for local governments and decision-makers.

1.1. The Global Perspective of Traffic Accidents

Traffic accidents continue to be a significant public health problem globally for both developed and developing countries. According to World Health Organization (WHO) data, traffic accidents cause the deaths of approximately 1.3 million people and injuries to more than 50 million people worldwide each year. The fact that more than 90% of traffic accidents occur in

ISBN NR: 978-625-5694-92-8

low- and middle-income countries is associated with the inadequacy of traffic safety policies, infrastructure investments, and supervision mechanisms in these countries [6-7].

In developed countries, speed controls, intelligent transportation systems, alcohol and drug checks, mandatory seat belt applications, and advanced driver training programs are widely implemented to reduce traffic accidents. As a result of the implementation of such policies in OECD countries, there has been a significant decrease in traffic accident-related death rates over the past twenty years. In contrast, in developing countries like Turkey, traffic accidents continue to be a significant problem parallel to the increasing number of motor vehicles and the rapid pace of urbanization [8].

1.2. Studies Conducted on Traffic Accidents in Türkiye

Academic studies on traffic accidents in Turkey reveal that accidents occur largely due to human factors. Analyses based on TÜİK data show that approximately 90% of fatal and injury-causing accidents are caused by driver errors. Among these errors, exceeding speed limits, intersection violations, inattentiveness, driving under the influence of alcohol, and failure to comply with traffic rules stand out.

Demirbaş and colleagues (2021) examined the effects of traffic safety trainings on driver behaviors and found that the accident rates of drivers who received training decreased significantly. Kuyumcu and colleagues (2020), on the other hand, stated that the most common driver error in urban traffic accidents is not adjusting speed according to road and traffic conditions. Sungur and colleagues (2014) studied traffic accidents from an epidemiological perspective and emphasized the determining role of the human factor in accidents [1, 9, 10].

1.3. Studies on Traffic Accidents Specifically in Konya Province

Studies conducted specifically in Konya province show that traffic accidents are concentrated in certain areas in terms of time and space. Diler and colleagues (2023) examined the hourly, daily, and seasonal distribution of traffic accidents in the city of Konya and revealed that accidents are particularly concentrated during noon and evening hours, periods when traffic density increases. The same study indicated that the districts of Selçuklu, Meram, and Karatay stand out in terms of accident density [6].

The large surface area of Konya and the abundance of its rural areas create differences in the causes of traffic accidents between the city center and rural regions. In accidents occurring in rural areas, excessive speed, single-vehicle accidents, and collisions with animals are more common, while in the city center, violations at intersections, failure to maintain safe following distances, and pedestrian accidents come to the forefront. This situation indicates that traffic safety policies in Konya should be developed taking regional differences into account [3-4].

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1.4. Policy Approaches to Prevent Traffic Accidents

Many policies are suggested in the literature to prevent traffic accidents. Intelligent transportation systems, speed corridors, electronic enforcement systems (EDS), and dynamic signaling applications stand out as effective tools in reducing accidents. It has been reported that EDS systems implemented in European countries reduce traffic accidents by 20–30% [11-12].

In Turkey, although such applications have become widespread in recent years, increasing traffic congestion in large cities may limit the effectiveness of these measures. Specifically in Konya, increasing inspections on ring roads and main urban arteries, improving infrastructure for pedestrian safety, and strengthening driver training programs are considered important policy areas [13,14,15].

2. MATERIALS AND METHODS

This study is a quantitative and descriptive research aimed at analyzing the annual changes and risk factors of traffic accidents occurring in the province of Konya. Within the scope of the research, secondary data on traffic accidents that occurred in Konya between 2015 and 2024 were used. The data used in the study were obtained from official and reliable institutions. The main data sources are as follows:

- Turkish Statistical Institute (TÜİK): Road Traffic Accident Statistics (2015–2024)
- General Directorate of Security (EGM): Records of fatal and injury traffic accidents in Konya province
- Ministry of Transport and Infrastructure: Data on urban transportation and traffic infrastructure in Konya.

In the study, only traffic accidents recorded in official records were evaluated; unreported accidents with material damage were excluded from the scope. The following methods were used in the analysis of the data:

- **Descriptive statistics:** Distribution of traffic accidents by year, number of deaths and injuries
- **Time series analysis:** Determination of trends between 2015–2024
- **Spatial analysis:** Evaluation of the density of traffic accidents in the districts of Selçuklu, Meram and Karatay and on main transportation axes
- **Regression analysis:** Examination of the effects of driver faults, pedestrian errors and other variables on traffic accidents

Through these methods, the main dynamics of traffic accidents in Konya province have been revealed.

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2.1. Study Limitations and Future Research

This study is limited to official records regarding traffic accidents that occurred in the province of Konya. Unreported accidents causing property damage and off-the-record incidents could not be included in the analysis. Additionally, the data used in the study are at an annual level, and therefore do not allow for detailed analysis on an hourly or daily basis.

In future studies, it is recommended to use micro-level data to examine the hourly and seasonal distribution of traffic accidents in more detail. Furthermore, addressing the socio-demographic factors that influence driver behaviors specifically in Konya will contribute to making traffic safety policies more targeted.

3. RESEARCH RESULTS AND DISCUSSION

3.1. Annual Change in Traffic Accidents in Konya Province (2015–2024)

This study covers only traffic accidents that occurred within the borders of Konya province and were recorded by official institutions. The data used in the study were obtained from the Turkish Statistical Institute (TÜİK) Road Traffic Accident Statistics, and unreported or undocumented accidents were not included in the analysis. In Table 1 and Table 2, the annual distribution of traffic accidents between 2015-2024 is also shown for both Turkey and specifically for Konya.

Table 1. Annual distribution of traffic accidents in Turkey between 2015 and 2024 [16-25]

Year	Total Number of Accidents	Number of Deaths	Number of Injured
2015	1.313.359	7.530	304.421
2016	1.182.491	7.300	303.812
2017	1.202.716	7.427	300.383
2018	1.229.364	6.675	307.071
2019	1.168.144	5.473	283.234
2020	983.808	4.866	226.266
2021	1.186.353	2.421	274.615
2022	1.232.957	5.229	288.696
2023	1.314.136	6.548	350.855
2024	1.444.026	6.351	385.117

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Table 2. Annual distribution of traffic accidents in Konya between 2015-2024 [16-25].

Year	Total Number of Accidents	Number of Deaths	Number of Injured
2015	34.515	307	12.023
2016	31.261	333	12.363
2017	31.064	325	11.632
2018	31.477	294	11.133
2019	29.277	259	10.107
2020	24.087	254	7.472
2021	30.662	269	8.975
2022	32.003	244	9.701
2023	36.190	307	12.318
2024	40.136	300	12.750

In the period 2015–2019, it is observed that the number of traffic accidents across Turkey fluctuated relatively but remained at high levels. During this period, the annual number of accidents was approximately in the range of 1.1–1.3 million. In the same period, the number of deaths was around 7,000, and the number of injuries varied between 280,000–310,000. The year 2020 was an exceptional year, with a significant decrease in the number of accidents, deaths, and injuries due to the reduction in traffic mobility caused by the COVID-19 pandemic. The total number of accidents decreased to 983,808, the number of deaths to 4,866, and the number of injured to 226,266. Starting from 2021, with the normalization process, an increasing trend in traffic accidents was observed again. Especially in 2023 and 2024, both the total number of accidents and the number of injured reached the highest values in the series. The increase in the number of deaths following the sharp decline seen in 2021 highlights the importance of the sustainability of safety measures despite the increase in traffic density.

Traffic accidents in Konya show a trend similar to that of Turkey as a whole. During the 2015–2019 period, the number of accidents gradually decreased, and in 2020, due to the impact of the pandemic, it fell to the lowest level (24,087). After 2021, the number of accidents in Ankara increased rapidly and reached the highest level in 2024 with 40,136. This increase can be associated with Ankara's population growth, the rise in the number of vehicles, and urban traffic density. When Konya is compared with Turkey as a whole, the sharp decline in 2020 at both levels shows the direct impact of the pandemic on traffic. The upward trend after 2021 indicates that traffic volume quickly exceeded previous levels. Despite the increase in the number of accidents in Konya, the limited rise in fatalities suggests that emergency response, health services, and road safety practices are relatively effective.

As a result, the data show that traffic accidents continue to be a structural problem and that sustainable traffic safety policies are particularly needed in metropolitan areas. This trend indicates that traffic accidents in Konya are a structural problem in the long term and that short-term external factors (such as the pandemic) only create temporary effects.

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3.2. Distribution of Traffic Accidents with Fatalities and Injuries

Traffic accidents occurring in the province of Konya are evaluated in three main groups: fatal, injury, and property-damage accidents. During the examined period, property-damage accidents constituted the majority of total accidents, while fatal and injury accidents are of more critical importance in terms of their social impact. Figure 1 shows the annual change of total traffic accidents in Konya between 2015 and 2024. Figure 2 presents the distribution of fatal and injury accidents by year. The graphs clearly indicate a general increasing trend, except for the pandemic year.

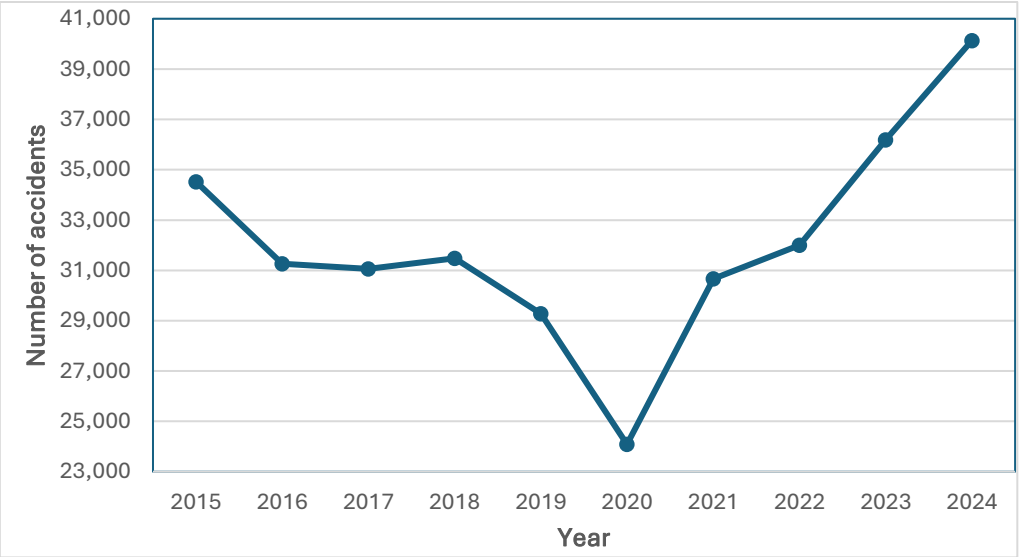

Figure 1. Annual changes in traffic accidents in Konya [16-25].

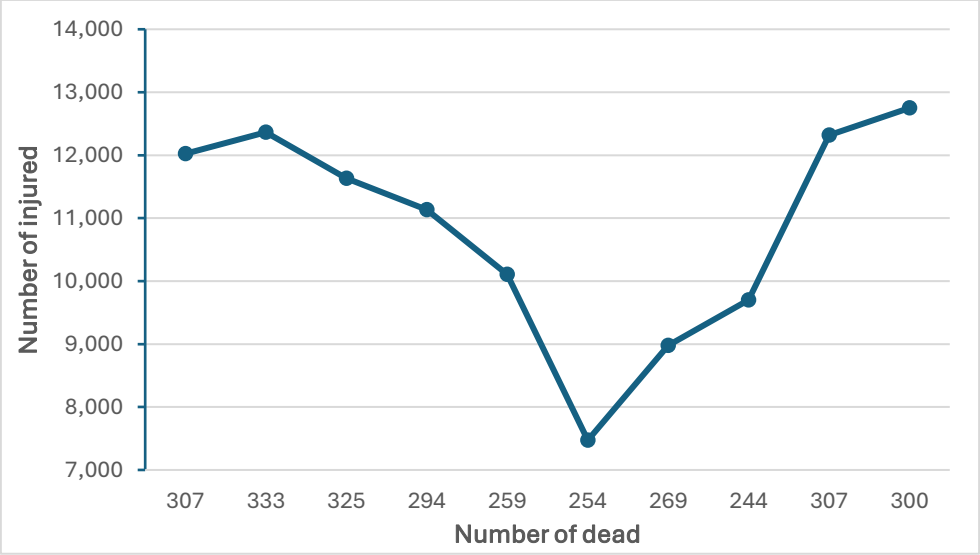

Figure 2. Annual change in the number of dead and injured between 2015 and 2024 [16-25].

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Although the number of deaths has fluctuated relatively limitedly over the years, it reached relatively high values in 2016, 2023, and 2024. In terms of the number of injuries, a significant increase is particularly noticeable in 2023 and 2024. When the number of deaths by year is examined, it is observed that it remained at relatively high levels during the period 2015–2019 and experienced a significant decline in 2020 due to the pandemic. In the post-pandemic period, alongside the increase in the number of accidents, there has also been a renewed upward trend in the number of deaths and injuries. However, in the long term, a relative decrease in the rate of fatal accidents is noticeable. This situation can be associated with developments in vehicle safety systems and improvements in emergency health services.

3.3. Spatial Distribution of Traffic Accidents

When the spatial distribution of traffic accidents in Konya is examined, it is observed that the accidents are concentrated mainly in the city center and on major transportation arteries. In particular, the districts of Selçuklu, Meram, and Karatay stand out as the areas with the highest accident density due to both high population density and high daily traffic volume. This situation reveals the strong relationship between urban density and traffic accidents [26].

When evaluating the main transportation axes; it has been determined that traffic accidents occur more frequently on the Ankara Ring Road, Adana Ring Road, Istanbul Road, Beyşehir Road, and Karaman Road. These routes are corridors where urban and intercity transportation intersect and where transit traffic load is high, and with these characteristics, they are considered high-risk transportation areas. In particular, junction points, sections with signalization systems, and transition areas providing connection to ring roads are among the main spatial elements where accidents are concentrated. In Figure 3, the spatial distribution of traffic accidents in Konya according to latitude and longitude is shown.

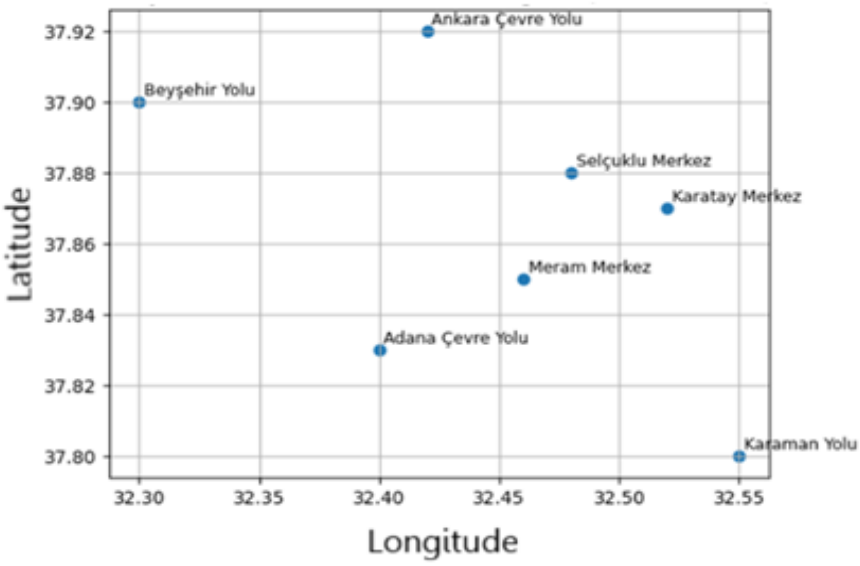

Figure 3. The spatial distribution of traffic accidents in Konya

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When the main transportation axes are evaluated; it has been determined that traffic accidents occur more frequently on the Ankara Ring Road, Adana Ring Road, İstanbul Road, Beyşehir Road, and Karaman Road. These routes are corridors where urban and intercity traffic intersect, with a high load of transit traffic, and are considered high-risk transportation areas due to these characteristics. Particularly, junction points, sections with signalization systems, and transition areas connecting to ring roads are among the main spatial elements where accidents are concentrated.

In rural areas, traffic accidents are seen to occur more often as single-vehicle accidents and collisions with animals. It has been determined that such accidents occur more frequently, especially during nighttime hours, on road sections with insufficient lighting, and in areas with limited visibility. This situation highlights the importance of improving rural road infrastructure and enhancing lighting and warning systems for traffic safety. When evaluated in general, the spatial distribution of traffic accidents in Konya is directly related to urban density, transportation infrastructure, and road usage characteristics. These findings point to the necessity of local-scale, spatially sensitive planning and intervention strategies aimed at increasing traffic safety.

3.4. Distribution by Causes of Traffic Accidents

When examining the causes of traffic accidents resulting in death and injury that occurred in the province of Konya, it is observed that driver faults clearly hold the largest share by far. According to TÜİK data, most of the accidents are caused by driver errors. Among these errors, exceeding speed limits, intersection violations, carelessness, driving under the influence of alcohol, and not maintaining a safe following distance stand out. Table 3 shows the distribution of traffic accidents in Konya Province by cause in percentage terms. This distribution clearly reveals the decisive role of the human factor in traffic accidents.

Table 3. Rates of driver errors in traffic accidents in Konya [16-25].

Driver Error	Type Description	Rate (%)
Exceeding Speed Limits	Driving above legal speed limits	32
Carelessness and Absentmindedness	Mobile phone use, distraction	24
Intersection and Right-of-Way Violation	Red light violation, failure to yield the right of way	15
Failure to Maintain Safe Following Distance	Failure to maintain a safe distance between vehicles	10
Driving Under the Influence of Alcohol	Driving under the influence of alcohol above the legal limit	6
Failure to Obey Traffic Signs and Markers	Driving under the influence of alcohol above the legal limit	5
Other Driver Errors	Illegible lane changes, sudden maneuvers, etc.	8
Total		**100**

ISBN NR: 978-625-5694-92-8

When the distribution of fatal and injury-causing traffic accidents in Konya province is examined according to their causes, it has been determined that the vast majority of the accidents are caused by driver errors. According to TÜİK data, driver faults account for approximately 89% of traffic accidents occurring in Konya. This finding clearly demonstrates the decisive role of the human factor in the occurrence of traffic accidents. Among driver errors, exceeding speed limits (32%) and inattention/distraction (24%) stand out as the most prominent causes. These are followed, respectively, by violations of intersection and right-of-way rules (15%), not maintaining a safe following distance (10%), and driving under the influence of alcohol (6%). In addition, not obeying traffic signs and signals (5%) and other driver errors (8%) are also among the factors influencing the occurrence of accidents.

The findings indicate that traffic accidents in Konya are caused not only by road or vehicle conditions but largely by driver behavior. In particular, the high rates of violations due to speeding and lack of attention reveal that the level of risk has increased on both urban and main transportation routes. This largely overlaps with previous national and regional studies on the causes of traffic accidents in Konya. As is the case across Turkey, driver errors being the primary determinant of accidents in Konya indicates that traffic safety is closely related to behavioral factors rather than technical infrastructure.

The fact that speeding and inattention are among the most common driver faults necessitates questioning the adequacy of existing inspection mechanisms and driver training. It is particularly important to expand electronic enforcement systems for speed control on urban roads and ring roads and to increase sanctions for factors that cause driver distraction (such as mobile phone use). The significant share of errors such as intersection violations and failure to maintain safe following distances indicates that the effectiveness of road geometry, signalization systems, and warning signs should be enhanced in areas with heavy traffic flow. Although the rate of driving under the influence of alcohol is relatively lower, considering its effect in increasing the severity of accidents, the continuity of enforcement in this area is of critical importance.

3.5. Time Series Trends

Time series analysis aims to reveal the changes, trends, and unusual breaking points of traffic accidents over the years. In this context, when traffic accidents that occurred in Konya between 2015 and 2024 are examined, a generally fluctuating but long-term increasing trend is observed. In particular, urbanization, the increase in vehicle ownership, and the intensive use of main transportation routes stand out as the main factors affecting the rise in the number of accidents.

During the period under review, it is observed that the number of accidents remained relatively high until 2019, while in 2020, there was a significant decrease due to the reduction in traffic mobility caused by the impact of the COVID-19 pandemic. After the pandemic, it has been determined that in 2021 and the following years, with the normalization process, traffic accidents began to show an increasing trend again. This situation indicates that traffic accidents in Konya are largely directly related to traffic volume and human mobility.

ISBN NR: 978-625-5694-92-8

When the traffic accidents that occurred in Konya between 2015 and 2024 are evaluated along with their causes and spatial distributions, it is seen that a significant portion of the accidents are caused by driver errors. In particular, speeding, inattentiveness, and non-compliance with traffic rules are among the main reasons for the accidents. Additionally, it is notable that the accident density is higher in the city center and on major transportation arteries. Based on these findings, the following measures should be prioritized to reduce traffic accidents in Konya:

- Increasing training activities on drivers' compliance with traffic rules and safe driving techniques, especially spreading awareness activities aimed at young and new drivers.
- Increasing inspections concerning risky driving behaviors, primarily speeding violations and driving under the influence of alcohol, and ensuring their continuity.
- Making road arrangements at sections and intersections with high accident density, improving signaling systems, and taking measures to increase visibility.
- Making pedestrian crossings more visible, implementing physical arrangements to enhance pedestrian safety, and raising awareness among pedestrians about compliance with traffic rules.

The findings of the time series analysis reveal that traffic accidents in Konya constitute a persistent transportation safety problem; they emphasize the necessity of addressing this issue through a holistic approach to education, enforcement, and infrastructure-based policies.

3.6. Regression Analysis

A multiple linear regression analysis was applied in order to reveal the determining factors of traffic accidents that occurred in Konya province between 2015 and 2024. In the analysis, the annual number of traffic accidents was used as the dependent variable, while driver faults, pedestrian errors, vehicle faults, and factors related to road conditions were used as independent variables.

The results of the regression analysis indicate that the model is generally statistically significant. The multiple correlation coefficient (R) of the model was found to be high, which demonstrates a strong relationship between the dependent and independent variables. An R^2 value above 75% shows that traffic accidents in Konya can largely be explained by the variables used in the analysis. The high adjusted R^2 value also indicates that the explanatory power of the model is maintained despite the use of multiple variables.

According to the Durbin-Watson test results, there is no autocorrelation problem in the model. This is an important finding that increases the reliability of the regression model. When the ANOVA results are examined, it has been determined that the model is generally significant and that at least one of the independent variables has a significant effect on traffic accidents ($p < 0.05$). Table 4 shows the regression coefficients of traffic accidents in Konya between 2015 and 2024.

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Table 4. Regression coefficients of traffic accidents in Konya between 2015-2024

Variable	B	SE	t	p	%95 GA
Constant (Intercept)	2034.74	9.05	224.89	< .001	[2013.35, 2056.13]
X_1	-0.10	0.05	-1.85	.106	[-0.22, 0.03]
X_2	0.001	0.001	1.27	.244	[-0.001, 0.003]

Not: N = 10. Model statistics: R = .58, R^2 = .34, Corrected R^2 = .15, F(2, 7) = 1.81, p = .23. B = regression coefficient; SE = standard error; GA = confidence interval.

The results of the multiple linear regression analysis presented in Table 4 reveal the statistical characteristics of the model established to explain traffic accidents that occurred in Konya between 2015 and 2024. When examining the explanatory level of the model, it is seen that approximately 34% of the total variance in the dependent variable is explained by the independent variables included in the model (R^2 = .34). However, the relatively low value of the adjusted R^2 (.15) indicates that the explanatory power of the model is limited, considering the sample size and the number of variables.

When the overall significance of the model was evaluated, it was determined that the regression model was not statistically significant, F(2, 7) = 1.81, p = .23. This result indicates that the independent variables included in the model, when considered together, do not significantly explain traffic accidents.

When the regression coefficients are examined, it is observed that the first independent variable (X_1) has a negative effect on traffic accidents, but this effect is not statistically significant (B = −0.10, p = .106). The confidence interval including zero supports that the effect of this variable on traffic accidents is not reliable. The coefficient of the second independent variable (X_2) is positive, but this variable also does not have a statistically significant effect on traffic accidents (B = 0.001, p = .244).

The statistical significance of the constant term (Intercept) (p < .001) indicates that the expected value of the dependent variable is high when the independent variables are zero. However, this finding does not mean that the overall explanatory power of the model is sufficient.

When evaluated in general, the findings in Table 3 indicate that traffic accidents in Konya cannot be adequately explained by only the two independent variables included in the model. This suggests that multidimensional variables such as driver behaviors, road and intersection geometry, traffic density, environmental conditions, and spatial factors play an influential role in the occurrence of traffic accidents. Therefore, it is anticipated that models developed with more comprehensive datasets and additional variables in future studies will provide stronger results in explaining traffic accidents.

4. CONCLUSION

This study comprehensively examined the annual changes, spatial distribution, and key risk factors affecting traffic accidents that occurred in Konya province between 2015 and 2024. Analyses based on data from the Turkish Statistical Institute (TÜİK) and relevant official institutions revealed that traffic accidents in Konya have shown a long-term increasing trend, with this trend only being temporarily disrupted during extraordinary circumstances such as the pandemic.

The findings indicate that traffic accidents in Konya largely occur due to human factors, particularly driver errors. Regression analysis results showed that the impact of driver errors on traffic accidents is statistically significant and strong. While pedestrian errors and vehicle faults also have a certain degree of effect, these factors were found to play a more limited role compared to driver errors.

Spatial analyses have shown that traffic accidents are concentrated in certain areas in Konya. The districts of Selçuklu, Meram, and Karatay stand out as the areas with the highest accident risk due to population density and traffic volume. In addition, it has been determined that traffic accidents are concentrated on major transportation routes such as Ankara Ring Road, Adana Ring Road, Istanbul Road, and the Beyşehir and Karaman axes. This situation clearly demonstrates the impact of Konya's strategic location in terms of transit passages on traffic safety.

It shows that policies aimed at preventing traffic accidents in Konya province should be addressed with a long-term, holistic approach that takes local dynamics into account. It is understood that strategies to reduce traffic accidents in Konya should not be limited to physical infrastructure improvements alone; they need to be supported by education, supervision, and awareness-based policies targeting driver behavior. This holistic approach is considered to contribute to reducing both the number and severity of traffic accidents.

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ISBN NR: 978-625-5694-92-8

STRUCTURAL OPTIMIZATION AND PERFORMANCE ANALYSIS OF SLIM RELAY DESIGN

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ABSTRACT

This study is a thesis that emerged from the need to provide structural optimization of slim relays used in industrial automation and electrical systems, improving their mechanical durability in compliance with standards and enhancing their electromagnetic performance. Due to the global market demand and the lack of sufficient know-how among companies in such studies, domestic production of these types of relays has been limited. The study focuses on addressing fundamental problems encountered in conventional relay designs, such as high temperature rise, mechanical deformation, irregularities in magnetic flux distribution, and high production costs. By applying structural optimization techniques, the weight-to-strength ratio of the relay has been improved, material usage has been reduced, and thermal conductivity has been increased, thereby enhancing reliability under long-term operating conditions. Domestic companies have generally relied either on sample products or on trial-and-error methods to resolve magnetic field issues in relays where current flows through the coil, typically after the production process has already been completed. In this study, critical regions were identified using the Finite Element Method (FEA), and by optimizing these regions, potential problems were resolved before the manufacturing stage. Analyses conducted using the Ansys Maxwell simulation software revealed that the magnetic field required for the design was initially insufficient. After optimizing the design and repeating the analysis, it was observed that the appropriate magnetic force was achieved. Thus, a homogeneous distribution of magnetic flux density was ensured, eliminating potential design errors before the production stage. Based on the optimized design obtained from the analysis results, prototype mold productions were carried out. The most important aspect considered in this process was ensuring that the raw materials used in the analysis trials were exactly the same as those used in the manufactured parts. In order to compare the data obtained from the analysis results, the prototype molded parts were produced using actual manufacturing techniques and raw materials, and the assembly processes were completed. This assembly process was supported with specially designed apparatus to enable real testing, and observations were made regarding the feasibility of production. Since no issues were encountered during manufacturing and the real test results

showed that the force values were within the required standards, automation line studies were subsequently carried out. With the assistance of analysis, it has been observed that investing in such studies is appropriate, as these types of optimization approaches can find broader applications in electromechanical systems and contribute to the widespread adoption of energy-efficient and compact designs.

Keywords : Slim relay, structural optimization, Finite Element Method (FEA), electromagnetic performance, energy efficiency, apparatus, automation line.

ÖZET

Bu çalışma, endüstriyel otomasyon ve elektrikli sistemlerde kullanılan slim rölelerin yapısal optimizasyonunu sağlayarak mekanik dayanıklılığının,standartlara uygun ve elektromanyetik performansı açısından iyileştirilmesinin , global pazardaki ihtiyaç neticesinde firmaların bu tip çalışmalarda know-how bilgilerinin fazla olmamasından dolayı yerli üretim yapamamasından ortaya çıkmış bir tez çalışmasıdır. Geleneksel röle tasarımlarında karşılaşılan yüksek sıcaklık artışı, mekanik deformasyon, manyetik akı dağılımlarındaki düzensizlikler ve üretim maliyetleri gibi temel problemlerin giderilmesi hedeflenmiş olup çalışma bu detaylar üzerinde yoğunlaşarak yapılmıştır. Yapısal optimizasyon teknikleri uygulanarak rölenin ağırlık mukavemet oranı iyileştirilmiş, malzeme kullanımı azaltılmış ve termal iletkenlik arttırılarak uzun süreli çalışma koşullarında güvenirliği arttırılmıştır. Yerli firmalar bobinden akım geçen rölelerde ya numune ürünlere bağlı kalmış ya da deneme yanılma yöntemiyle üretim tamamlandıktan sonra manyetik alan çalışmalarını çözmüşlerdir. Çalışmada sonlu elemanlar yöntemi (FEA) kritik bölgeler tespit edilmiş ve bu bölgelerin optimizasyonu sağlanarak üretim yapılmadan oluşabilecek sorunlar çözülmüştür. Yapılan Ansys Maxwell analiz programında tasarımda gerekli olan manyetik alanın yeterli olmadığı görülmüş olup tasarım optimize edilerek tekrar analiz yapıldığında uygun manyetik kuvvetin oluştuğu görülmüştür. Böylece, manyetik akı yoğunluğunun homojen dağılımı sağlanarak rölenin üretim yapılmadan önce oluşabilecek hataları giderilmiştir. Analiz sonucu ortaya çıkan optimize tasarım ile prototip kalıp üretimleri yapılmıştır. Burada dikkat edilen en önemli unsur analiz denemelerinde de kullanılan hammadde ile üretim yapılan parçanın birebir uygun olmasıdır. Analiz sonuçları ile elde edilen verileri karşılaştırmak amacıyla prototip kalıplaması yapılan parçalar gerçek üretim teknikleri ve hammadde ile üretilmiş olup montajlama işlemleri tamamlanmıştır. Bu montajlama işlemi reel testlerin yapılabilmesi amacıyla tasarlanmış aparatlarla desteklenmiş ve üretim yapılıp yapılamayacağı gözlemlenmiştir. Üretim yapımında sorun olmadığından ve yapılan reel testler de istenen standartlar kapsamında kuvvet değerleri uygun çıktığından otomasyon hattı çalışmaları yapılmıştır. Bu tür optimizasyon yaklaşımlarının elektromekanik sistemlerde daha geniş bir kullanım alanı bulması ve enerji verimliliği olan, kompakt tasarımların yaygınlaşmasına katkıda bulunmuş olması analizin de yardımıyla bu tür çalışmalara yatırım yapılmasının uygun olduğu görülmüştür.

Anahtar Kelimeler : Slim röle , yapısal optimizasyon , sonlu elemanlar yöntemi (FEA) , elektromanyetik performans , enerji verimliliği , aparat , otomasyon hattı

1.GİRİŞ

Elektriksel açıdan röle, bir devredeki anahtarlama işlemini, kendisinden geçen akımdan bağımsız bir kontrol sinyali aracılığıyla gerçekleştiren bir elektromekanik veya yarı iletken tabanlı anahtarlama elemanıdır [1]. Temel işlevi, düşük güç seviyesindeki bir kontrol devresi ile yüksek güç gerektiren bir yük devresi arasında güvenli ve kontrollü bir bağlantı kurmaktır [2]. Bu yönüyle röleler, hem kontrol hem de koruma amaçlı kullanılan önemli devre elemanları arasında yer alır.

Elektromekanik rölelerde çalışma prensibi, bobin üzerinden geçen akımın oluşturduğu manyetik alanın mekanik bir hareket üretmesine dayanır [3]. Bobine uygulanan gerilim sonucunda oluşan manyetik alan, manyetik nüve üzerinden armatürü harekete geçirir. Bu hareket, röle kontaklarının konum değiştirmesine neden olarak [4] devrenin açılması veya kapanmasını sağlar. Böylece kontrol devresinden bağımsız olarak yük devresinde anahtarlama işlemi gerçekleştirilmiş olur.

Rölelerin en önemli elektriksel özelliklerinden biri galvanik izolasyon sağlamalarıdır [2]. Bu izolasyon sayesinde kontrol devresi ile güç devresi arasında doğrudan elektriksel bağlantı bulunmaz. Bu durum, özellikle hassas elektronik bileşenlerin yüksek gerilim, ani akım değişimleri veya kısa devre gibi olumsuz etkilerden korunmasını sağlar. Aynı zamanda sistem güvenliğini artırır ve farklı gerilim seviyelerinde çalışan devrelerin birlikte kullanılabilmesine olanak tanır.

Röleler çalışma yapılarına göre farklı kategorilere ayrılmaktadır. Elektromekanik röleler fiziksel hareketli kontaklara sahipken, katı hal röleleri yarı iletken elemanlar kullanarak mekanik hareket olmadan anahtarlama yapar. Katı hal röleleri daha hızlı anahtarlama, sessiz çalışma ve uzun ömür gibi avantajlar sunarken; elektromekanik röleler yüksek akım taşıma kapasitesi [5] ve maliyet avantajı nedeniyle yaygın olarak tercih edilmektedir.

Sonuç olarak röleler, elektrik ve elektronik sistemlerde kontrol, izolasyon ve koruma fonksiyonlarını bir arada sunan kritik bileşenlerdir. Özellikle endüstriyel otomasyon, güç elektroniği ve kontrol sistemlerinde güvenilir anahtarlama elemanları olarak önemli bir rol üstlenirler.

Gelişen endüstriyel sistemler ve otomasyon teknolojileri, kontrol ekipmanlarının hem fiziksel boyutlarının küçültülmesini hem de performanslarının artırılmasını zorunlu kılmaktadır. Bu gereksinim doğrultusunda tasarlanan slim röleler, kompakt yapıları ve işlevsel özellikleri sayesinde modern elektriksel kontrol sistemlerinde önemli bir yer edinmiştir [6]. Özellikle sınırlı alanlara sahip pano ve modüler sistemlerde, yüksek yoğunluklu yerleşime olanak tanımaları, bu rölelerin tercih edilmesinde belirleyici bir faktör olmaktadır [7]. Slim röleler, temel olarak düşük seviyeli kontrol sinyalleri ile daha yüksek güçteki devrelerin güvenli ve etkin bir şekilde anahtarlanmasını sağlayan elemanlardır. Bu röleler, sahip oldukları dar gövde tasarımı sayesinde geleneksel rölelere kıyasla daha az yer kaplarken, benzer anahtarlama işlevlerini yerine getirebilmektedir. Bunun yanı sıra, kontrol ve güç devreleri arasında elektriksel izolasyon sağlayarak sistem güvenliğine katkıda bulunmaktadır. Teknolojik

ISBN NR: 978-625-5694-92-8

gelişmelerle birlikte slim rölelerin performans, dayanıklılık ve enerji verimliliği açısından önemli ölçüde iyileştirildiği görülmektedir. Bu durum, söz konusu elemanların endüstriyel otomasyon, bina yönetim sistemleri ve çeşitli kontrol uygulamalarında daha yaygın biçimde kullanılmasına zemin hazırlamıştır. Ayrıca modüler yapıları sayesinde sistem entegrasyonunu kolaylaştırmaları, bakım ve işletme süreçlerinde avantaj sağlamaktadır.Slim rölelerin diğer rölelere göre avantajları aşağıdaki gibi sıralanabilir:

- Boyutları normal rölelere göre oldukça ince yapılıdır.
- Modüler bir tasarıma sahiptir ve panolarda az yer kaplar.
- AC veya DC enerji ile çalışabilme özelliğine sahiptir.
- LED göstergeleri bulunur.
- Bakım ve değiştirme işlemleri kolaydır.
- DIN raya kolay montaj yapılabilir.

Bu çalışmada, slim rölelerin yapısal ve fonksiyonel özellikleri ele alınmış, 3 boyutlu tasarım yapılarak analizlerle çalışma performansı gözlenmiş ve prototip üretimleri yapılmıştır. Yapılan prototip üretimleri sonrasında gerçek ortam testleri yapılarak sonuçlar karşılaştırılmıştır.

2. TASARIM VE ANALİZ ÇALIŞMALARI

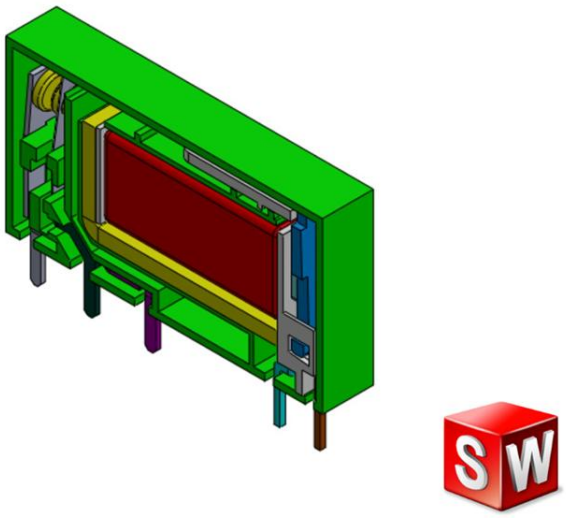
2.1. Tasarım Çalışmaları

Bu çalışmada tasarım çalışmalarının yapılabilmesi için öncelikle yurtiçi ve yurtdışı pazarda yer sahibi olan diğer markaların slim röle tasarımları incelenmiştir. Kullanılan hammaddelerin de belirlenebilmesi için hem projenin yürütüldüğü şirketteki know-how kullanılmış hem de benchmarking çalışmaları ile hammaddeler belirlenmiştir. Slim röle tasarımları incelenerek bir slim rölenin hangi parçalardan meydana geldiği belirlenmiş ve 3 boyutlu tasarım modelleri Solidworks ortamında tamamlanmıştır. Projenin sağlıklı üretilebilmesi açısından diğer bölümlerle de iş birliği yapılmış ve tasarımın otomasyona uygun hale getirilmesi sağlanmıştır.

Her ne kadar slim röle için yurtiçi ve yurtdışı pazarlar belli markalar tarafından yürütülse de hepsinin ortak noktası ucuz işçilik olduğundan rekabet edilebilmesi için tasarım tam otomasyona uygun hale getirilmiştir. Bir slim rölenin temel iç bileşenleri şunlardır:

- Bobin: Elektrik enerjisini manyetik enerjiye çevirir.
- Karkas: Bobini taşıyan yapıdır.
- Nüve: Manyetik alanı yönlendirir.
- Armatür: Manyetik alan tarafından çekilen hareketli parçadır.
- Armatür Kolu: Armatürün hareketini kontağa iletir.
- Boyunduruk: Manyetik devrenin kapanmasını sağlar.
- Plastik Gövde ve Kapak

ISBN NR: 978-625-5694-92-8

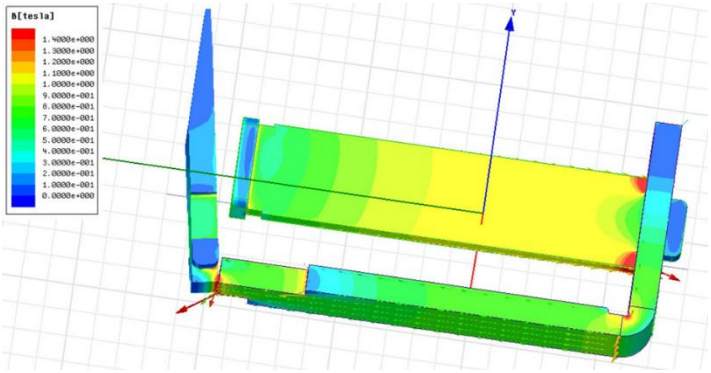


Görsel 1. Slim Röle Bileşenlerinin Solidworks Programında Montajlanmış Tasarımı

Çeşitli hammaddeler kullanılarak üretim metotları da göz önüne alınarak , metaller için saf demir, gövde plastikleri için LCP (liquid crystal polimer) hammaddesine karar verilmiştir. Saf demir kolay bulunamadığından ve maliyet ön planda olduğundan EREĞLİ 7114 hammaddesi de bu projede saf demirin verdiği sonucu vermiştir. Gövde plastiklerinde LCP malzemesinin seçilmesindeki en büyük etken hem standardın TS EN 60947-5-1 istediği testlerden geçebilmesi , elektriksel ürünlerde kullanıma uygun olması ve gövde kapak arasında ultrasonik kaynak uygulanacağı için akışkan olmasından dolayı tercih edilmiştir. Yüksek sıcaklıklarda ergiyerek enjeksiyon makinelerinde kullanımı gerçekleşmektedir.

2.2. Analiz Çalışmaları

3 boyutlu tasarımın Solidworks ortamında tamamlanmasından sonra atanmış gerçek malzemelerle birlikte bobin elektromanyetik kuvvet analizinin yapılabilmesi için tasarım sonlu elemanlar yöntemi [8] için Ansys Maxwell [9] programına aktarılmıştır. Burada 24 V ve 10.192 sarım sayılı bobin tasarımları için analizler yapılmış ve çıkan sonuçlara göre tasarım revize edilmiştir [10].



Görsel 2. Ansys Maxwell Elektromanyetik Analiz 170 Amper-Sarım , İlk Tasarım

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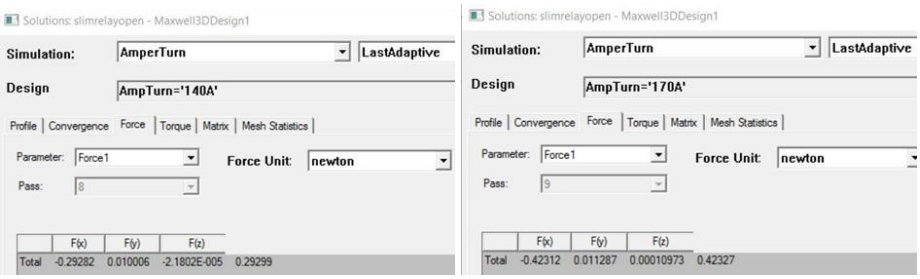
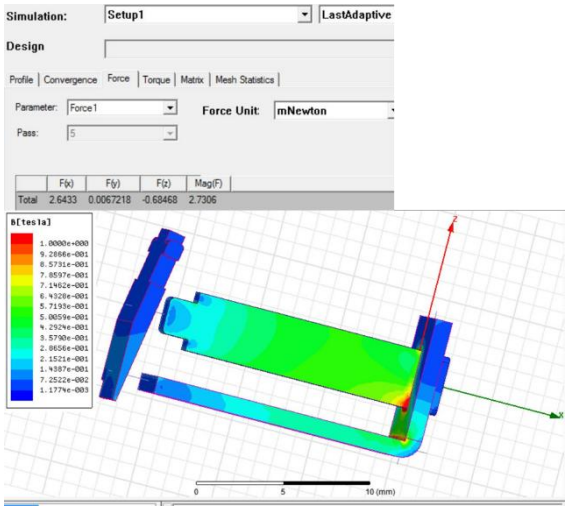
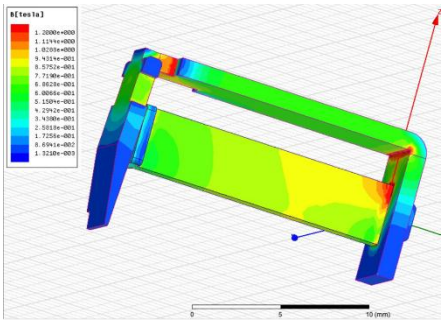


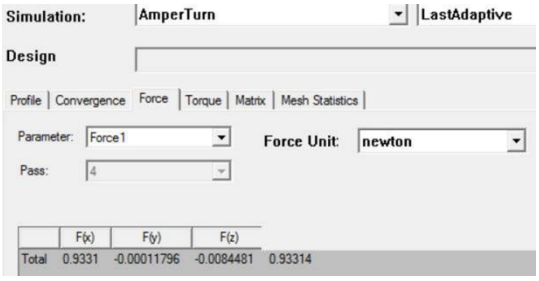
Görsel 3. 140 Amper Sarım ve 170 Amper Sarımdaki kuvvet değerleri , İlk tasarım



Görsel 4. Boyunduruğun pozisyon değiştirdiği tasarım ve kuvvet değeri , 2.revizyon



Görsel 5. Hava boşluğu alınmış , armatüre açı verilmiş tasarım , 3.revizyon



Görsel 6. Elektormanyetik Kuvvet Değeri , 3.revizyon

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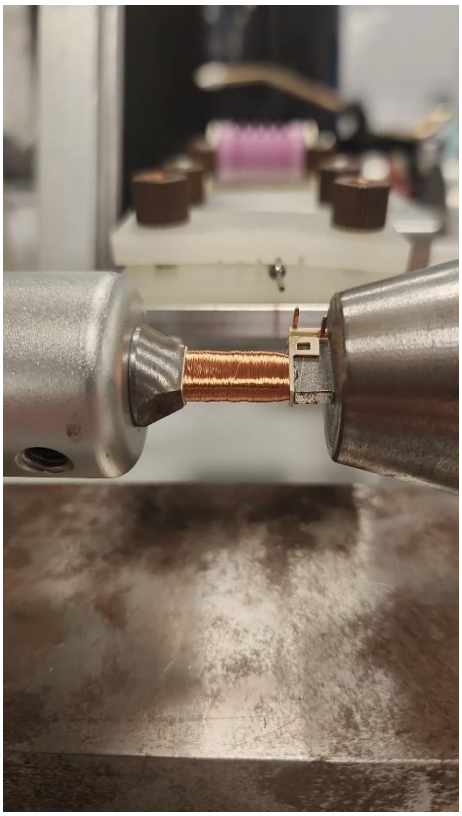
2.3. Üretim Çalışmaları

3 boyutlu revizyon tasarımın Solidworks ortamında tamamlanmasından ve kullanılan malzemelerin belirlenmesinden sonra tasarımı doğrulamak adına 3D print yazıcılardan prototip baskı alınmış ve montajlama evreleri kontrol edilmiştir. Montajlama aşamasında sorun çıkmamış , gerçek testlerin yapılması ve gerçek hammaddeler ile üretim yapılabilmesi için kalıp prototip üretimine verilmiş ve kalıp çalışmaları yapılmıştır. Burada kesme kalıpları ve plastik kalıpları çok hassas toleranslarla üretilmiştir. Bobinin giriş ve çıkışında kullanılan 0,5X0,5 kare tel için rulo olarak piyasada bulunamadığından kalıp içerisine deneme amacıyla yapılabilmesi için el ile tek tek beslenmiştir. Bu şekilde yapılmasıyla birlikte otomasyonun zorluğu azaltılmış olmuştur. Açık ve kapalı dediğimiz kontaklarda gümüş perçinlerin hassas şekilde çakılması için aparatlar tasarlanmış ve prototipleri yapılmıştır. Bu aparatlarda aynı zamanda çift taraflı gümüş kontak çakılan masif kontaklar da üretilmiştir. Parçalar çok hassas olduğundan bobin sarımını piyasada yaptırmadığımızdan özel sarım makinesinin tasarlanması gerektiğinden kendi bünyemizdeki bobin sarım makinesine özel aparat yaparak sarma işlemini gerçekleştirdik. Parça üretimleri tamamlandıktan sonra reel ortamda gerçek hammaddeler ile basılan parçalar montajlanmış ve teste verilmiştir.



Görsel 7. Bobin Sarımı

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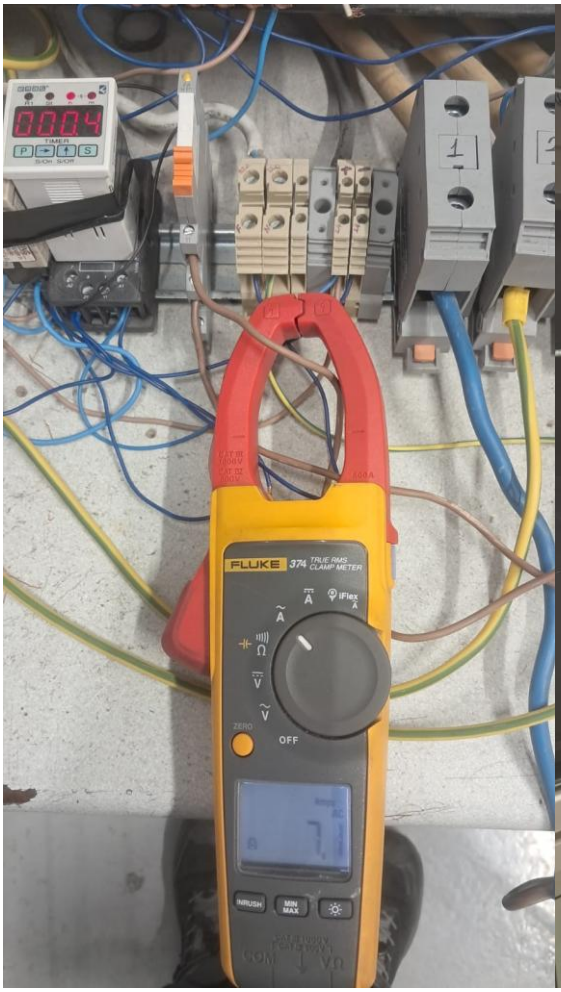
2.4. Test Çalışmaları

Röle standardı TS EN 60947-5-1 içeriğine uygun olacak şekilde aşağıdaki testler yapılmış ve ürünün çalışması test edilmiştir.



Görsel 8. Elektriksel test

Görsel 9. Kızaran tel

3. SONUÇLAR VE DEĞERLENDİRME

Yapılan test sonuçlarına göre ürün ilk üretimde bobin üzerinden 7,1 Amper geçerek çalıştığı gözlemlenmiştir. Slim rölelerdeki elektromanyetik kuvvet aralığı 0,5-1,2 Nevton arasındadır. İlk tasarımdaki analizde çıkan sonuç 0,2-0,4 Newton aralığındadır ve bu bize yaptığımız tasarımın uygun olmadığını göstermektedir. İkinci revizyonda ise model değiştirilmiş boyunduruk üst tarafa alınmıştır. Burada da kuvvet istenilen miktarlarla uyumlu olmadığından 3. Revizyon yapılmıştır. Burada hava boşlukları azaltılmış armatüre bu anlamda açılar verilmiştir. Son revizyonda 0,9 Newtonluk analiz sonucu çıkmış ve bu değerlere göre kalıp prototipleri yapılarak teste verilmiştir. Yapılan analiz çalışmaları neticesinde zaman kaybetmeden ve maliyeti arttırmadan ürünün ilk testleri başarıyla geçmesi sağlanmıştır.

Analizlerle [11] bu sonuçlar görülmeden ilk tasarımdaki değerlerle kalıp yapılsaydı hem kalıp revizyonları çok zor olacak hem zaman kaybı olacak hem de maliyet artacaktı.

4. GENEL DEĞERLENDİRME VE SONUÇLAR

Öncelikle bu projenin yapılması amacı yerli olarak slim röle üretiminin firmalar tarafından yapılmamasıdır. Bunun altında ise firmaların bu konuda fazla bilgi sahibi olmadığı , özellikle bobin olan konularda deneme yanılma yöntemlerine başvurması ve maliyetin bu şekilde artmasıdır. Yapılan analizle birlikte deneme yanılma yapılmadan da üretimin yapılabileceği gözlemlenmiştir. Piyasada rekabet edilebilmesi açısından maliyetin düşük olması gerekmektedir. Gerek analiz yaparak gerek tasarımın tüm girdilerini tamamlayarak yapılan prototip çalışmaları maliyetin azaltılmasında önemli rol oynamaktadır. Burada rekabet açısından üretim miktarlarının arttırılması gerekmektedir. Bu yüzden de otomasyon sistemlerine büyük iş düşmektedir. Prototip için yapılan tüm işlemlerin otomasyon sürecinde yapılması hem maliyet açısından çok önemlidir hem de insan hatalarının önüne geçtiği için kalite ve verimliliği arttırmaktadır [8].

.

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ISBN NR: 978-625-5694-92-8

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ISBN NR: 978-625-5694-92-8

DESIGN AND STRUCTURAL VIBRATIONAL ANALYSIS OF A WINDOW CLEANING DRONE USING FINITE ELEMENT METHOD

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ÖZET

Yüksek katlı binaların dış cephe temizliklerinde hâlen büyük ölçüde insan gücüne dayalı vinç sistemleri kullanılmaktadır. Bu durum hem yüksek operasyon maliyetlerine hem de iş sağlığı ve güvenliği açısından önemli risklere yol açmaktadır. Bu çalışmada, söz konusu riskleri azaltmak ve temizlik sürecini otonom hâle getirmek amacıyla, cam yüzeyleri algılayarak temizlik işlemini otomatik olarak gerçekleştirebilen bir drone tasarımı yapılmıştır. Tasarımı yapılan sistemin gövde ve motor yapılarının operasyonel yükler altındaki davranışı, Sonlu Elemanlar Yöntemi (Finite Element Method, FEM) kullanılarak incelenmiştir. Drone'un üç boyutlu modeli oluşturularak ANSYS Workbench ortamında analiz edilmiştir. Mesh yapısında global eleman boyutu 3,5 mm, motor bağlantı bölgelerinde ise 1 mm lokal eleman boyutu kullanılmış; ortalama Element Quality değeri 0,77, Skewness değeri ise 0,93 olarak elde edilmiştir. Malzeme olarak karbon fiber kompozit ve PLA tercih edilmiş, her bir motor merkezine 69,058 N itki kuvveti uygulanmıştır. Alt yüzeyler sabit sınır koşulu (Fixed Support) olarak modellenmiştir. Statik analiz sonuçları, maksimum deformasyonun 7,77 mm ile kol uçlarında, maksimum eşdeğer gerilmenin ise 164,29 MPa olduğunu göstermektedir. Bu değerler, kullanılan malzemenin akma sınırının altında kalarak yapısal bütünlüğün korunduğunu ortaya koymaktadır. Elde edilen sonuçlar, geliştirilen cam temizleme drone sisteminin yapısal olarak güvenilir, yeterli rijitliğe sahip ve operasyonel kullanıma uygun olduğunu göstermektedir.

Anahtar Kelimeler: Cam temizleme drone, sonlu elemanlar analizi, yapısal analiz, ANSYS.

ISBN NR: 978-625-5694-92-8

1. GİRİŞ

Son yıllarda insansız hava araçları (İHA) teknolojisindeki hızlı gelişmeler, bu sistemlerin endüstriyel ve ticari uygulamalarda yaygın bir kullanım alanı bulmasını sağlamıştır. Özellikle dört rotorlu (quadcopter) yapılar; yüksek manevra kabiliyeti, stabil uçuş özellikleri ve yük taşıma kapasitesi sayesinde öne çıkmakta ve birçok görev için tercih edilmektedir. Görüntüleme, haritalama, afet izleme, tarımsal ilaçlama ve bina denetimi gibi çeşitli uygulamalarda yaygın olarak kullanılmaları bu sistemlerin adaptif yapısını ortaya koymaktadır.

Yüksek katlı binaların dış cephe temizliği gibi hem insan güvenliği hem de maliyet açısından riskli ve karmaşık operasyonlarda geleneksel yöntemlerin (örneğin vinç ya da iskele sistemleri) yerini otonom ya da yarı otonom İHA sistemlerinin alması, bu alandaki teknolojik ilerlemenin en dikkat çekici örneklerinden biridir. Örneğin, Guo ve arkadaşları, flapping-wing sistemine sahip bir emiş drone geliştirerek bu alandaki yenilikçi yaklaşımlardan birini sunmuşlardır (1). Al-Hulaibi ve arkadaşları ise karbon fiber gövdeli ve sekiz pervaneli yapıya sahip SkyBot adını verdikleri sistemle yüksek basınçlı yıkama ve güçlü hava üfleme mekanizmalarını entegre etmiş, böylece hem temizlik süresini azaltmış hem de operasyonel maliyetleri önemli ölçüde düşürmüştür (2). Uddin ve arkadaşları tarafından geliştirilen APM tabanlı sistem, su püskürtme ve mikrofiber fırçalama fonksiyonlarını bir arada sunarak yüksek katlı cam yüzeylerde ekonomik ve esnek bir çözüm sağlamaktadır (3). Ayrıca Raghav ve arkadaşları, yüksek katlı binalar için dört pervaneli otonom bir temizlik drone tasarlamış ve sistemin uygulama senaryolarını detaylandırmıştır (4).

Bu tür uygulamalar, yalnızca görev odaklı sistemlerin kontrol algoritmaları ve sensör yapılarıyla değil; aynı zamanda gövde dayanımı, aerodinamik verimlilik ve titreşim davranışı gibi yapısal tasarım unsurlarıyla da desteklenmelidir. Özellikle gövde geometrisinde meydana gelen küçük deformasyonların dahi uçuş kararlılığı üzerinde doğrudan etkili olduğu bilinmektedir. Bu bağlamda, yapısal dayanımın sonlu elemanlar yöntemi (Finite Element Analysis – FEA) ile değerlendirilmesi büyük önem arz etmektedir. Ahmad ve arkadaşları, quadcopter gövdesinin malzeme bazlı optimizasyonunu FEA ile gerçekleştirerek farklı frekans ve gerilme davranışlarını karşılaştırmıştır (5). Benzer şekilde, Marneni ve arkadaşları FEA tabanlı analiz teknikleriyle quadcopter çerçevesinin mekanik performansını iyileştirmeye yönelik stratejiler sunmuştur (6).

Al-Haddad ve Subramanian gibi çalışmalar, bu tür sistemlerin yapı stabilitesi ve yük taşıma güvenliği açısından optimize edilmesi gerektiğini vurgulamaktadır. Yapısal analizlere yönelik bu yaklaşım, dronların görev esnasında karşılaşabilecekleri itki kuvvetleri, dışsal darbe ve titreşim gibi koşullara karşı daha güvenilir hale getirilmesini sağlamaktadır. (7; 8).

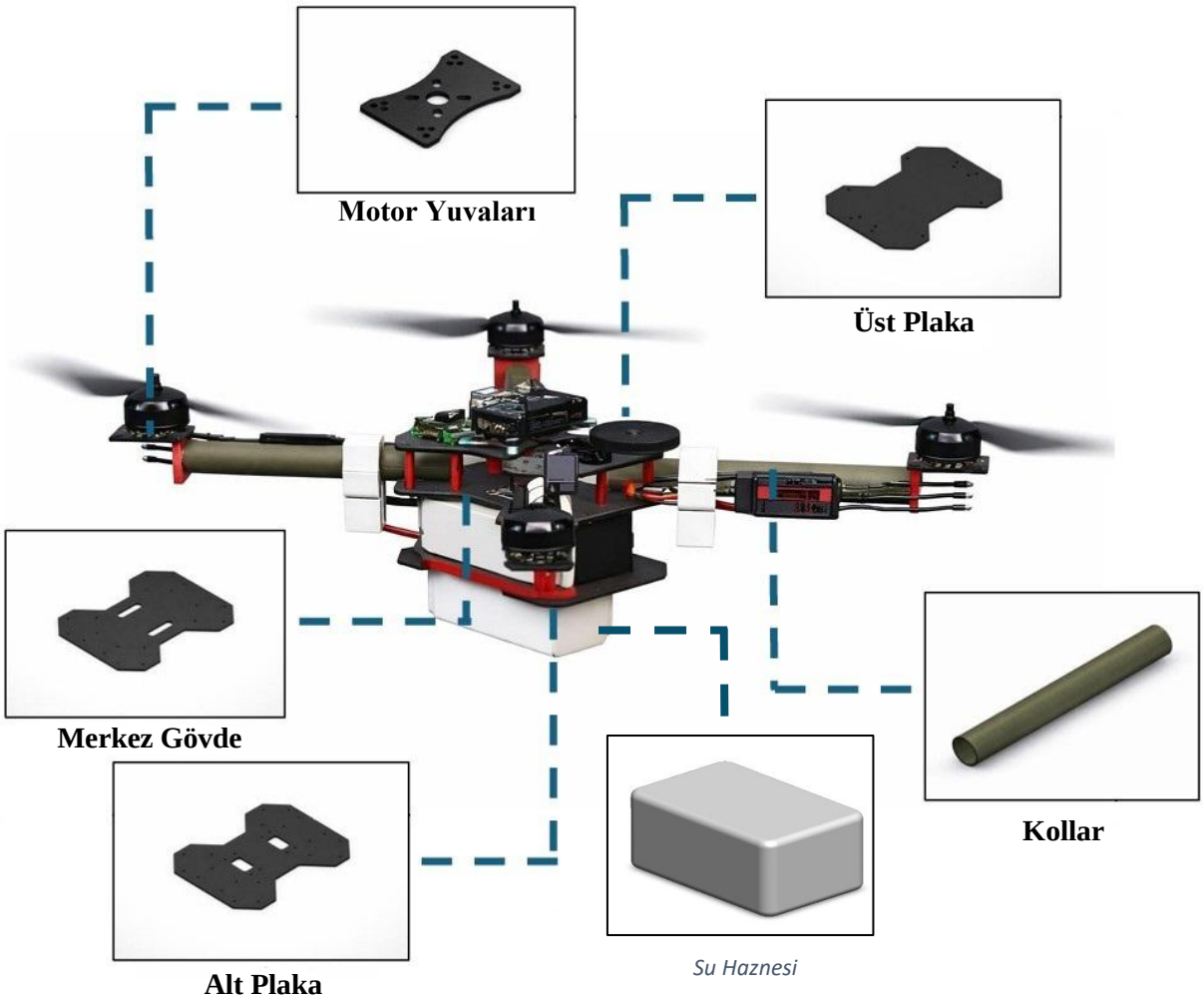
Bu çalışma kapsamında, özel bir görev için tasarlanan quadcopter gövdesi üzerinde ANSYS Workbench ortamında statik analizler gerçekleştirilmiştir. Analizlerin amacı, gövde yapısının operasyonel yükler altındaki mekanik dayanımını değerlendirmek ve olası zayıf bölgeleri belirlemektir. Elde edilen deformasyon, eşdeğer gerilme ve mesh kalitesi sonuçları

ISBN NR: 978-625-5694-92-8

doğrultusunda karbon fiber ve PLA malzemelerinin kullanım güvenliği incelenmiş ve yapının görev yükleri altında yeterli mekanik performans gösterdiği belirlenmiştir.

2. CAM TEMİZLEME DRONE'UN MODELLENMESİ

Bu çalışmada tasarlanan quadcopter, cam temizleme uygulamaları için özel olarak geliştirilmiş olup; tasarım sürecinde hem mekanik dayanım hem de hafiflik esas alınmıştır. İHA'nın ana yapısı, merkez gövde, dört adet kol, motor yuvaları, pervaneler ve bağlantı plakalarından oluşmaktadır. Tasarımın üç boyutlu modeli SolidWorks ortamında hazırlanmış, ardından sonlu elemanlar analizleri için ANSYS Workbench yazılımına aktarılmıştır. Quadcopter, dört adet pervane ve motordan oluşan X tipi simetrik bir konfigürasyona sahiptir. Bu yapı, yüklerin kollar arasında dengeli bir biçimde dağılmasını sağlarken uçuş sırasında sistemin kararlılığını artırmaktadır. Ayrıca gövdenin orta kısmına entegre edilmesi planlanan cam temizleme mekanizmasının dengeli taşınması için uygun bir geometrik düzen oluşturulmuştur. Sonrasında genel olarak tasarımı yapılan drone'un görüntüsü Görsel 1'de verilmiştir.



Görsel 1 Tasarımı Yapılmış Drone'un Görüntüsü

ISBN NR: 978-625-5694-92-8

Tasarımın merkezinde bulunan gövde bölümü, uçuş kontrol kartı, güç dağıtım kartı, sensörler ve batarya gibi elektronik bileşenlerin yerleşimi için uygun alanlar içermektedir. Gövde, taşıyıcı kolları birbirine bağlayan rijit bir plaka olarak işlev görmektedir. Dört adet kol (arm), merkez gövdeden dışa doğru uzanmakta ve uç kısımlarında motor yuvalarını taşımaktadır. Her kol, cıvata bağlantıları ile gövdeye sabitlenmiş olup gerektiğinde kolayca değiştirilebilecek modüler bir yapıya sahiptir.

Bu kolların tasarımında, minimum ağırlık ve maksimum dayanım hedeflenmiştir. Bu nedenle kollar içi boş profiller olarak modellenmiş ve yüksek moment taşıma kapasitesi sağlayacak şekilde optimize edilmiştir.

Her biri bir motor ve pervane taşıyan kollar, sistemin en fazla yük alan elemanlarıdır. Statik analiz sonuçları, en yüksek deformasyonun bu bölgelerde meydana geldiğini göstermektedir. Kolların yapısal rijitliği, uçuş sırasında oluşabilecek titreşimlerin azaltılması açısından büyük önem taşımaktadır.

Gövde kısmı, elektronik bileşenlerin yer aldığı ana taşıyıcıdır. Kütleyi azaltmak için belirli bölgelerde delikler açılmıştır. Tasarımda malzeme olarak karbon fiber takviyeli polimer ve PLA kullanılmıştır. Bu malzemeler hem hafiflik hem de yeterli mukavemet açısından uygun bulunmuştur.

Alt plaka, gövdeyi oluşturan kolları birleştirir ve aynı zamanda pil, sensör ve kamera gibi bileşenlerin montajına olanak tanır. Üst plaka ise elektronik kartları korur ve yapıya genel rijitlik kazandırır.

Her bir motor yuvası, motorun çapına tam olarak uyacak biçimde tasarlanmış ve eksenel doğrultuda hizalanmıştır.

3. SONLU ELEMANLAR ANALİZİ (FINITE ELEMENT METHOD – FEM)

Drone gövdesinin yapısal dayanımını ve titreşim davranışını incelemek amacıyla sonlu elemanlar yöntemi (FEM) kullanılmıştır. Çalışmanın bu bölümünde analizde kullanılan yöntem, sınır koşulları, yükleme değerleri, malzeme özellikleri ve mesh yapısına ilişkin detaylar sunulmaktadır. Analizlerde kullanılan üç boyutlu model, SolidWorks ortamında oluşturulmuş ve STEP formatında ANSYS'e aktarılmıştır. Model, merkez gövde, dört kol, motor yuvaları, üst ve alt plakalardan oluşmaktadır. Bağlantı noktaları rijit (bonded contact) kabul edilmiştir. Drone gövdesinin üretiminde kullanılabilecek iki farklı malzeme incelenmiştir: karbon fiber takviyeli polimer ve PLA (polilaktik asit). Malzeme özellikleri Çizelge 1'de verilmiştir. Bu değerler literatürde belirtilen mekanik özellikler ve ilgili test standartları dikkate alınarak belirlenmiştir (9; 10; 11).

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Çizelge 1 Malzeme Özellikleri

Material	Elastic Modulus [GPA]	Poisson Ratio	Shear Modulus [GPA]	Yield Strength [MPA]	Density [G/CM3]	Tensile Strength [MPA]
Karbon Fiber	230-245	0.23	25-30	3950	1.77	3750-3900
Pla	0.3-3.5	0.36	1.1-1.3	70	1.20-1.25	48-53

3.1. Yapısal Analiz Sonlu Elemanlar Teorisi

Sonlu elemanlar yöntemi (FEM), karmaşık geometrilere sahip yapıların analitik olarak çözülemeyen diferansiyel denklemlerinin yaklaşık sayısal çözümü için kullanılan bir yöntemdir. Yöntemin temel prensibi, sürekli bir yapıyı sonlu sayıda elemanlara ayırmak ve her eleman için yer değiştirme, gerilme ve şekil değiştirme ilişkilerini tanımlamaktır.

Bir elastik katı için temel denge denklemi genel olarak şu şekilde ifade edilir:

$$[K]\{u\}=\{F\}$$

Burada;

- $[K]$: sistemin rijitlik matrisi,
- $\{u\}$: düğüm yer değiştirme vektörü,
- $\{F\}$: dış yük vektörüdür.

Rijitlik matrisi her eleman için ayrı ayrı tanımlanır ve tüm sistem için birleştirilir:

$$[K]=\int_V [B]^T[D][B]dV$$

Burada;

- $[B]$: şekil değiştirme (strain–displacement) matrisini,
- $[D]$: malzemenin elastisite matrisini (malzeme özelliklerine bağlı),
- $[V]$: eleman hacmini göstermektedir.

Gerilme ve şekil değiştirme arasındaki ilişki, Hooke kanununa dayanmaktadır.

$$\{\sigma\}=[D]\{\varepsilon\}$$

Ve şekil değiştirme–yer değiştirme ilişkisi ise:

$$\{\varepsilon\}=[B]\{u\}$$

ISBN NR: 978-625-5694-92-8

Şeklinde tanımlanır.

Statik analizlerde amaç, dış yükler altındaki yer değiştirmeleri $\{u\}$çözmek, ardından şekil değiştirme $\{\varepsilon\}$ve gerilmeleri $\{\sigma\}$hesaplamaktır.

Toplam deformasyon (total deformation), sistemdeki tüm düğüm yer değiştirmelerinin bileşke büyüklüğüdür ve şu şekilde ifade edilir:

$$\delta_{tot}=\sqrt{u_x^2+u_y^2+u_z^2}$$

Von Mises eşdeğer gerilmesi ise üç eksenli gerilme durumunu tek bir skaler büyüklük olarak tanımlamak için kullanılır:

$$\sigma_{vm}=\sqrt{\frac{1}{2}[(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+3(\tau_{xy}^2+\tau_{yz}^2+\tau_{zx}^2)}$$

Bu ifade, karmaşık gerilme durumlarının malzemenin akma sınırı ile karşılaştırılmasında kullanılır. Eğer $\sigma_{vm}<\sigma_{yieldise}$ yapı güvenli kabul edilir.

3.2. Serbest Titreşim Sonlu Elemanlar Teorisi

Modal analiz, yapının doğal frekanslarını ve titreşim modlarını belirlemek amacıyla gerçekleştirilir. Bu analizde temel hareket denklemi şu şekilde ifade edilir:

$$[M]\{u\}+[K]\{u\}=0$$

Burada;

•$[M]$: sistemin kütle matrisi,

•$[K]$: rijitlik matrisi,

•$\{u\}$: yer değiştirme vektörüdür. Serbest titreşim çözümünde yer değiştirme, zamana bağlı bir harmonik fonksiyon olarak yazılır:

$$\{u(t)\}=\{\phi\}\sin(\omega t)$$

Bu ifade hareket denklemine yerleştirildiğinde şu özdeğer problemi elde edilir:

$$([K]-\omega^2[M])\{\phi\}=\{0\}$$

Burada;

• ω: doğal açısal frekans,

•$\{\phi\}$: titreşim mod şekli (mode shape)'dir.

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Bu denklem çözülerek yapının doğal frekansları ($fi = \omega i/2\pi$) ve mod şekilleri bulunur. Elde edilen frekanslar, motorların çalışma frekanslarıyla karşılaştırılarak rezonans riski değerlendirilir. Bu teorik temeller doğrultusunda oluşturulan matematiksel model, ANSYS Workbench ortamında üç boyutlu olarak çözülmüş, her bir eleman için rijitlik ve kütle matrisleri otomatik olarak hesaplanmıştır. Elde edilen sonuçlar sonraki bölümde statik ve modal analiz değerlendirmeleriyle sunulmuştur.

3.3. Sınır Koşulları Ve Yükleme

Statik analizde, drone'un dört motoruna etki eden itki kuvvetleri hesaplanarak modele uygulanmıştır. Her bir motordan elde edilen itki değeri 69,058 N olarak belirlenmiştir. Bu kuvvetler, motor yuvalarının alt yüzeylerine dik doğrultuda uygulanmıştır. Sonlu elemanlar analizinde kullanılan karbon fiber takviyeli polimer ve PLA malzemelerinin genel mekanik özellikleri Çizelge 1'de verilmiştir. Bu malzemeler, yüksek dayanım/ağırlık oranı ve üretim kolaylığı açısından seçilmiştir. Modelleme aşamasında bileşenler arasındaki temas bölgeleri "Bonded Contact" ve "No Separation Contact" olarak tanımlanmış, böylece bağlantı noktalarında ayrılma veya kayma olmadan kuvvet aktarımı sağlanmıştır.

Tasarım boyutları belirlenen modelin CAD verileri hazırlanarak ANSYS Workbench ortamına aktarılmıştır. Analiz sürecinde Static Structural ve Modal modülleri kullanılmıştır.

Her bir motor tarafından üretilen itme kuvveti aşağıda gösterildiği gibi hesaplanabilir:

$$P*D^3*RPM^2*10^{-10}=oz$$

Burada D pervanenin çapı, P pervanenin hatvesi, RPM motorun dakikada dönüş hızıdır. Analiz amacıyla alınan veriler:

- D= 18 inç
- P= 6 inç

$RPM = 400 * 22.2V$

(22.2 V- 6S pil kullanılmaktadır.)

$$5{,}5*18^3*(400*22.2)^2*10^{-10}=248.396544 \text{ oz}$$

Her motorun hesaplanan itme kuvveti 248.96544 oz'a eşittir. Newton olarak kullanacağımız için 248.96544 oz değeri 69,058 N olarak hesaplanmıştır. Analizde kullanılan itki değeri, 18×6 inç pervane ve 6S batarya ile çalışan yüksek itki kapasiteli fırçasız motorların üretici performans verileri dikkate alınarak belirlenmiştir.

Merkez gövdenin alt kısmı, uçuş sırasında sabit bir referans noktası olarak kabul edilerek "Fixed Support" koşulu altında sınırlandırılmıştır. Böylece analiz sırasında gövdenin konum sabitliği sağlanmıştır.

3.4. Sonlu Elemanlar Modeli Eleman Özellikleri

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Mesh kalitesi, analiz sonuçlarının güvenilirliği açısından değerlendirilmiştir. Yapılan incelemelerde iki temel kriter dikkate alınmıştır: Element Quality ve Skewness.

Element Quality değeri, mesh elemanlarının geometrik düzgünlüğünü ifade eden bir ölçüttür ve eleman hacmi ile kenar uzunlukları arasındaki oran dikkate alınarak hesaplanır. Değerin 1'e yaklaşması, eleman kalitesinin yüksek olduğunu göstermektedir. Bu çalışmada elde edilen ortalama Element Quality değeri 0,77521 olarak bulunmuştur.

Skewness kriteri ise elemanların ideal geometriden sapma miktarını ifade eder. Skewness değeri 0'a yaklaştıkça eleman şeklinin ideal olduğu kabul edilir. Analiz modelinde elde edilen maksimum Skewness değeri 0,92979'dur. Bu değer, literatürde kabul edilen sınır değerlerin altında olup mesh kalitesinin analiz için yeterli olduğunu göstermektedir.

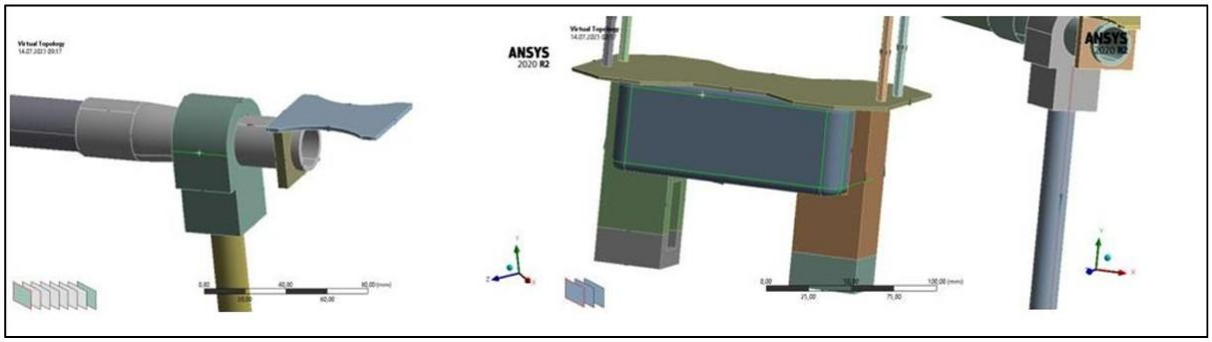
Bu mesh değerlendirme kriteri en çok kullanılan ve geçerli bir kriterdir.

$$Skewness = \frac{Optimum\ Eleman\ Boyutu\text{-}Aktif\ Eleman\ Boyutu}{Optimum\ Eleman\ Boyutu}$$

- 0.98 – 1 = Kabul edilemez bir mesh kalitesi
- 0.80 – 0.94 = Kabul edilebilir bir mesh kalitesi
- 0.25 – 0.50 =İyi bir mesh kalitesi olarak kabul edilir

Drone'a ait Skewness değeri maksimum 0,92979'dir. Bu da kabul edilebilir bir mesh kalitesi aralığında bulunmuştur.

Analiz öncesinde model üzerinde mesh işlemi gerçekleştirilmiştir. Mesh işlemi uygulanmadan önce, analiz sonuçlarına etkisi bulunmayan küçük delikler kapatılmış ve modelin topolojisi sadeleştirilmiştir. Mesh kalitesini artırmak amacıyla Virtual Topology yöntemi uygulanmış ve modelin geometrik sürekliliği iyileştirilmiştir. Uygulanan yöntemler Görsel 2 ve Görsel 3'te gösterilmiştir.



Görsel 2 Virtual Topology

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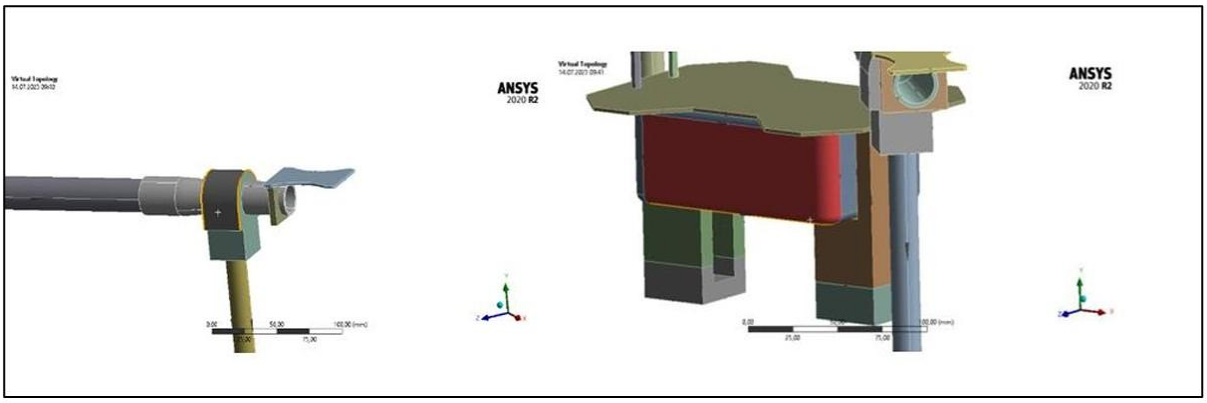
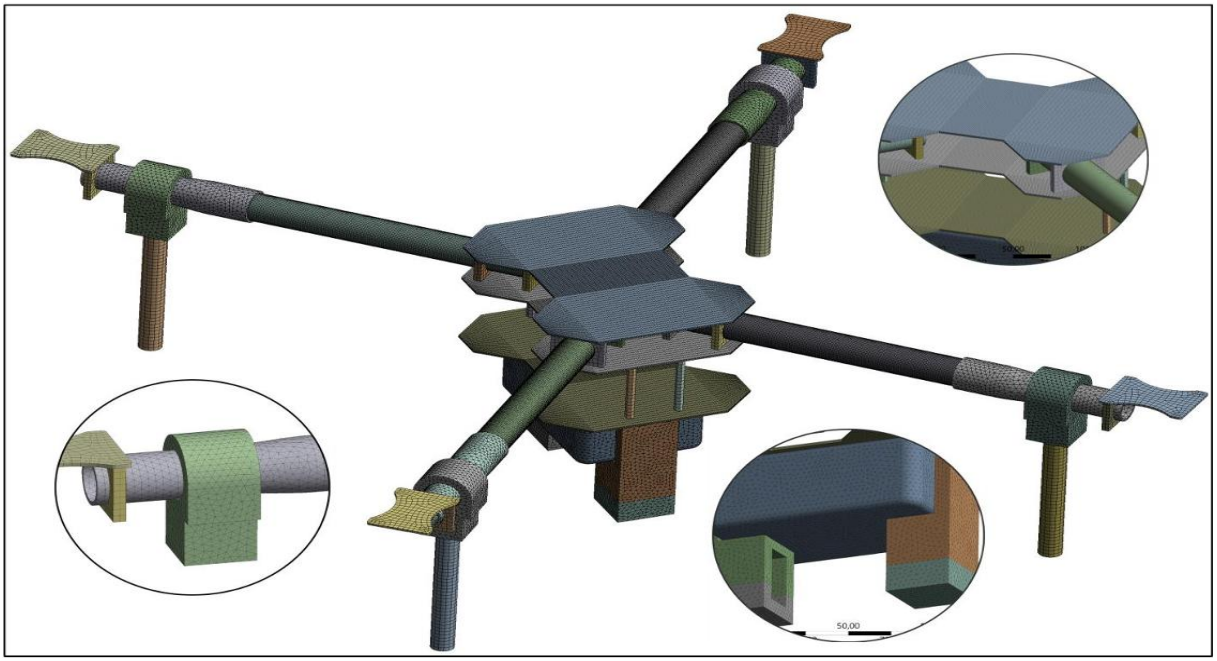


Görsel 3 Virtual Topology-2

Mesh oluşturma sürecinde global ve local mesh stratejileri kullanılmıştır. Gövde üzerinde kaliteyi düşüren yedi bölge belirlenmiş ve bu bölgelere "Body Sizing" yöntemiyle 1 mm eleman boyutu uygulanmıştır. Modelin diğer kısımlarında ise eleman boyutu 3.5 mm seçilerek mesh yoğunluğu ile çözüm süresi arasında denge sağlanmıştır. Oluşturulan ağ yapısı Görsel 4'te gösterilmiştir.



Görsel 4 Sonlu Elemanlar Modelinin Görünümü

Motorlardan elde edilen toplam itme kuvveti, her bir motora eşit olarak 69,058 N değerinde uygulanmıştır. Kuvvetler, drone'un ağırlığına zıt yönde ve motor eksenine dik doğrultuda tanımlanmıştır. Böylece, sistemin kalkış anındaki yük durumu modellenmiştir. Her bir motor tarafından oluşturulan bu kuvvetler ve sabit destek bölgeleri (Fixed Support), analiz ortamında

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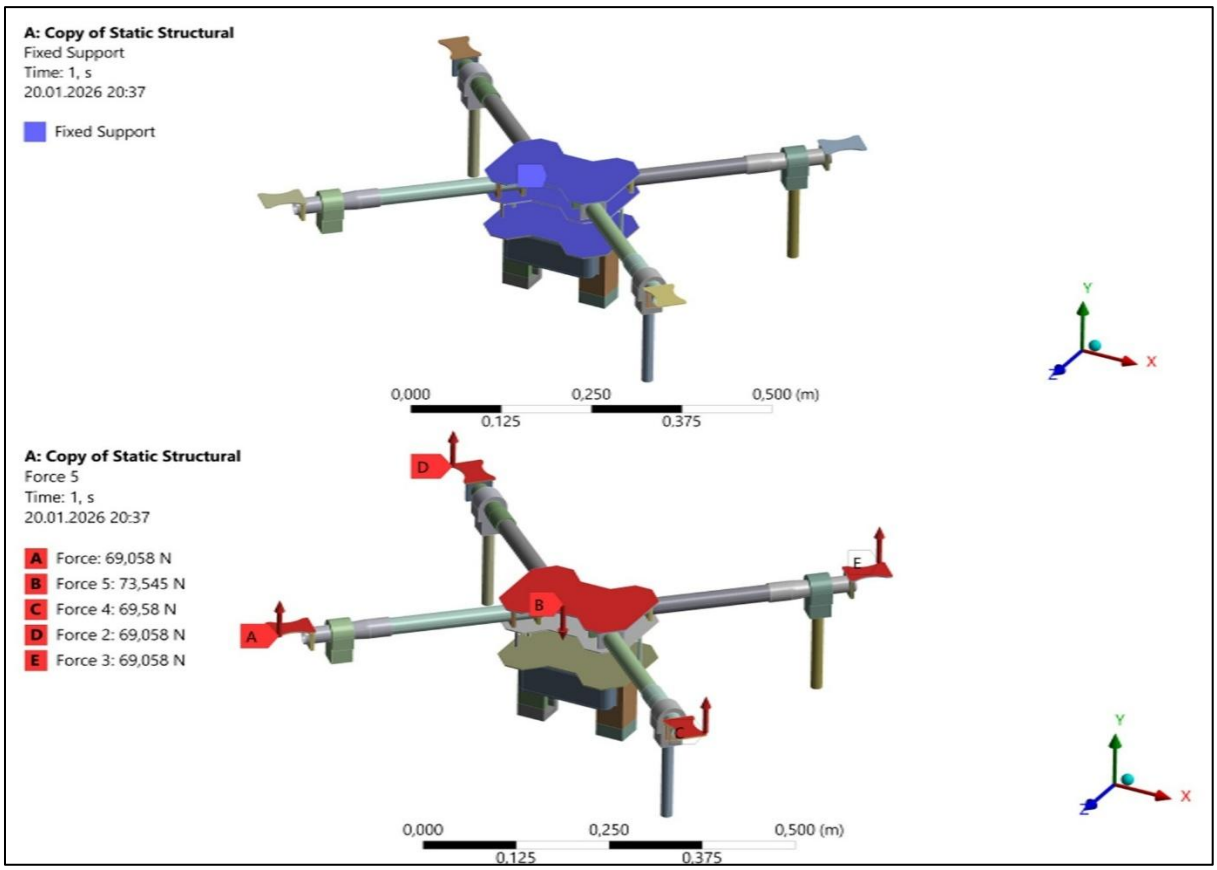
tanımlanmış ve Görsel 5'te gösterilmiştir. Gövdenin taban plakası, analizde referans yüzey olarak seçilmiş ve sabitlenerek yapının genel hareketi kısıtlanmıştır.



Görsel 5 Sınır Şartları ve Yükleme

Kolların iç kenar bölgelerinde maksimum toplam deformasyon 7,7697 mm olarak ölçülmüştür. Sabitlenen bölgelerde deformasyon sıfır olarak elde edilmiştir. Ortalama toplam deformasyon ise 0,67289 mm olarak hesaplanmıştır. Bu değer, yapının tam güç altında dahi elastik sınırlar içinde kaldığını ve genel rijitliğin uçuş koşulları için yeterli olduğunu göstermektedir.

Eşdeğer gerilme (Von Mises equivalent stress) dağılımı incelendiğinde, maksimum gerilme değeri 164,29 MPa olarak belirlenmiştir. Sabit destek bölgelerinde gerilme değeri 0 MPa olarak gözlenmiştir. Elde edilen maksimum gerilme değeri, karbon fiber takviyeli polimer malzemenin akma dayanımı olan 230 MPa'nın altında kalmaktadır. Bu sonuç, gövdenin uygulanan yükler altında kalıcı deformasyona veya kırılmaya maruz kalmadan çalışabileceğini ortaya koymaktadır.

Yapılan analizde elde edilen sonuçlar dikkate alındığında, gövde malzemesi, motor karakteristikleri (KV değeri) ve pervane boyutlarının tümü analizde etkili parametreler olarak değerlendirilmiştir. Gövde üzerindeki gerilme ve deformasyon değerleri, motorlardan üretilen itme kuvveti ve yapının geometrik özellikleriyle doğrudan orantılıdır.

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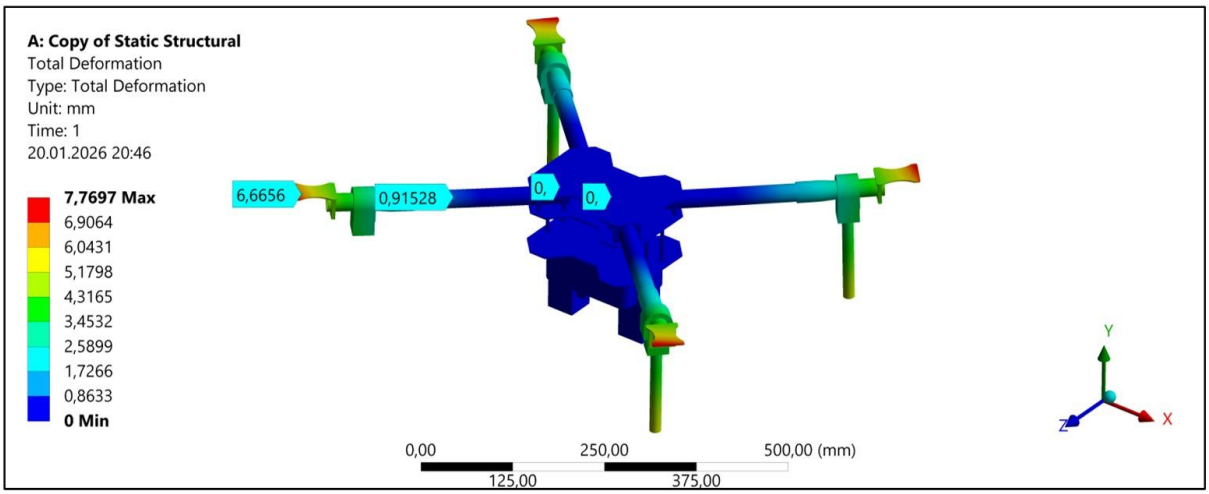
Elde edilen gerilme ve deformasyon konturları, gövdenin farklı yük koşullarında davranışını belirlemede önemli bir referans niteliğindedir. Bu konturlar, ilerleyen tasarım çalışmalarında farklı malzeme seçeneklerinin, kesit geometrilerinin ve destek konfigürasyonlarının değerlendirilmesine imkân tanımaktadır. Böylece, özel görev koşullarına uyarlanabilen daha dayanıklı ve optimize edilmiş gövde yapılarının tasarımı mümkün hale gelmektedir.

4. ANALİZ SONUÇLARI

Bu çalışmada, cam temizleme uygulamalarına yönelik olarak tasarlanan quadcopter gövdesinin dayanımı Sonlu Elemanlar Yöntemi (FEM) kullanılarak değerlendirilmiştir. Analizler ANSYS Workbench yazılımı üzerinde gerçekleştirilmiş ve elde edilen sonuçlar drone gövdesinin genel mekanik davranışını ortaya koymuştur.

Statik analiz sonuçlarına göre, motorlardan uygulanan 69,058 N değerinde itki kuvveti altında yapıda maksimum toplam deformasyon 7,77 mm, ortalama deformasyon ise 0,67 mm olarak elde edilmiştir. Deformasyonun en yoğun olduğu bölgeler, kolların uç kısımları ve motor bağlantı noktalarıdır. Bu durum, bu bölgelerin yük aktarımında kritik rol oynadığını göstermektedir. Drone'un verilen yükleme şartlarına göre toplam yer değiştirme analizi Görsel 6'da verilmiştir.



Görsel 6 Drone'un Toplam Yer Değiştirme Sonucu

Eşdeğer (Von Mises) gerilme dağılımı incelendiğinde, maksimum gerilme değeri 164,29 MPa olarak belirlenmiştir. Bu değer, kullanılan karbon fiber takviyeli polimer malzemenin akma dayanımı olan 230 MPa'nın altında kalmaktadır. Drone'un verilen yükleme şartlarına göre gerilme analizi Görsel 7'de verilmiştir. Dolayısıyla yapı elastik sınırlar içinde kalmakta ve yük altında kalıcı şekil değişimi oluşmamaktadır.

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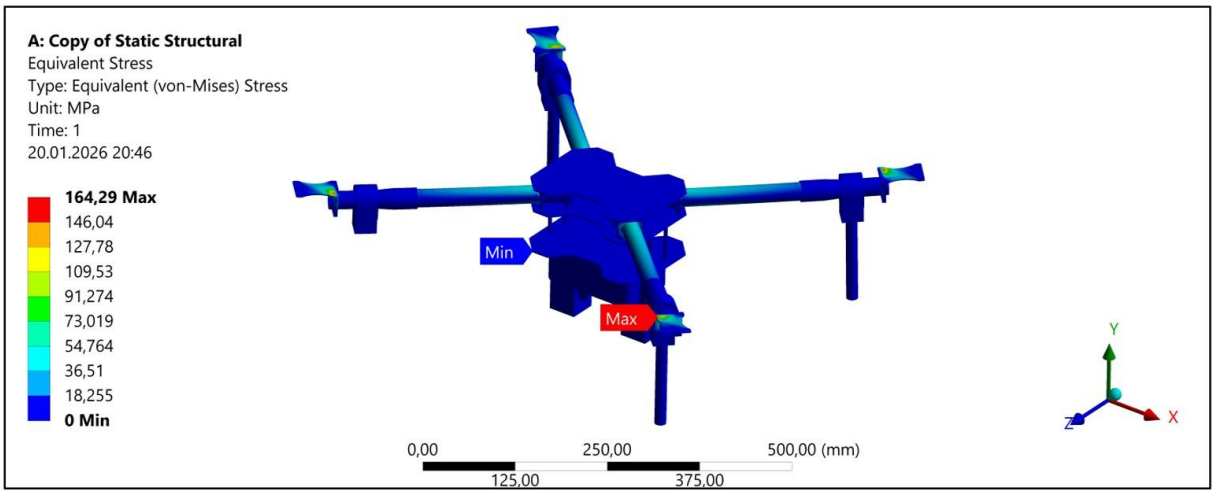

Görsel 7 Drone'un Von Mises Gerilme Dağılımı

Genel olarak değerlendirildiğinde, analizler sonucunda tasarlanan drone gövdesinin belirlenen yükleme koşulları altında yeterli rijitlik ve dayanım gösterdiği tespit edilmiştir. Gövde yapısında herhangi bir kritik bölgeye ilişkin aşırı gerilme veya malzeme sınırlarını aşan deformasyon görülmemiştir. Bu bulgular, tasarımın pratik uygulamalar için uygun olduğunu ortaya koymaktadır.

Drone üzerinde uygulanan statik yükler nedeniyle yapıda aynı zamanda titreşim etkilerinin oluştuğu görülmüştür. Bu kapsamda, motorların ürettiği itki kuvvetleri altında gövdenin dinamik davranışını incelemek amacıyla ön gerilmeli (pre-stress) modal analiz gerçekleştirilmiştir. Analizde her bir motor için 69,058 N'luk itki kuvveti tanımlanmış ve bu yükleme koşulları altında toplam altı mod için frekans hesaplamaları yapılmıştır. Elde edilen mod frekansları incelendiğinde, düşük frekanslı ilk modda gövdede genel bir bükülme eğiliminin ortaya çıktığı, orta frekanslara doğru ilerledikçe kollar üzerinde lokal titreşimlerin belirginleştiği ve daha yüksek frekanslarda burulma etkilerinin baskın hale geldiği anlaşılmıştır. En yüksek frekans değerine sahip altıncı modda ise titreşim genliğinin özellikle lineer motor bağlantısının uç kısmında yoğunlaştığı tespit edilmiştir. Bu bölgedeki yer değiştirme miktarının diğer noktalara kıyasla daha yüksek olması, yapısal tasarımda dikkate alınması gereken kritik bir bölge olduğunu göstermektedir.

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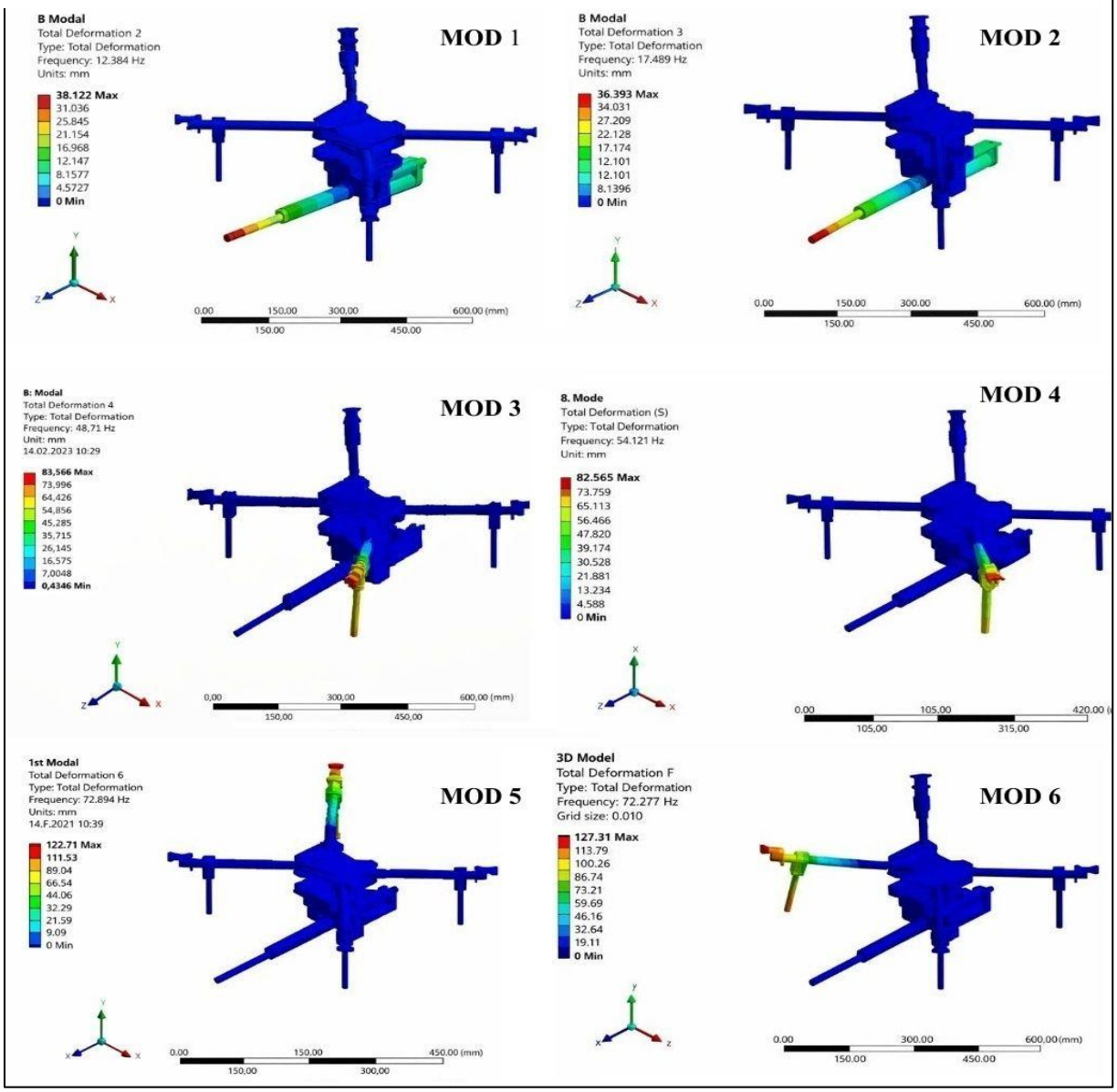
Görsel 8 Modal Analiz Total Deformasyon Mod Görünümleri



Yapılan analizler sonucunda farklı modlarda elde edilen frekans değerleri Çizelge 2'de verilmiştir. Bu frekanslara karşılık gelen titreşim davranış biçimleri ise Görsel 8'de gösterilmiştir.

Çizelge 2 Doğal Frekans Değerleri

MOD NO	DOĞAL FREKANS (HZ)
1	12,38 Hz
2	17,48 Hz
3	49,71 Hz
4	54,12 Hz
5	72,89 Hz
6	72.27 Hz

5. GENEL DEĞERLENDİRME VE SONUÇLAR

Bu çalışmada cam temizleme için bir dron tarasarımı gerçekleştirilmiş. Tasarımı yapılan dronun yapısal analiz ve titreşim analizleri gerçekleştirilmiştir. Sonuç olarak, gerçekleştirilen sonlu elemanlar analizi, tasarlanan quadcopter gövdesinin operasyonel koşullar altında güvenli ve kararlı bir davranış sergilediğini göstermiştir. Bu çalışma, gelecekte yapılacak deneysel doğrulama ve tasarım optimizasyonu çalışmaları için sağlam bir temel oluşturmaktadır. Bununla birlikte faydalık yüklerin artırılması durumunda tasarım üzerinde aşağıda belirtilen öneri ve yapısal değişiklikler yapılarak yeni koşullara dayanaklı modellerin oluşturulmasına olanak sağlanabilir:

- Kolların uç kısımlarında oluşan gerilme birikimlerinin azaltılması için, bu bölgelerde lokal kalınlık artırımı veya malzeme takviyesi yapılması önerilmektedir.

- Farklı malzeme seçeneklerinin (örneğin alüminyum veya kompozit hibrit yapılar) incelenmesi hem ağırlık hem de dayanım açısından optimizasyon sağlayabilir.

- Ayrıca dinamik yükler, motor titreşimleri ve çevresel etkiler dikkate alınarak sistemin yorulma ömrü analizleri yapılabilir.

Analiz sonuçlarından elde edilen bilgiler ışığında sistemin deneysel modellenmesine geçilmiş olup ileriki çalışmalarda, modelin gerçek üretim geometrisi üzerinden elde edilecek prototip verileriyle sayısal sonuçların karşılaştırılması gerçekleştirilecektir.

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ISBN NR: 978-625-5694-92-8

SABİT KANATLI MİNİ İHA SİSTEMLERİNİN AHP YAKLAŞIMIYLA PERFORMANS DEĞERLENDİRMESİ

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ÖZET

İnsansız hava araçları (İHA), son yıllarda askeri, sivil ve endüstriyel alanlarda giderek daha yaygın şekilde kullanılmaktadır. Özellikle sabit kanatlı mini İHA sistemleri; uzun uçuş süreleri, geniş operasyonel menzil ve yüksek irtifa kabiliyetleri sayesinde keşif, gözetleme ve veri toplama görevlerinde önemli avantajlar sunmaktadır. Ancak farklı üreticiler tarafından geliştirilen İHA sistemlerinin teknik özellikleri ve operasyonel performansları arasında önemli farklılıklar bulunmaktadır. Bu nedenle uygun İHA platformunun seçimi çok kriterli bir karar problemi olarak ele alınmaktadır. Bu çalışmada sabit kanatlı mini İHA sistemlerinin genel performanslarının karşılaştırılması amacıyla Analitik Hiyerarşi Prosesi (AHP) yöntemi kullanılmıştır. Çalışmada beş farklı İHA sistemi değerlendirilmiştir. Değerlendirme kriterleri olarak operasyonel menzil, uçuş süresi, maksimum irtifa, maksimum kalkış ağırlığı ve kanat açıklığı dikkate alınmıştır. AHP yöntemi ile kriter ağırlıkları belirlenmiş ve alternatif İHA sistemlerinin performans skorları hesaplanmıştır. Analiz sonuçlarına göre en yüksek performans skoruna sahip İHA platformunun İHA-5 olduğu belirlenmiştir.

Elde edilen sonuçlar, çok kriterli karar verme yöntemlerinin İHA platformlarının sistematik değerlendirilmesinde etkili bir araç olduğunu ve benzer sistemlerin değerlendirilmesinde de uygulanabilirliğini göstermek adına örnek bir çalışma olarak sunulmuştur.

Anahtar Kelimeler : İnsansız hava aracı, AHP, Çok kriterli karar verme, Performans değerlendirmesi, Mini İHA

1.GİRİŞ

İnsansız hava araçları (İHA), son yıllarda havacılık teknolojilerinin en hızlı gelişen alanlarından biri haline gelmiştir. İHA sistemleri askeri operasyonlardan afet yönetimine, tarımsal izleme faaliyetlerinden çevresel gözleme kadar çok geniş bir kullanım alanına sahiptir [1]. Özellikle sabit kanatlı mini İHA platformları, düşük operasyon maliyetleri ve yüksek operasyonel esneklikleri sayesinde birçok görev için tercih edilmektedir [2].

Sabit kanatlı mini İHA sistemleri, döner kanatlı sistemlere kıyasla daha uzun uçuş süreleri ve daha geniş operasyonel menzil sağlayabilmektedir. Bu özellikler özellikle keşif, gözetleme ve

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sınır güvenliği gibi görevlerde önemli avantajlar sunmaktadır. Bununla birlikte, farklı üreticiler tarafından geliştirilen İHA sistemlerinin teknik özellikleri ve performans parametreleri önemli ölçüde farklılık gösterebilmektedir.

Bu durum, uygun İHA platformunun seçimini karmaşık bir karar problemi haline getirmektedir. Bu tür problemlerde birden fazla kriterin aynı anda değerlendirilmesi gerekmektedir. Bu nedenle çok kriterli karar verme (ÇKKV) yöntemleri, mühendislik sistemlerinin değerlendirilmesinde yaygın olarak kullanılmaktadır.

Hamurcu ve ark. AHP-TOPSIS yöntemleri çerçevesinde savunma amaçlı kriterlerle İHA seçimi için analizler uygulamıştır. 7 kriter ikili kıyaslamalarla AHP yöntemi ile ağırlıklandırılmıştır. Bu ağırlıklar 6 İHA için TOPSIS yöntemi ile analiz edilerek en performanslı alternatif belirlenmiştir [3].

Özge yüksek lisans tezinde iç güvenlik kullanımı için 5 farklı İHA nın arasından harekâtlarda kullanmak amacıyla en iyi olanın seçiminde ÇKKV yöntemlerinden AHP yi kullanmıştır. Seçimde alt kriterleri olan 6 kriter kullanılmıştır [4].

Rodriguez ve Lozana, askerî eğitim amaçlı uçak seçiminde AHP yöntemini kullanarak 13 farklı kriter ile analiz etmiştir. AHP ağırlıkları FRIM ve RIM metodlarında kullanılarak 4 eğitim amaçlı askerî uçak arasından en iyisi elde edilmiştir [5].

Genç ELECTRE III ve PROMETHEE II metodlarını kullanarak 6 askerî tankın 7 kriter ışığında kıyaslamalı değerlendirilmesini yapmıştır [6].

Çarman ve ark. ülkedeki şehre ait yerlerin gözlenmesi amacıyla belli sistemlerin yerleştirilmesi için matematiksel modelde ağırlıkları belirlemek amacıyla AHP yöntemi kullanılmıştır [7].

Eren ve Uçakçıoğlu havacılık sektörüne ait bir firmanın savunma sanayii bünyesinde yer alan 8 alternatif yatırım projesinin en iyisinin seçimini yapmak için VIKOR ve AHP metodlarından faydalanmıştır. Araştırmada kriterler olarak proje seçimini etkileyen ekonomik katkı, personel sayısı, bağımlılık durumu, süre ve bütçe belirlenmiştir. Proje, kriter ağırlıkları hesaplanarak skorlanmıştır [8].

Ulucan 4 farklı İHA arasından sivil ve askerî görevler için en iyisinin seçimini Delphi metodu ile araştırmıştır. 10 farklı kriterin belirlenmesinde uzman görüşleri doğrultusunda hareket edilmiştir. Alternatif belirlenmesinde sezgisel olarak ve sistemlerin simülasyonunu yaparak İHA alternatifleri tasarlanmıştır. Ortam belirsizlikleri de araştırmaya dahil edilmiştir. Bunun için elde edilmek istenen sıralama Gri İlişkisel Analizle elde edilmiştir [9].

Lin ve ark. askerî ihtiyaçlara uygun İHA seçimi için bilgisayar esaslı ara yüz ağırlıklandırılmış bulanık ortalamayla elde edilmiştir. Bu metodla en efektif ve ideal seçimi karar vericilerin belirlemesinde pratik bir çözüm sunulmuştur [10].

Analitik Hiyerarşi Prosesi (AHP), çok kriterli karar verme yöntemleri arasında en yaygın kullanılan yaklaşımlardan biridir. AHP yöntemi karmaşık karar problemlerini hiyerarşik bir yapı içerisinde modelleyerek kriterlerin göreli önemlerinin belirlenmesini ve alternatiflerin sıralanmasını mümkün kılmaktadır [11-13].

Bu çalışmada sabit kanatlı mini İHA sistemlerinin genel performanslarının değerlendirilmesi amacıyla AHP yöntemi kullanılmıştır. Çalışmada beş farklı İHA platformu belirlenen performans kriterlerine göre karşılaştırılmış ve en uygun sistem belirlenmiştir.

ISBN NR: 978-625-5694-92-8

2. MATERİALS AND METHODS

2.1. Alternatif İHA Sistemleri

Bu çalışmada sabit kanatlı mini insansız hava araçlarının performanslarının karşılaştırılması amacıyla farklı üreticiler tarafından geliştirilmiş beş farklı İHA platformu değerlendirilmiştir. Seçilen platformlar benzer operasyonel sınıfta yer alan ve literatürde yaygın olarak kullanılan mini İHA sistemleri arasından belirlenmiştir. Bu sistemlerin seçilmesindeki temel amaç, farklı teknik özelliklere sahip platformların çok kriterli bir karar verme yöntemi ile karşılaştırılmasını sağlamaktır.

Değerlendirmeye dahil edilen İHA sistemlerine ait temel teknik özellikler Çizelge 1'de sunulmuştur [14]. Bu özellikler, platformların operasyonel performansını belirleyen önemli parametreleri içermektedir. İHA sistemlerinin karşılaştırılmasında kullanılan teknik veriler üretici firmalar tarafından yayımlanan teknik dokümanlardan ve açık kaynaklardan elde edilmiştir.

Çizelge 1. Mini Sabit Kanatlı İHA Sistemlerinin Teknik Özellikleri

İHA	Kanat Açıklığı (m)	Menzil (km)	İrtifa (m)	Uçuş Süresi (dk)	MTOW (kg)
İHA -1	3.0	20	457	240	11
İHA -2	3.2	20	500	120	12
İHA -3	2.0	15	1000	80	3.5
İHA -4	2.0	15	5000	90	4
İHA -5	1.9	45	1500	150	5.5

İHA platformlarının performans değerlendirmesinde farklı operasyonel özellikleri temsil eden beş kriter dikkate alınmıştır. Bu kriterler İHA sistemlerinin uçuş kabiliyeti, operasyonel etkinliği ve aerodinamik özelliklerini temsil eden temel parametrelerden oluşmaktadır.

Çizelge 2. Değerlendirme Kriterleri

Kriter	Açıklama
Menzil	İHA'nın operasyonel uçuş mesafesi
Uçuş Süresi	Maksimum havada kalma süresi
Maksimum İrtifa	Ulaşılabilecek maksimum uçuş yüksekliği
MTOW	Maksimum kalkış ağırlığı
Kanat Açıklığı	Aerodinamik performansı etkileyen parametre

Bu kriterlerden menzil, uçuş süresi, maksimum irtifa ve kanat açıklığı fayda kriteri, maksimum kalkış ağırlığı ise maliyet kriteri olarak değerlendirilmiştir. Fayda kriterlerinde daha yüksek değerler tercih edilirken, maliyet kriterlerinde daha düşük değerler daha avantajlı kabul edilmektedir.

2.2. Değerlendirme Kriterleri

İnsansız hava araçlarının operasyonel performanslarının değerlendirilmesinde çok sayıda teknik parametre dikkate alınmaktadır. Bu çalışmada mini sabit kanatlı İHA sistemlerinin

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performanslarını karşılaştırabilmek amacıyla literatürde yaygın olarak kullanılan ve operasyonel etkinliği doğrudan etkileyen beş temel kriter belirlenmiştir. Bu kriterler menzil, uçuş süresi, maksimum irtifa, maksimum kalkış ağırlığı (MTOW) ve kanat açıklığıdır.
Seçilen kriterler, İHA sistemlerinin görev etkinliği, aerodinamik performansı ve operasyonel kabiliyetlerini temsil edecek şekilde belirlenmiştir. Değerlendirme sürecinde kriterlerin karar üzerindeki göreli önemleri Analitik Hiyerarşi Prosesi (AHP) yöntemi kullanılarak belirlenmiştir.
Çalışmada kullanılan kriterlerin açıklamaları aşağıda verilmiştir.

Menzil (Range), bir İHA'nın kontrol istasyonundan uzaklaşabileceği maksimum operasyonel mesafeyi ifade etmektedir. Özellikle keşif, gözetleme ve uzun mesafeli görevlerde menzil kritik bir performans göstergesidir. Daha yüksek menzil değerine sahip sistemler daha geniş alanların izlenmesine olanak sağlamaktadır.

Uçuş süresi (Endurance), bir İHA'nın yakıt veya enerji kapasitesine bağlı olarak havada kalabildiği maksimum süreyi ifade etmektedir. Uzun uçuş süresi, özellikle sürekli gözetleme ve keşif görevlerinde operasyonel avantaj sağlamaktadır. Bu nedenle uçuş süresi performans değerlendirmesinde önemli bir kriter olarak ele alınmıştır.

Maksimum irtifa (Maximum Altitude), İHA'nın ulaşabileceği en yüksek operasyonel uçuş yüksekliğini göstermektedir. Yüksek irtifa kabiliyeti, daha geniş görüş alanı elde edilmesini ve bazı hava koşullarından daha az etkilenerek görev yapılmasını sağlayabilmektedir.

Maksimum kalkış ağırlığı (MTOW), bir İHA'nın kalkış sırasında taşıyabileceği toplam ağırlığı ifade etmektedir. Bu ağırlık; hava aracı yapısı, yakıt veya batarya kapasitesi ile faydalı yükleri kapsamaktadır. Ancak yüksek MTOW değeri sistemin taşınabilirliğini ve operasyonel esnekliğini azaltabileceği için bu kriter çalışmada maliyet kriteri olarak değerlendirilmiştir.

Kanat açıklığı (Wingspan), İHA'nın aerodinamik performansını doğrudan etkileyen önemli bir tasarım parametresidir. Daha büyük kanat açıklığı genellikle daha iyi süzülme performansı ve enerji verimliliği sağlayabilmektedir. Bu nedenle kanat açıklığı da değerlendirme sürecinde dikkate alınan kriterler arasında yer almaktadır.

Bu çalışmada menzil, uçuş süresi, maksimum irtifa ve kanat açıklığı kriterleri fayda kriteri, maksimum kalkış ağırlığı ise maliyet kriteri olarak değerlendirilmiştir. Fayda kriterlerinde yüksek değerler tercih edilirken, maliyet kriterlerinde daha düşük değerler daha avantajlı kabul edilmektedir. Bu kriterler kullanılarak alternatif İHA sistemlerinin performansları Analitik Hiyerarşi Prosesi yöntemi ile karşılaştırılmıştır.

3. AHP YAKLAŞIMI VE DEĞERLENDİRMELER

AHP, karmaşık karar problemlerinin analiz edilmesinde kullanılan en yaygın çok kriterli karar verme yöntemlerinden biridir. Yöntem ilk olarak Saaty tarafından geliştirilmiş olup karar vericilerin farklı kriterleri sistematik bir şekilde değerlendirmesine olanak sağlamaktadır. AHP yöntemi, karar problemlerinin hiyerarşik bir yapı içerisinde modellenmesine ve kriterler ile alternatiflerin göreli önemlerinin belirlenmesine olanak tanımaktadır.

AHP yöntemi aşağıdaki aşamalardan oluşmaktadır:

ISBN NR: 978-625-5694-92-8

-Problem için hiyerarşik yapı oluşturulması
-Kriterler için ikili karşılaştırma matrislerinin oluşturulması
-Kriter ağırlıklarının hesaplanması
-Tutarlılık oranının hesaplanması
-Alternatiflerin performans değerlerinin normalize edilmesi
-Nihai performans skorlarının hesaplanması

Kriterler arasındaki göreli önem dereceleri belirlenirken Saaty tarafından geliştirilen 1–9 ölçeği kullanılmıştır. Bu ölçekte 1 değeri iki kriterin eşit derecede önemli olduğunu ifade ederken, 9 değeri bir kriterin diğerine göre son derece daha önemli olduğunu göstermektedir.

AHP yönteminde kriter karşılaştırmaları sonucunda elde edilen matrislerin tutarlılığının kontrol edilmesi gerekmektedir. Bu amaçla tutarlılık indeksi (CI) ve tutarlılık oranı (CR) hesaplanmaktadır. Tutarlılık indeksi aşağıdaki eşitlik ile hesaplanmaktadır.

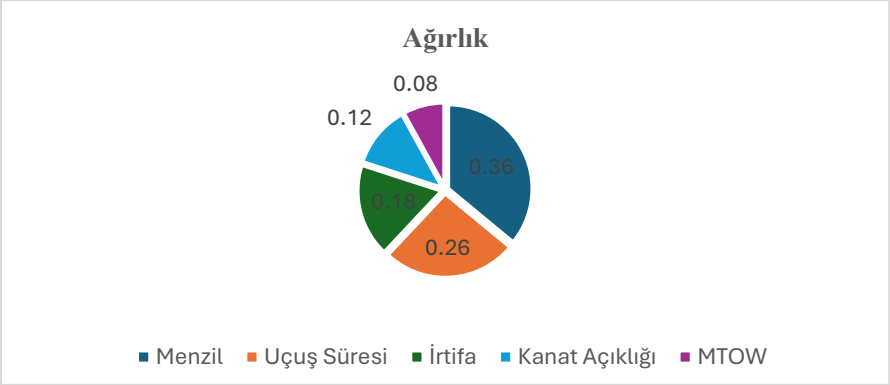
$$CI = \frac{\lambda_{max} - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

Burada n kriter sayısı, CI tutarlılık indeksi, CR tutarlılık oranı ve RI rastgele indeks değerini ifade etmektedir. AHP yönteminde CR < 0.10 olması durumunda karşılaştırma matrisinin tutarlı olduğu kabul edilmektedir.

Bu çalışmada AHP yöntemi kullanılarak sabit kanatlı mini İHA sistemlerinin performansları karşılaştırılmıştır. Karar problemi üç seviyeli bir hiyerarşik yapı içerisinde modellenmiştir. Hiyerarşinin en üst seviyesinde çalışmanın amacı yer almakta olup, orta seviyede değerlendirme kriterleri ve en alt seviyede alternatif İHA sistemleri bulunmaktadır.

Kriterler arasındaki ikili karşılaştırmalar sonucunda kriterlerin göreli önem ağırlıkları hesaplanmış ve sonuçlar Görsel 1'de verilmiştir.



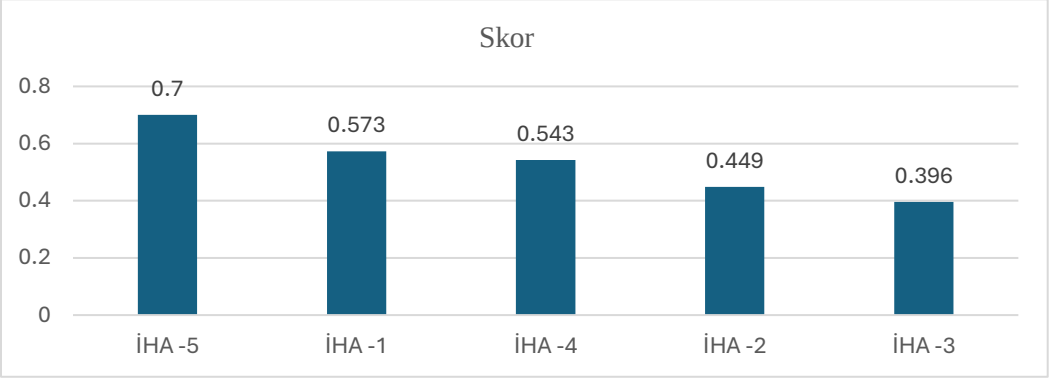
Görsel 1. Kriter Ağırlıkları

Analiz sonuçlarına göre en önemli kriterin menzil olduğu belirlenmiştir. Bu kriteri sırasıyla uçuş süresi, maksimum irtifa, kanat açıklığı ve maksimum kalkış ağırlığı kriterleri takip etmektedir. Menzil ve uçuş süresi kriterlerinin yüksek ağırlıklara sahip olması, sabit kanatlı

ISBN NR: 978-625-5694-92-8

mini İHA sistemlerinin operasyonel performansının büyük ölçüde uçuş süresi ve görev menziline bağlı olduğunu göstermektedir.
Belirlenen kriter ağırlıkları kullanılarak alternatif İHA sistemlerinin performans değerleri hesaplanmıştır. Her bir alternatif için normalize edilmiş kriter değerleri ilgili kriter ağırlıkları ile çarpılarak toplam performans skorları elde edilmiştir. Bu işlem sonucunda alternatif İHA sistemlerinin nihai performans skorları hesaplanmış ve sıralama elde edilmiştir.

Elde edilen sonuçlar Görsel 2'de gösterilmektedir.



Görsel 2. AHP Analiziyle Elde Edilen Skorlar

Görsel 2 incelendiğinde alternatif İHA sistemlerinin performans skorları arasında belirgin farklılıklar olduğu görülmektedir. Analiz sonuçlarına göre en yüksek performans skoruna sahip platform İHA-5 olarak belirlenmiştir. Bu platform özellikle yüksek operasyonel menzil ve dengeli performans parametreleri sayesinde diğer alternatiflere göre daha avantajlı bir konumda yer almaktadır.

4. SONUÇ

Bu çalışmada sabit kanatlı mini insansız hava araçlarının performans değerlendirmesi Analitik Hiyerarşi Prosesi yöntemi kullanılarak gerçekleştirilmiştir. Çalışmada beş farklı İHA sistemi beş farklı performans kriteri açısından değerlendirilmiştir.
AHP analizi sonucunda kriter ağırlıkları belirlenmiş ve alternatif İHA sistemlerinin genel performans skorları hesaplanmıştır. Analiz sonuçlarına göre İHA-5 olarak kodlanan marka en yüksek performans değerine sahip platform olarak belirlenmiştir. Bu sonuç, özellikle yüksek operasyonel menzil ve dengeli performans parametreleri sayesinde elde edilmiştir.
Çalışma sonuçları çok kriterli karar verme yöntemlerinin insansız hava aracı sistemlerinin performans değerlendirilmesinde etkili bir yöntem olduğunu göstermektedir. Gelecekte yapılacak çalışmalarda farklı performans kriterlerinin ve farklı çok kriterli karar verme yöntemlerinin birlikte kullanılması daha kapsamlı değerlendirmeler yapılmasına katkı sağlayabilir.

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ISBN NR: 978-625-5694-92-8

KÜÇÜK İNSANSIZ HAVA ARAÇLARI İÇİN KARBON/EPOKSİ KOMPOZİT MALZEME SEÇİMİ

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ÖZET

İnsansız hava araçlarının (İHA) yapısal tasarımında kullanılan kompozit malzemeler, platformun ağırlık, dayanım ve aerodinamik performansı üzerinde doğrudan etkilidir. Karbon fiber takviyeli epoksi kompozitler yüksek mukavemet ve ağırlık oranları nedeniyle havacılık uygulamalarında yaygın olarak tercih edilmektedir. Bu çalışmada küçük boyutlu İHA platformları için uygun karbon/epoksi kompozit malzemelerin belirlenmesi amacıyla Analitik Hiyerarşi Prosesi (AHP) yöntemi kullanılmıştır. Çalışmada bu amacı gerçekleştirmek için beş farklı karbon/epoksi kompozit malzeme alternatifi değerlendirilmiştir. Malzeme seçiminde çekme dayanımı, elastisite modülü, gerilim değerleri ve maliyet değeri kriter olarak ele alınmıştır. AHP yöntemi kullanılarak kriter ağırlıkları belirlenmiş ve alternatif malzemelerin performans skorları hesaplanmıştır. Elde edilen sonuçlara göre IM7/8551-7 kompozit malzemesinin İHA yapısal uygulamaları için en uygun alternatif olduğu belirlenmiştir.

Bu çalışma İHA gibi stratejik araçların efektif çalışmasına katkıda bulunabilecek malzemeler konusunda araştırma yapan profesyoneller için çok kriterli karar verme yöntemleri ile yapılabilecek analizlere örnek bir uygulama olarak sunulmuştur.

Anahtar Kelimeler : Çok kriterli karar verme, İnsansız hava aracı, Malzeme dayanımı, Küçük İHA, Performans değerlendirmesi

1.GİRİŞ

İnsansız hava araçları (İHA), son yıllarda askeri, sivil ve ticari alanlarda yaygın olarak kullanılmaktadır. Bu sistemlerin performansını belirleyen en önemli faktörlerden biri yapısal tasarımda kullanılan malzemelerdir. İHA platformlarında kullanılan malzemelerin yüksek mukavemet, düşük ağırlık ve iyi yorulma dayanımı gibi özelliklere sahip olması gerekmektedir [1-3]. Günümüz mühendislik uygulamalarında, özellikle yüksek performans ve hafiflik gerektiren savunma, havacılık, denizcilik, otomotiv ve spor ekipmanları gibi birçok ileri teknoloji sektöründe, geleneksel malzemelere (çelik, alüminyum) güçlü bir alternatif olarak karbon fiber takviyeli epoksi kompozit malzemeler ön plana çıkmaktadır. Bu malzemeler, karbon fiberlerin sağladığı üstün mekanik özellikler ile epoksi reçine matrisinin kimyasal dayanıklılık ve şekillendirilebilirlik avantajlarını bir araya getirir. Kompozit malzemeler

ISBN NR: 978-625-5694-92-8

özellikle havacılık sektöründe yüksek özgül mukavemet ve özgül rijitlik değerleri nedeniyle önemli bir yere sahiptir. Karbon fiber takviyeli epoksi kompozitler, sahip oldukları yüksek özgül mukavemet (ağırlığına oranla mukavemet) ve yüksek özgül elastisite modülü sayesinde, aynı mukavemet değerlerine sahip metalik malzemelere kıyasla %40-70 oranında ağırlık tasarrufu sağlama potansiyeline sahiptir. Bunun yanı sıra, mükemmel yorulma dayanımı, üstün korozyon ve kimyasal direnç, düşük ısıl genleşme katsayısı ve tasarım esnekliği gibi avantajlar sunarlar. Bu özellikler, mühendislerin parça birleştirme sayısını azaltan, aerodinamik ve estetik açıdan optimize edilmiş, kompleks geometrili yapıları tek bir operasyonda üretebilmesine olanak tanımaktadır. Karbon fiber takviyeli epoksi kompozitler, düşük yoğunlukları ve yüksek mekanik performansları sayesinde İHA gövde ve kanat yapılarında da yaygın olarak kullanılmaktadır [4, 5].

Ancak, bu üstün performans özelliklerinin yanında, İHA platformlarında karbon fiber takviyeli epoksi kompozit malzemelerin kullanımına dair bazı önemli avantaj ve kısıtlamalar da bulunmaktadır.

İHA'larda her bir kilogram ağırlık tasarrufu, doğrudan daha uzun havada kalış süresi, artırılmış faydalı yük kapasitesi (kamera, sensör, mühimmat) ve gelişmiş manevra kabiliyeti anlamına gelmektedir. Karbon fiber epoksi kompozitler, yüksek özgül mukavemetleri sayesinde, gövde, kanat ve kuyruk gibi ana yapısal elemanlarda önemli ağırlık azaltımı sağlayarak İHA'ların operasyonel performansını üst seviyeye taşır.

İHA'lar, özellikle zorlu çevre koşullarında (deniz üstü görevler, yüksek irtifa, sıcak-soğuk döngüleri) görev yapmaktadır. Karbon fiber kompozitlerin mükemmel korozyon ve yorulma direnci, metalik yapılarda sıkça rastlanan yorulma çatlakları ve korozyon problemlerini ortadan kaldırır. Bu durum, filodaki İHA'ların bakım periyotlarını uzatır, bakım maliyetlerini düşürür ve operasyonel hazır bulunurluğu artırır.

Kompozit üretim teknikleri, aerodinamik verimliliği en üst düzeye çıkaran karmaşık kanat profillerinin ve gövde formlarının üretilmesine imkan tanır. Ayrıca, antenler, sensörler veya yakıt tankları gibi bileşenlerin yapısal elemanlara entegre edilmesi (gömülü antenler, integral yakıt tankları) mümkün hale gelir. Bu fonksiyonel entegrasyon, parça sayısını azaltır, montaj süresini kısaltır ve sistem güvenilirliğini artırır.

Karbon fiber kompozitler, belirli tasarım ve üretim teknikleri ile radar soğurucu özellikte (RAM - Radar Absorbing Material) üretilebilmekte veya kaplanabilmektedir. Bu özellik, özellikle askeri İHAlar için hayati önem taşıyan düşük radar izi (stealth) gereksinimini karşılamada kritik rol oynar. Ayrıca, karbon fiber malzemeler, içindeki anten ve sensörlerin çalışmasını engellemeyecek şekilde tasarlanabilir.

Ancak bazı dezavantajlarıda göz önünde bulundurulmalıdır.

Havacılık sınıfı karbon fiber prepreg malzemeler ve otoklav gibi özel üretim ekipmanları, geleneksel metal işlemeye kıyasla daha yüksek ilk yatırım ve malzeme maliyeti gerektirir. İhale değerlendirmelerinde, bu yüksek başlangıç maliyeti, İHA'nın tüm ömrü boyunca sağladığı yakıt tasarrufu, bakım avantajları ve performans kazanımları ile birlikte (ömür boyu maliyet analizi) değerlendirilmelidir.

Termoset epoksi reçinelerin geri dönüşümü karmaşık bir süreçtir. Özellikle hurdaya ayrılan İHA gövdelerinin veya üretim atıklarının çevreye duyarlı bir şekilde bertarafı, sürdürülebilirlik

ISBN NR: 978-625-5694-92-8

odaklı ihalelerde bir zorluk teşkil edebilir ve bu konuda çözümler (örneğin, geri dönüştürülebilir termoplastik kompozit alternatifleri) değerlendirilmeye alınmalıdır.

Kompozit yapılarda oluşan iç hasarlar (delaminasyon, fiber kırılması) gözle tespit edilemeyebilir ve taşınabilir ultrasonik cihazlar gibi özel teçhizat gerektirir. Ayrıca, operasyon sahasında (field) meydana gelen hasarların onarımı, özel eğitimli personel, belirli sıcaklık-nem koşulları ve özel onarım kitleri gerektirdiğinden lojistik açıdan karmaşık olabilir. İhale şartnamelerinde, tedarikçinin saha destek ve onarım kabiliyeti mutlaka sorgulanmalıdır.

Havacılık standartlarında (ASK, DEF STAN gibi) kompozit parça üretimi, süreç parametrelerine (sıcaklık, basınç, vakum, fiber oryantasyonu) son derece duyarlıdır. Tutarlı ve yüksek kalitede üretim, deneyimli iş gücü ve sıkı kalite kontrol süreçleri (tahribatsız muayene) gerektirir. İhale değerlendirmesinde, yüklenicinin bu alandaki teknik yeterliliği, sertifikasyonları ve referansları kritik önem taşır.

Karbon fiber iletkendir ancak metaller kadar iyi bir iletken değildir. Bu nedenle, İHA gövdelerinde yıldırım çarpmasına karşı koruma sağlamak için metal örgü veya iletken kaplamalar gibi ek önlemler alınması gerekebilir. Bu da maliyeti ve ağırlığı artırabilecek ek bir tasarım gereksinimidir.

Malzeme seçimi süreci genellikle birden fazla kriterin birlikte değerlendirilmesini gerektiren karmaşık bir karar problemidir. Bu konuda yapılan bazı araştırmalar Çizelge 1'de sunulmuştur.

Çizelge 1. İHA lar İçin Malzeme Kullanımı İle İlgili Bazı Araştırmalar

Kompozit Malzeme	Metod	Çalışma	Ref.
Grafit lifleri, cam, karbon ve grafit, Kevlar, bor ve karbon lifleri	Organik bir öncü maddenin pirolizi örneğin rayon veya Poli-akrilonitril veya petrol zifti	Kompozit İHA Geliştirmesinde Uygulamalı Entegre Tasarım	6
Ön Gövde Bileşenleri Üç katmanlı üst kaplama: karbon fiber, petek yapı, ve cam elyafı	Kompozit malzemelerin mekanik özelliklerinin karşılaştırılması, çekme dayanımı testi ile gerçekleştirilir.	İnsansız Hava Araçları Kompozit Malzemelerinin Mekanik Özellikleri	7
Lamine kompozit ve sandviç yapı (Ecamgöğü/Epoksi, Kevlar/Epoksi, Karbon/Epoksi)	Vakum Torbalama Yöntemi ve oda sıcaklığında Kürleme	Hafif Sandviç Kompozit İHA Kanadının Üretimi ve Yapısal Analizi	8
Polimer matris kompozitler sürekli liflerle güçlendirilmiş polimer matris kompozitler (Laminatlar ve sandviç		İnsansız hava araçlarının (İHA) kanat yapısının kompozit malzemeler kullanılarak tasarımı ve üretimi.	9

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yapılar)			
Karbon Elyaf Takviyeli Polimer (CFRP) lamine kompozit	Katman kombinasyonları	İnsansız hava aracı (İHA) NACA4415 kanadının havacılık uygulamalarında kompozit katman yöneliminin performans analizi	10
Karbon elyaf takviyeli polimer (CFRP) kompozit	Dokuma ve tek eksenli prepreg kumaşların formu	Deneysel titreşim analizi kompozit İHA kanadı	11
Sandviç kompozit (fiberglas ve polyester reçine ve mikroparçacıklar)	Elle kalıplama tekniği	İHA kanadı için sandviç kompozitin analizi, üretimi ve testi	12

Çok kriterli karar verme yöntemleri malzeme seçim çalışmalarında sıklıkla kullanılmaktadır. Bu yöntemlerden biri olan Analitik Hiyerarşi Prosesi (AHP), karar vericilerin farklı kriterleri sistematik olarak değerlendirmesine olanak sağlayan güçlü bir yöntemdir.
Bu çalışma kapsamında, yukarıda avantaj ve dezavantajları İHA platformları özelinde özetlenen karbon fiber takviyeli epoksi kompozit malzemeler arasından, belirli bir İHA tedarik ihalesi için en uygun olanının seçilmesi hedeflenmektedir. Bu seçim süreci, birden fazla ve genellikle birbiriyle çelişen kriteri bir arada değerlendirmeyi gerektirdiğinden, çok kriterli bir karar verme problemi olarak karşımıza çıkmaktadır. Bu karmaşık karar problemine sistematik ve bilimsel bir çözüm sunmak amacıyla, AHP yöntemi kullanılacaktır. AHP, karar vericilerin hem nesnel verileri hem de sübjektif yargıları bir arada değerlendirerek, hiyerarşik bir yapı içerisinde en uygun alternatifi belirlemesine olanak tanıyan etkili bir araçtır. Bu bildiride, belirlenen 5 farklı karbon fiber takviyeli epoksi kompozit malzeme, İHA teknik, ve ekonomik kriterler doğrultusunda AHP yöntemi ile analiz edilerek en uygun malzeme seçimi gerçekleştirilmiştir.

2. MATERİALS AND METHODS

2.1. Alternatif Kompozit Malzemeler

Çalışmada karbon fiber takviyeli epoksi matrisli beş farklı kompozit malzeme alternatifi değerlendirilmiştir. Bu malzemeler havacılık uygulamalarında yaygın olarak kullanılan malzeme sistemleri arasından seçilmiştir. Karbon/epoksi kompozit malzemelerin mekanik özellikleri Çizelge 2'de sunulmuştur [13].

Çizelge 2. Karbon/Epoksi Kompozit Malzemelerin Mekanik Özellikleri

Malzeme	Çekme Dayanımı (ksi)	Elastisite Modülü (Msi)	Gerilim (%)
T300/934	245	20	1.0–1.2
IM7/8551-7	400	24	1.62

ISBN NR: 978-625-5694-92-8

P75/934	135	44	0.2–0.5
AS4/3501-6	100	10	1.0
IM6/3501-6	330	23	1.5

Çizelge 2 ‘de farklı kompozit malzemelerin mekanik özelliklerinin önemli ölçüde değiştiği görülmektedir. Bu farklılıklar malzeme seçimi sürecinde çok kriterli değerlendirme yapılmasını gerekli kılmaktadır.

2.2. Değerlendirme Kriterleri

Malzeme seçiminde dört temel kriter dikkate alınmıştır.

Çekme dayanımı, malzemenin çekme yükleri altında kırılmadan dayanabileceği maksimum gerilmeyi ifade eder. Yüksek çekme dayanımı, İHA yapısının aerodinamik yükler altında güvenli şekilde çalışmasına katkı sağlar. Elastisite modülü, bu parametre malzemenin rijitlik derecesini temsil eder. Yüksek elastisite modülü, özellikle kanat yapılarında oluşabilecek elastik deformasyonların sınırlanmasına yardımcı olur. Gerilim kapasitesi, malzemenin kırılma öncesinde gösterebildiği deformasyon miktarını ifade eder. Daha yüksek gerinim değerleri malzemenin daha sünek davranmasını sağlayarak yapısal güvenliği artırabilir. Maliyet, malzemenin birim kütle başına üretim maliyetini göstermektedir. Özellikle seri üretim süreçlerinde maliyet kriteri önemli bir karar faktörüdür. Bu çalışmada çekme dayanımı, elastisite modülü ve gerilim kriterleri fayda kriteri, maliyet ise maliyet kriteri olarak ele alınmıştır.

3. AHP ANALİZİ

Çok kriterli karar verme yöntemlerinden AHP, karar problemlerinin karmaşık çerçevelerinin analiz edilmesinde kullanılan en yaygın yöntemlerden birisidir. AHP analizinde fayda kriteri (1) ve maliyet kriteri (2) değerleri aşağıdaki formüller yardımıyla hesaplanmıştır [14]. Normalize karar matrisi ve kriter ağırlıkları Çizelge 3 ve Çizelge 4’de verilmiştir.

$$r_{ij} = \frac{x_{ij}}{\sum_i x_{ij}} \quad (1)$$

$$r_{ij} = \frac{\min(x_{ij})}{x_{ij}} \quad (2)$$

Çizelge 3. Normalize Karar Matrisi

Malzeme	Çekme Dayanımı	Elastisite Modülü	Gerilim	Maliyet
T300/934	0.203	0.170	0.231	0.75
IM7/8551-7	0.332	0.204	0.340	0.63
P75/934	0.112	0.374	0.073	0.50
AS4/3501-6	0.083	0.085	0.210	1.00
IM6/3501-6	0.274	0.196	0.315	0.76

Kriterlerin AHP ile belirlenen ağırlıkları ve toplam skor hesabı aşağıdaki formülle elde edilmiştir.

ISBN NR: 978-625-5694-92-8

$$V_i = \sum_j w_j \cdot r_{ij} \quad (3)$$

Çizelge 4. Kriter Ağırlıkları

Kriter	Ağırlık w_j	Açıklama
Çekme Dayanımı	0.40	Malzemenin eksenel yük altındaki dayanım kapasitesi
Elastisite Modülü	0.25	Malzemenin rijitlik derecesi
Gerinim	0.20	Malzemenin kırılmadan deformasyon kapasitesi
Maliyet	0.15	Birim maliyet, düşük olması avantaj

AHP yaklaşımı ile kriter ağırlıkları hesaplandıktan sonra alternatif malzemelerin performans değerleri normalize edilmiş ve ağırlıklı performans skorları elde edilmiştir.

Çizelge 5. Ağırlıklı Normalize Karar Matrisi ve Nihai Skor

Malzeme	Çekme Dayanımı (0.40)	Elastisite Modülü (0.25)	Gerinim (0.20)	Maliyet (0.15)	Toplam Skor
T300/934	0.081	0.043	0.046	0.113	0.283
IM7/8551-7	0.133	0.051	0.068	0.094	0.346
P75/934	0.045	0.094	0.015	0.075	0.229
AS4/3501-6	0.033	0.021	0.042	0.150	0.246
IM6/3501-6	0.110	0.049	0.063	0.114	0.336

Normalize karar matrisi, her kriterin birimlerinden bağımsız olarak alternatiflerin karşılaştırılabilmesini sağlamaktadır. Fayda kriterleri için sütun toplamına bölme, maliyet kriteri için ters normalizasyon uygulanmıştır. Daha sonra kriter ağırlıkları ile çarpılarak ağırlıklı normalize karar matrisi elde edilmiştir.

Toplam skorlar, her alternatifin tüm kriterler göz önüne alındığında ne kadar avantajlı olduğunu göstermektedir. Skorlar incelendiğinde IM7/8551-7 kompozit malzemesi en yüksek toplam skora sahip olduğu için küçük İHA yapısal uygulamaları için en uygun alternatif olarak öne çıkmaktadır.

4. SONUÇ

Bu çalışmada küçük insansız hava araçlarının yapısal bileşenlerinde kullanılabilecek karbon fiber takviyeli epoksi kompozit malzemeler çok kriterli karar verme yaklaşımı kullanılarak değerlendirilmiştir. Analitik Hiyerarşi Prosesi yöntemi ile gerçekleştirilen analizde çekme dayanımı, elastisite modülü, gerilim kapasitesi ve maliyet kriterleri dikkate alınmıştır.

Analiz sonuçları IM7/8551-7 kompozit malzemesinin genel performans açısından en uygun alternatif olduğunu göstermiştir. Bu malzeme yüksek mekanik dayanım özellikleri sayesinde

küçük İHA platformlarının yapısal elemanlarında avantaj sağlayabilecek bir seçenek olarak öne çıkmaktadır.

Çalışma sonuçları, çok kriterli karar verme yöntemlerinin havacılık mühendisliğinde malzeme seçimi gibi karmaşık karar problemlerinin çözümünde etkin bir şekilde kullanılabileceğini ortaya koymaktadır. Gelecekte yapılacak çalışmalarda yoğunluk, yorulma dayanımı ve üretim yöntemleri gibi ek parametrelerin değerlendirme sürecine dahil edilmesi daha kapsamlı analizlerin gerçekleştirilmesine katkı sağlayabilir.

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ISBN NR: 978-625-5694-92-8

DESIGN AND PROTOTYPE FABRICATION OF A COST-EFFECTIVE SUBSTRATE CLEANER FOR LAB SCALE SEMICONDUCTOR PROCESSES

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ABSTRACT

Semiconductor manufacturing technologies lie at the core of national security and technological independence strategies. Surface cleaning of substrates such as glass substrates or wafers represents a critical step in semiconductor processing and is one of the primary factors directly influencing final device yield. However, the high cost of commercial cleaning systems designed to meet industrial standards poses a significant barrier for small and medium scale laboratories and research groups operating under limited budgets. In this study, a low cost and modular substrate cleaning prototype based on an open-source hardware architecture was designed and fabricated for scenarios where access to commercial systems is not feasible. The device's outer chassis was manufactured from polymethylmethacrylate (PMMA), providing high mechanical durability and chemical resistance. A hybrid internal assembly was employed, combining PMMA components with custom designed parts produced via additive manufacturing (ABS/PLA). System control is implemented through an Arduino microcontroller, while precision nozzle motion and rotational movement are achieved using integrated stepper and DC motors. The cleaning process is carried out on a rotating chuck at a fixed speed of 350 RPM and a spray pressure of 3 bar, which were identified as optimal operating parameters. Deionized water and high purity nitrogen gas are delivered through a dual arm mechanism without requiring any mechanical contact or friction. Tests conducted on intentionally contaminated aluminum-coated glass substrates demonstrated through microscopic inspection—that the prototype effectively reduces surface contamination. This work demonstrates the feasibility of producing a high precision, cost-effective semiconductor substrate cleaning system at the

laboratory scale using local resources and engineering solutions.
Keywords: Semiconductor, Substrate Cleaning, Automation, Open-Source Hardware, Cost-Effective, Prototype Fabrication

1. INTRODUCTION

The fabrication of semiconductor devices and optical components relies on highly sensitive processing sequences involving the front-end, middle-of-line, and back-end stages, in which cleaning constitutes a recurring and critical operation throughout the manufacturing sequence (Okorn-Schmidt et al., 2014). During these processes, particulate contaminants remaining on the surface—particularly after treatments such as etching—can adhere to patterned substrates, thereby degrading electrical characteristics and causing substantial reductions in device yield. As device dimensions continue to scale down, the critical particle size associated with so-called "killer defects" correspondingly decreases, making even nanometer-scale contamination a major source of yield loss in manufacturing. Consequently, the presence of even a minute particle or organic residue on the surface may lead to irreversible defects during subsequent processing steps (Lee, Kim, and Lee, 2025; Okorn-Schmidt et al., 2014).

In this context, substrate cleaning emerges as one of the most critical steps not only for the removal of native oxide layers and particulate contamination from the surface, but also for achieving a stable and standardized surface quality despite variations across the supply chain (Willnauer et al., 2025). As semiconductor device structures become increasingly mechanically fragile, high particle removal efficiency (PRE) alone is no longer sufficient; cleaning technologies must also avoid inducing structural damage while maintaining substrate loss at a minimum (Hirano et al., 2006; Okorn-Schmidt et al., 2014). The substrate cleaning prototype developed in this work is specifically designed to maintain this critical balance, particularly in post-etch processing steps.

On the other hand, the high capital and operating costs of commercial substrate cleaning systems designed to meet industrial standards constitute a significant accessibility barrier for university R&D laboratories and independent research groups. However, the standard substrate cleaning systems should be accessible not only by the industrial manufacturers, but also by the mid/small-scale R&D laboratories which may be regarded as a critical mission to democratize semiconductors device research. Previous studies have shown that, in spin-processing applications such as thin-film coating, open-source and low-cost microcontroller-based systems (e.g., Arduino and PIC) can achieve results comparable to those of commercial instruments (Aziz et al., 2024; Kaddachi et al., 2016). Numerous studies have further shown that laboratory-scale devices developed using open-source hardware architectures can provide high performance while optimizing research budgets (Ali, 2020; Sadegh-Cheri, 2019). The primary motivation of the present study is therefore to develop a modular, low-cost, spin-type substrate cleaning prototype as an alternative to the high-cost commercial systems, drawing on the open-source hardware trends reported in the literature. The cost-effective system developed within this scope features a hybrid body and framed structure, consisting of a durable external enclosure integrated with fully custom-designed, 3D-printed components. The control

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infrastructure is based on an Arduino microcontroller, and although the system is capable of operating over variable process ranges, it was configured to operate under the conditions identified as optimal for efficiency, namely 350 RPM and the spraying of deionized (DI) water at 3 bar together with nitrogen gas through a dual-arm mechanism. The extent to which this accessible system satisfies the industrial objective of 'high particle removal without surface damage' was evaluated and is presented through microscopic observations performed on intentionally contaminated samples.

2. MATERIALS AND METHODS

2.1. Theoretical Background of the Two-Phase Cleaning Mechanism

Two-phase (liquid+gas) spray technology, which is an effective approach in semiconductor cleaning, is based on the impingement of micron-sized DI water droplets accelerated by nitrogen gas onto the substrate surface. Upon impact, these droplets generate a strong radial flow within the spreading liquid film, thereby overcoming the van der Waals forces that bind particulate contaminants to the surface and producing a substantial drag force and rolling moment on the particles, which facilitates their removal (Lee, Kim, and Lee, 2025; Okorn-Schmidt et al., 2014; Seike et al., 2010). In particular, the spin-cleaning configuration, in which the substrate is rotated during cleaning, reduces the thickness of the liquid film through centrifugal force, thereby weakening the hydrodynamic boundary layer at the surface. As a result, the cushioning effect, which otherwise diminishes cleaning efficiency, is suppressed, allowing water droplets to reach surface-bound particles with maximum force (Dhane et al., 2011; Okorn-Schmidt et al., 2014). This dynamic configuration maximizes cleaning efficiency by eliminating the cushioning effect arising from the damping of droplet impact energy by a thick liquid film. At the same time, detached particles can be removed from the substrate surface during both the spin-rinse and spin-drying stages, which reduces the likelihood of particle re-adhesion to the surface (Handa et al., 2021). Unlike conventional megasonic cleaning, these methods allow the droplet size and impact velocity to be controlled independently and therefore offer a critical advantage: owing to their high kinetic energy, they are capable of removing particulate contaminants at the micron, submicron, and even nanometer scale without causing mechanical damage to delicate circuit patterns (Hirano et al., 2006; Seike et al., 2010).

2.2. Design and Prototype Fabrication of a Modular Spin-Type Cleaner

Based on the theoretical principles outlined above, a low-cost, modular substrate cleaning prototype was developed at the laboratory scale to achieve high PRE in line with current open-source hardware trends (Kaddachi et al., 2016; Sadegh-Cheri, 2019). The main chassis of the prototype was designed as a hybrid assembly of 3D-printed ABS, PTFE and PMMA components to ensure maximum resistance to corrosion caused by DI water and high-pressure nitrogen gas. The prototype was also fitted with a transparent cover to allow real-time observation of the cleaning process (Figure 1).

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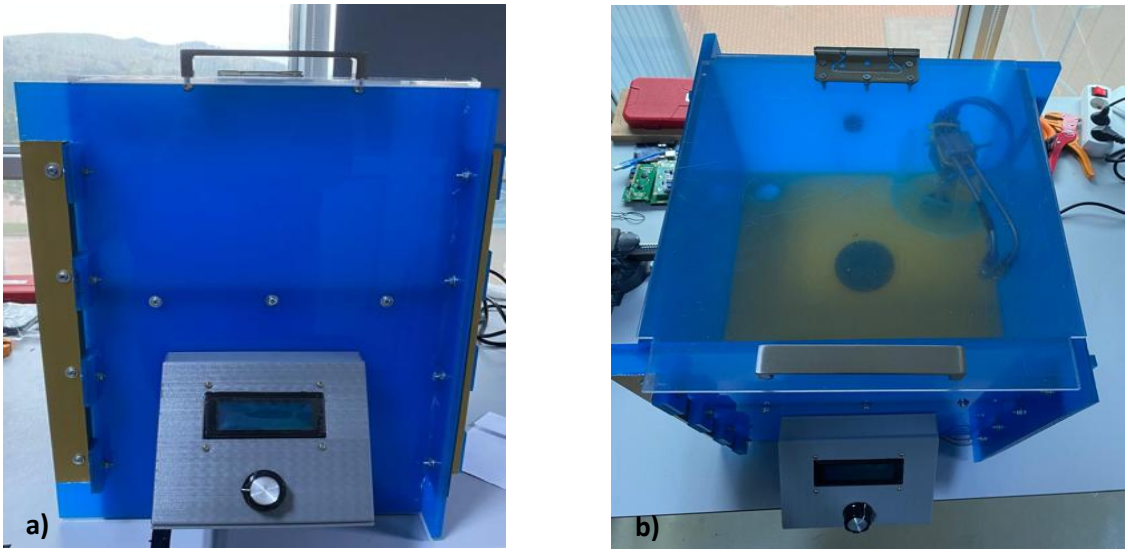

Figure 1. Prototype assembly: a) front view and b) top view.

The prototype is driven by a DC motor operating at a constant rotation speed of 350 RPM, which was determined on the basis of literature reports and preliminary evaluations to optimally perform the functions of liquid film thinning and suppression of the "cushioning effect" emphasized in the theory of two-phase cleaning. To ensure centering and positional stability of the specimen during rotation, a custom guide slot composed of four PMMA parts integrated into the rotating stage was used instead of a complex holder mechanism. To remove surface contaminants without mechanical or chemical contact, a dedicated dual-arm nozzle assembly consisting of DI water and nitrogen lines was integrated into the system (Figure 2). Precise radial motion of the cleaning arms was achieved using a stepper motor and a DM288N stepper motor driver, while nozzle positioning accuracy was maximized by incorporating an infrared (IR) centering sensor. To achieve the target jet impact energy without exceeding the structural damage threshold, DI water and nitrogen gas supplied to the nozzles were sprayed through pneumatic lines at a constant pressure of 3 bar. In this way, the droplet impact velocity, and thus the particle removal force, was optimized within a safe operating range (Seike et al., 2010).

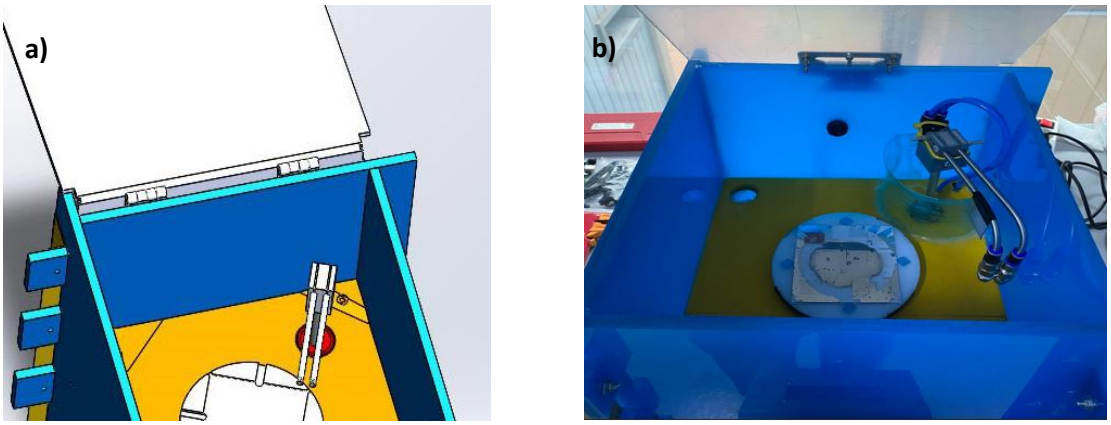

Figure 2. Two-phase cleaning mechanism: a) 3D design and b) prototype assembly view.

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2.3. Component Selection and Prototype Manufacturing Process

2.3.1. Design Approach and Decision Methodology

In recent years, the literature has emphasized in numerous studies that the use of open-source hardware (OSHW) in laboratory equipment can compete with commercial counterparts in terms of experimental reproducibility and modularity while optimizing research budgets (Pearce, 2020; Wenzel, 2023). With this motivation, the fundamental design approach adopted during the prototype development process was based on cost–performance optimization, rapid iteration capability, and testability under laboratory conditions. Rather than targeting a final product, the aim was to establish a low-risk and reproducible platform capable of functionally validating the system. To achieve this objective, component selection was evaluated holistically based on parameters such as mechanical adequacy, chemical resistance, ease of fabrication, procurement time, total system cost and re-manufacturing speed in the event of design revisions. In accordance with these criteria, alternative materials and drive systems were compared from both technical and economic perspectives.

2.3.2. Motor Selection and Drive System

The operating principle of the system is based on controlled rotational motion. Therefore, speed stability and sufficient torque generation were established as the primary criteria in motor selection. In the developed drive system, a DC motor was preferred for rotating the substrate stage, whereas stepper motors were used for the precise positioning of the cleaning arms (Figure 3). This selected motor configuration was preferred because of its ability to operate stably within the range of 300–1200 RPM, provide sufficient torque to meet the experimental load conditions, offer low initial investment and driver costs, and be readily available in the local market. As an alternative, servo motor systems were also evaluated; however, they were not preferred because of their high driver cost and the level of precision being unnecessary at the prototype stage. This decision was made by considering the balance between system requirements and economic optimization. In addition, comparative studies in the literature on drive units for spin-coating and rotating-platform systems indicate that DC/BLDC- and stepper motor-based drive systems provide sufficient speed stability and low cost at the laboratory scale (Mousavi et al., 2024; Quiroz Yepes et al., 2019).

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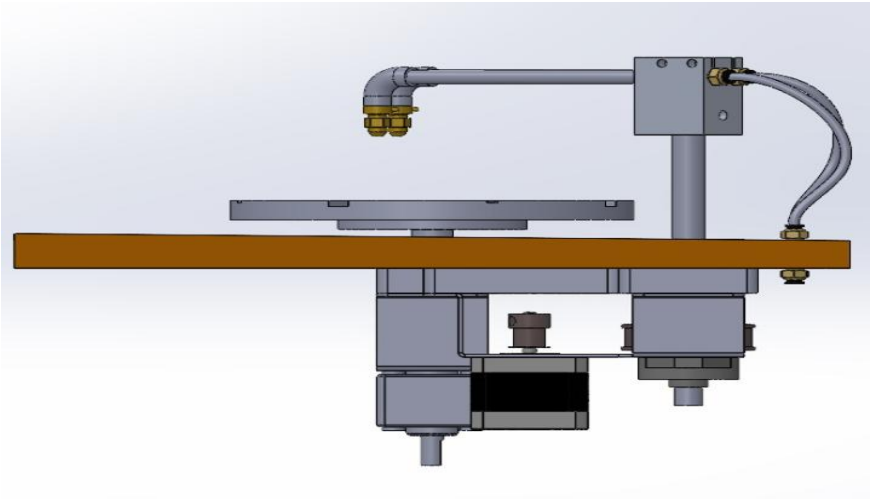

Figure 3. 3D design view of two-phase cleaning mechanism: liquid and gas pipelines together with the rotation mechanism.

2.3.3. Material Selection and Evaluation of Alternatives

PMMA was preferred for the body and structural support elements because of its low cost, ease of machining enabled by its compatibility with laser cutting and CNC processing, the transparency provided in the cover section for flow observation, and the advantages of rapid procurement and re-manufacturing in the event of design revisions. Parts that did not carry dynamic loads or operated under low stress were fabricated using a 3D printer with polylactic acid (PLA) filament because of its low cost, high dimensional reproducibility and ease of printing suitable for rapid prototyping. Since no high mechanical strength was required at the prototype stage, PLA provided sufficient performance. In contrast, acrylonitrile butadiene styrene (ABS) was used in the section that may also be referred to as the “process chamber”, which is in direct contact with liquids and cleaning chemicals, because it offers higher chemical resistance, superior impact resistance and greater thermal stability than PLA (Figure 4).

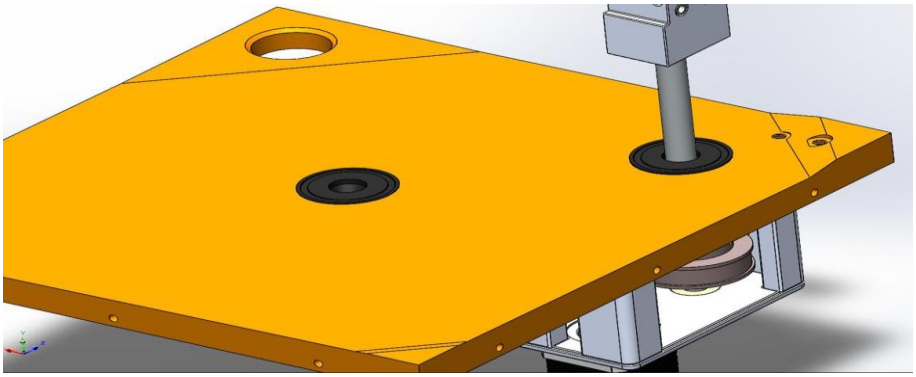

Figure 4. 3D design view of disassembled state of ABS washing basin.

As also emphasized in the literature, the use of thermoplastics such as PLA and ABS in the fabrication of laboratory-scale open-source hardware by means of 3D printing (FDM) dramatically reduces hardware costs while maximizing design flexibility compared with conventional manufacturing methods (Del Rosario et al., 2021; Winters et al., 2021). This

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hybrid design approach made it possible to keep the system cost under control by providing enhanced durability only in the regions where it was required.

2.3.4. Evaluation of Metal Alternatives

At the early stage of the design, 6061-series aluminum alloys, carbon steel and stainless steel sheet metals were evaluated for the main chassis. Although these materials offer advantages such as high strength, long service life and structural rigidity, they were not preferred at the prototype stage because of the high cost of CNC machining and cutting, the additional manufacturing time required for sheet bending and welding operations, the significant increase in the total system budget and the extension of re-manufacturing time in the event of a possible design revision. In particular, stainless steel, despite its high corrosion resistance, was not found to be compatible with the prototype objectives in terms of cost. Therefore, a hybrid structure (plexiglass + 3D printing) was preferred over a metal construction in the final design. This decision is consistent with the strategy of establishing a low-cost validation platform in the academic prototyping process.

2.3.5. Prototype Manufacturing Process

The prototype manufacturing process was carried out within the framework of a systematic workflow consisting of the following stages:

1. CAD modelling
2. Decomposition of functional subsystems
3. Material-based production planning
4. 3D printing production (PLA and ABS)
5. Plexiglass cutting and processing
6. Mechanical assembly
7. Error Detection, Feedbacks and System Improvement Notes
8. Revision and Optimization

Following these manufacturing steps, mechanical analyses were conducted, based on which the wall thicknesses in critical connection regions were increased, while the 3D printing infill density was reduced in low-stress regions. In this way, the optimization of the system in terms of strength, weight and cost was successfully achieved.

2.3.6. Views of the Prototype

This section presents the physical realization and hardware architecture of the modular substrate cleaning system developed in accordance with the material selection criteria and manufacturing processes detailed in Section 2.3. Figure 5 shows the overall external appearance of the fabricated prototype and the arrangement of its hardware components. In this architecture, the electrical components (motors, power supply and microcontroller) and the wet processing section (PMMA chamber and substrate guide slot) were physically completely isolated from each other in order to eliminate the risks of oxidation and short circuits that could arise from liquid contact and high humidity.

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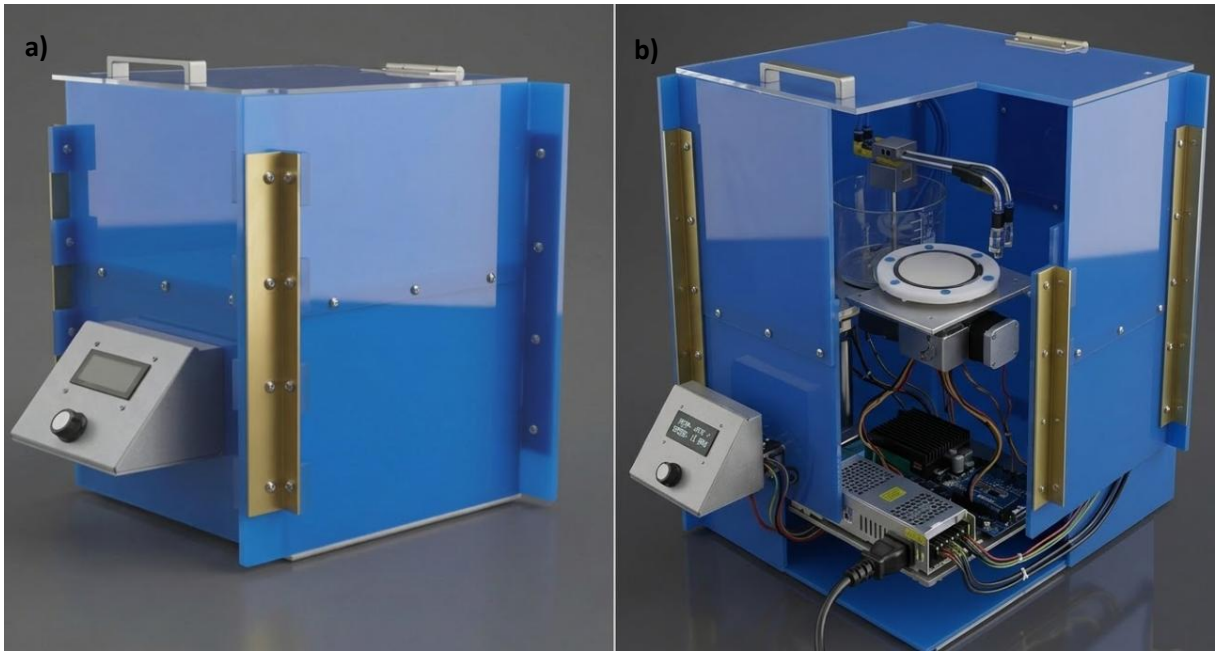

Figure 5. Fabricated prototype: a) assembled and b) sectional CAD assembly view.

The internal mechanism details constituting the motion and drive infrastructure of the system are presented in Figure 6 as CAD sectional views. The transparent PMMA material selected for the main body cover allows clear observation of the spraying mechanics, liquid flow and process sequence during operation. To ensure cost-effectiveness, the 3D-printed (PLA/ABS) process chamber, connection elements and belt–pulley drive system were successfully integrated into the system. This modular structure of the prototype provides easy access to and intervention on critical components for maintenance and possible revisions.

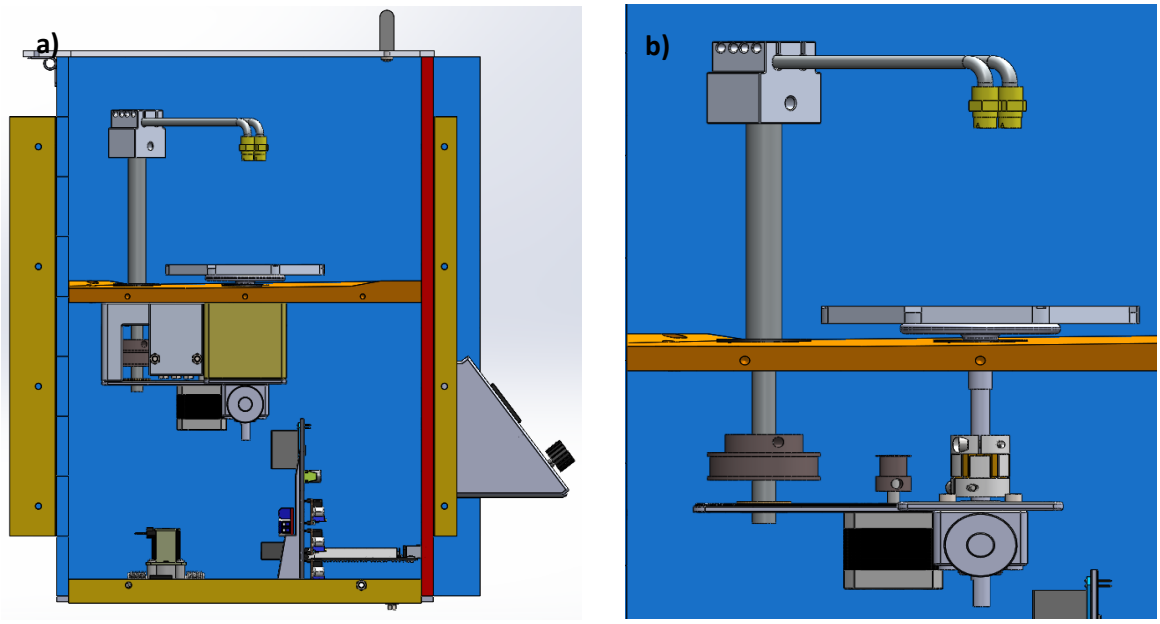

Figure 6. Cleaning mechanism: a) side sectional view and b) integration detail of nozzle movement and drive mechanism.

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2.4. Open-Source Hardware Architecture and Software Automation

In contrast to the “black-box” architecture and high costs of commercial spin-cleaning devices, current studies in the literature demonstrate that open-source microcontrollers offer high flexibility and cost-effectiveness in laboratory instrumentation (Winters et al., 2021). Based on this modular design philosophy, the Arduino platform was selected as the main control unit for the developed spin-type cleaner. System automation was structured to provide the researcher with full control over the process, owing to the flexibility of the hardware. While the rotation mechanism (substrate holder) is driven by a DC motor, high-precision M280 and DM288N stepper motor drivers have been integrated with stepper motors for the precise radial positioning of the cleaning arms (DI water and nitrogen nozzles) (Figure 7).

The software architecture was developed to reflect the customizability advantages cited in the literature to the end-user. The user interface (UI) is provided via a 4x20 LCD screen and a rotary encoder. Upon examining the flow chart presented in Figure 8, it is observed that users can rapidly select from four different predefined cleaning programs via the menu. Furthermore, owing to the system’s open-source software architecture, all operational parameters—such as rotational speed (RPM) and the durations of DI water and nitrogen spraying—can be easily modified by the researcher at the code level and fully customized according to new process requirements. This memory feature and flexible structure, which ensure standardization within the laboratory environment, demonstrate full compatibility with modern device integration and automation trends reported in the literature (Aziz et al., 2024).

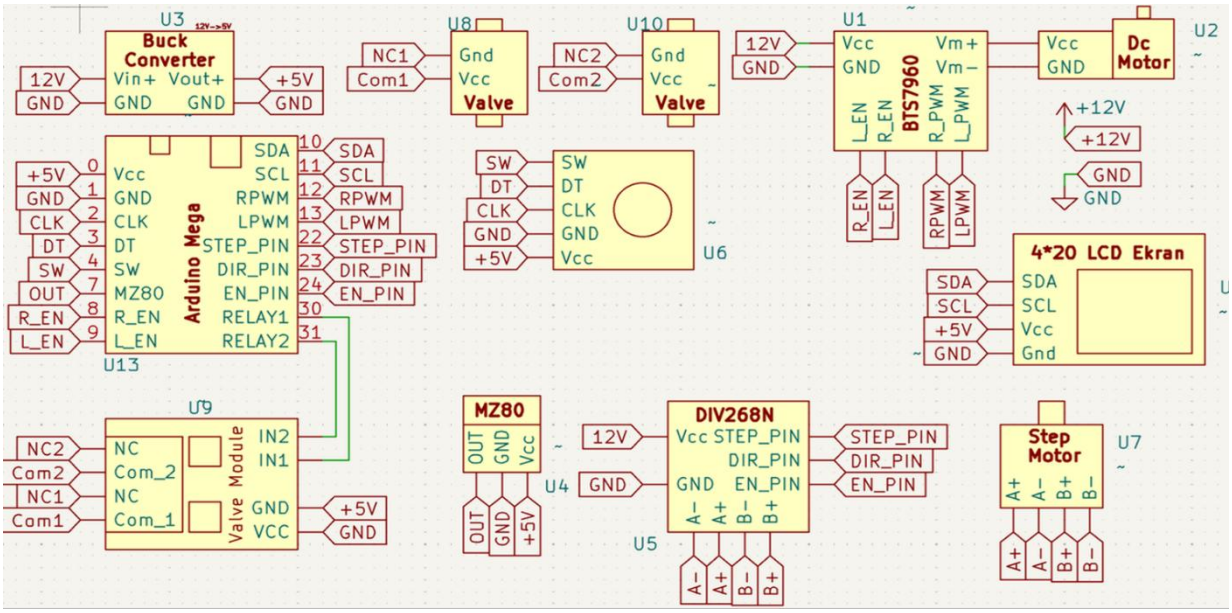

Figure 7. Electronic circuit diagram.

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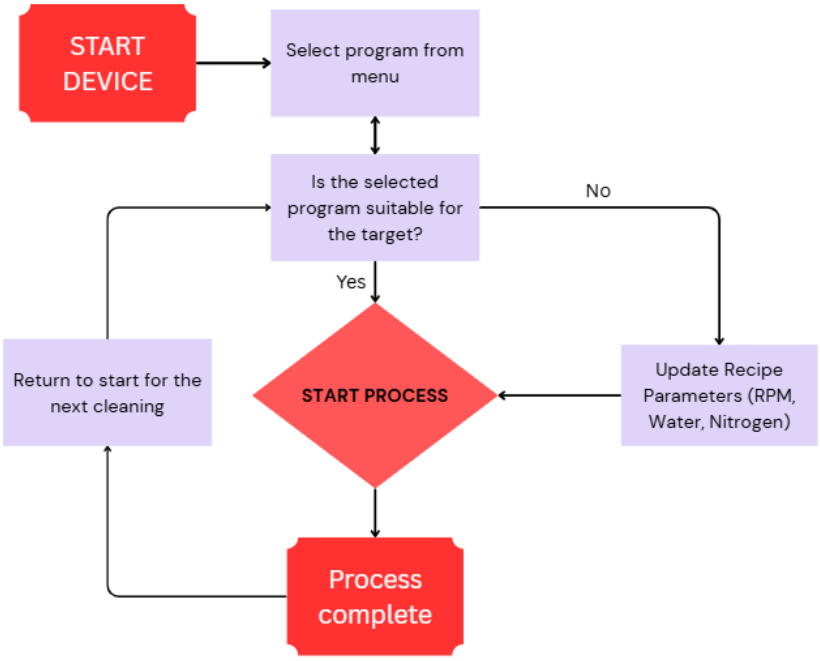

Figure 8. Software flow chart showing parametric control of the cleaning process and the "Soft Start/Stop" mechanism.

3. EXPERIMENTAL FINDINGS AND DISCUSSION

In this section, the laboratory performance of the designed open-source and modular spin-type substrate cleaner prototype was analyzed through the stability of the pneumatic system-supported nitrogen-based rinsing and drying processes, hydrodynamic particle removal efficiency and microscopic examinations. The evaluations were conducted within the framework of the operational flexibility and cost advantages the device offers to researchers.

3.1. Cleaning Performance and Microscopic Analysis

To test PRE of the fabricated prototype, aluminum-coated glass substrates were utilized, simulating semiconductor and thin-film manufacturing processes. Within the scope of the experimental methodology, two reference aluminum-coated glass samples were intentionally contaminated with particles and the physical effects of the cleaning performance were characterized using optical microscopy at a 2 mm scale. The flexibility provided by the Arduino-based control panel of the device enabled the testing of various parametric recipes-specifically 30, 45 and 60 seconds-consistent with "recipe management" approaches found in the literature (Aziz et al., 2024). Considering the critical influence of cleaning duration on liquid film formation and cleaning efficiency, the optimal cleaning process was executed at a turntable speed of 350 RPM under a constant pressure of 3 bar. This involved a combination of dissolving surface contaminants with DI water, followed by atomized drying and particle sweeping (spin-drying) utilizing a nitrogen gas jet.

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Upon examining the obtained microscope images (Figure 9), it was observed that the dense particle agglomerations on the "Contaminated" surfaces were removed to an extent optically equivalent to the cleanliness of the "Reference" sample. These results demonstrate that the combination of two-phase (gas+liquid) spraying and centrifugal force, as emphasized in the literature, provides sufficient energy to break the Van der Waals bonds on the surface. The most significant finding is that this successful particle removal performance was achieved without any mechanical contact—such as brushes, pads or corrosive chemicals—relying entirely on hydrodynamic and pneumatic forces without causing any structural or surface damage.

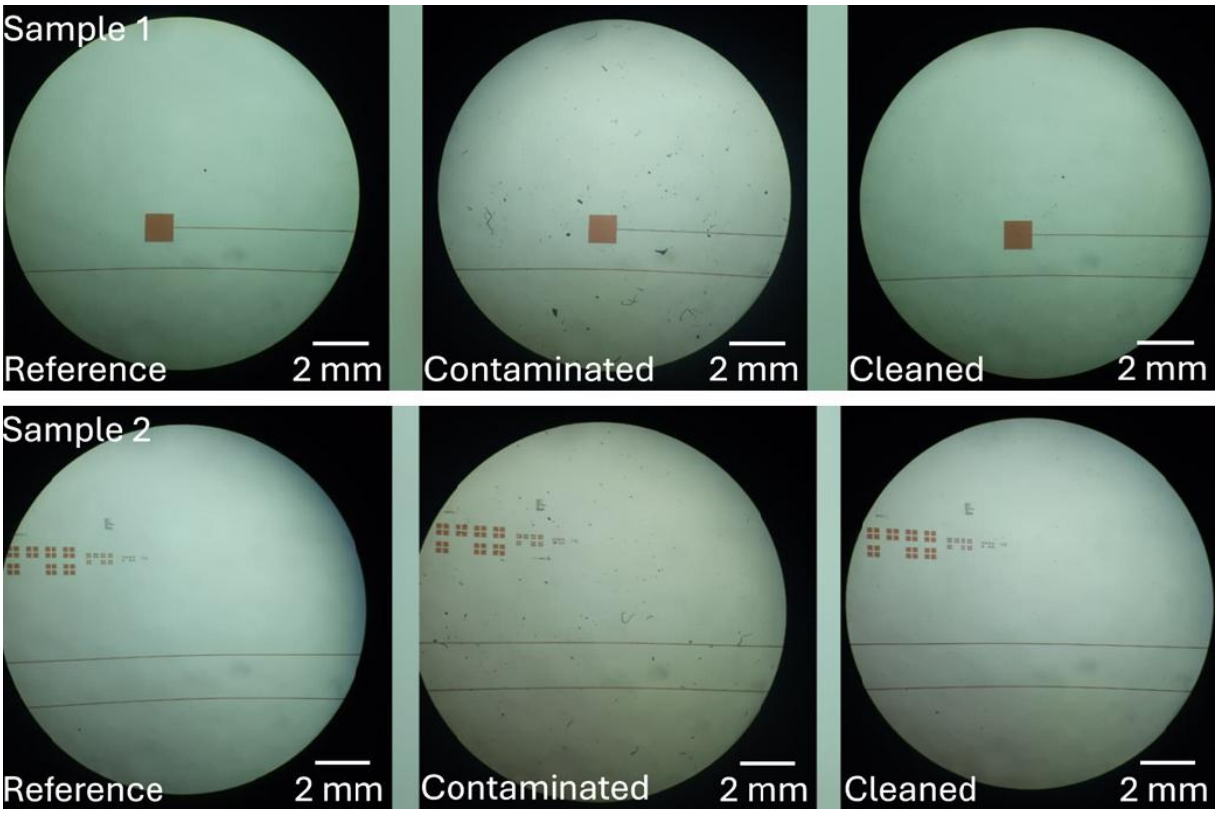

Figure 9. Optical microscope images of intentionally contaminated aluminum-coated glass substrates (Sample 1 and Sample 2) before and after cleaning with the fabricated substrate cleaner prototype.

3.2. Cost-Effectiveness and Evaluation of System Flexibility

The fact that the fabricated prototype's installation cost and operational flexibility are as important as its physical cleaning performance is one of the key findings of this study. Compared to commercial spin cleaning systems, which require investments of thousands of dollars and often entail maintenance and repair processes monopolized by the original manufacturers, this Arduino-based, open-source design reduces R&D costs to a level accessible for laboratory budgets.

The construction of the system using low-cost engineering polymers with high chemical

resistance, integrated with standard, off-the-shelf electronic control components (stepper/DC motor drivers), enables rapid and cost-effective repair by researchers in the event of potential malfunctions. Furthermore, the ability to store and edit four distinct cleaning recipes via the user interface enables the system to rapidly adapt to varying contamination density scenarios. This feature satisfies current requirements for technological traceability and process standardization, ensuring consistent high-quality output across each operation. These findings demonstrate that the prototype is not merely a low-cost alternative but also successfully meets the standards for programmability and reproducibility (process consistency) offered by commercial systems at the laboratory scale.

4. CONCLUSION AND FUTURE WORKS

In this study, a low-budget, modular, spin-type substrate cleaner prototype with an open-source hardware architecture has been successfully designed and manufactured as a solution to high equipment costs, which represent a critical barrier for semiconductor research laboratories. The prototype was fabricated using a 10 mm PMMA body, an Arduino microcontroller and a dual-arm pneumatic nozzle (DI water/nitrogen) system, and demonstrated high hydrodynamic cleaning performance at a speed of 350 RPM and a pressure of 3 bar. Tests conducted on intentionally contaminated aluminum-coated glass substrates verified at a microscopic level that the system provides effective surface cleaning without causing physical damage. This developed accessible system offers researchers full control over process parameters (RPM, liquid/gas spraying durations). As part of future work, it is aimed to develop the motor and balance structure to increase stability at high speeds and to integrate a vacuum chuck mechanism for the substrate fixing process.

In summary, this study proves that high-precision engineering prototype can be achieved even with limited budgets and contributes directly to the development of open-source scientific instruments in the literature with its unique hardware design, liberating researchers from commercial constraints.

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BALKAN 15th INTERNATIONAL CONFERENCE ON APPLED SCIENCES
March 20 – 22, 2026 – SKOPJE
ISBN NR: 978-625-5694-92-8

HAVA KAYNAKLI ISI POMPASI TEST SİSTEMİNİN LABORATUVAR ISITILMASI İÇİN KURULUMU VE PERFORMANSININ DEĞERLENDİRİLMESİ

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ÖZET

Bu çalışmada laboratuvar ısıtması için kullanılan ısı pompası test sisteminin kurulumu ve performansının ölçülmesi üzerine bir araştırma sunulmuştur. Laboratuvar içerisinde bir adet fan-coil kullanılmıştır. Fan-coil sistemi laboratuvar tavanına yerleştirilmiş ve su bağlantı ağızları plastik borular ile taşınarak laboratuvar dış duvarına sabitlenmiştir. Isı pompası test sistemi su bağlantı ağızları ile birleştirilmiş ve fan-coil ile entegre hale getirilmiştir. Fan-coil ve ısı pompası sistemleri ölçüm cihazları ile donatılarak test edilebilir hale getirilmiştir. Isı pompası sistemlerinin test edilmesine yönelik olarak örnek bir yaklaşım sunulmuştur. Isı pompası sistemi 30 dakika boyunca çalıştırılmış ve fan-coilden üflenen hava sıcaklık değerinin 15 °C'den 35 °C'ye ulaştığı belirlenmiştir. Yapılan hesaplamalar sonucu ısı pompası kompresör gücü 1,02 kW, ısıtma kapasitesi 4,95 kW ve COP ısıtma değeri 4,85 olarak elde edilmiştir. Metin, iki yana yaslı, Times New Roman, 12 punto olmalıdır.

Anahtar Kelimeler: Isı pompası, ısıtma kapasitesi, COP

1. GİRİŞ

Günümüzde, sağladığı avantajlar nedeniyle ısı pompası sistemlerinin kullanımları giderek yaygınlaşmaktadır. Bina ısıtılma ve soğutmasında, taşıt, gıda kurutma ve endüstriyel uygulamalar gibi daha birçok alanda kullanıldığı görülmektedir. Aşağıda ısı pompası sistemleri ile ilgili yapılan çalışmalardan ve elde edilen sonuçlardan örnekler verilmiştir. Bu çalışmalardan birinde Yılmazer ve ark. (2023) bir villanın ısıtılması için kullanılan ısı pompası sisteminin performansının değerlendirilmiştir. Isı pompası sistemi yerden ısıtma sistemleri birlikte kullanıldığında enerji tüketiminin 2052 kWh, CO2 tüketiminin ise 804kg azaldığı belirlenmiştir. Yıldız ve Karaarslan (2025), R134a kullanılan bir ısı pompası sisteminin kompresör yağına POE+ Al2O3 nano akışkanı ekleyerek sistemin performansını değerlendirmişlerdir. Nano akışkan eklenmesiyle sistem performansının %7 ile %40 arasında arttığı tespit edilmiştir. Kocakulak ve ark (2023) çalışmalarında 28m^2'lik bir test odası için kurulan su kaynaklı ısı pompası sisteminin performansını incelemişlerdir. COP değeri 2,58 elde edilirken, ekserji yıkımı açısından kompresör en yüksek ekserji yıkımı görülen ekipman olduğu sonucuna varılmıştır. Bu çalışmada ısı pompası sisteminin ve fan-coil ile entegre edilerek test sistemi oluşturulmuştur. Şartlandırılan ortam olarak bir laboratuvar seçilmiş ve ısı pompası sistemi ile laboratuvarın ısıtılması sağlanmıştır. Isı pompası sistemlerinin test edilmesine yönelik olarak örnek bir yaklaşım sunulmuştur.

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2. DENEYSEL ÇALIŞMALAR

Deneylerde yaklaşık 70 m^2 alanı olan laboratuvar olarak kullanılan tek katlı bir yapı kullanılarak gerçekleştirilmiştir. Görsel 1'de laboratuvarın iç ortamı görülmektedir. Deneysel düzenek fan coil, ısı pompası sistemi ve ara bağlantı borularından oluşmaktadır. Çalışma kapsamında 4 yöne üflemeli kaset tipi fan-coil kullanılmıştır. Fan-coil hava debisi 1600 m^3/h, besleme Gerilimi ise 220–240 V/1 faz/50 Hz'dır. Fan coil laboratuvarın tavanına asılmıştır ve Görsel 1'de görülmektedir. Isı pompası sistemi ise laboratuvar dışına konulmuş ve plastik borular fan-coil ile entegre hale getirilmiştir. Görsel 2'de görüldüğü gibi laboratuvar dış duvarına su bağlantı ağızları konumlandırılmıştır. Isı pompası sistemi bu bağlantı ağızları kullanılarak fan-coil ile entegre edilmiştir. Fan-coil laboratuvar tavanının orta bölümüne yerleştirilmiştir. Fan-coil'in hava üfleme kanatlarına yakın bir konumu sıcaklık ölçümü için termokupl yerleştirilmiş hava çıkış sıcaklığı belirli aralıklar ile ölçülmüştür.

Görsel 1. Fan-coil laboratuvar tavanı konumu

Sistem kompresör, sulu kondenser, evaporatör, genleşme valfleri ve yardımcı ekipmanlardan oluşturulmuştur. Isı pompası sisteminde soğutucu akışkan olarak R407C kullanılmıştır. Isı pompası sistemi kompakt bir yapıda tasarlanmış ve 60 litrelik bir su deposu bulundurmaktadır. Isı pompası sistemi istenildiği zaman ısıtma istenildiği taktirde soğutma modunda çalışabilecek şekilde dizayn edilmiştir. Bunun için ısı pompası sisteminde dört yollu valf kullanılmış ve çift yönlü çalışması sağlanmıştır.

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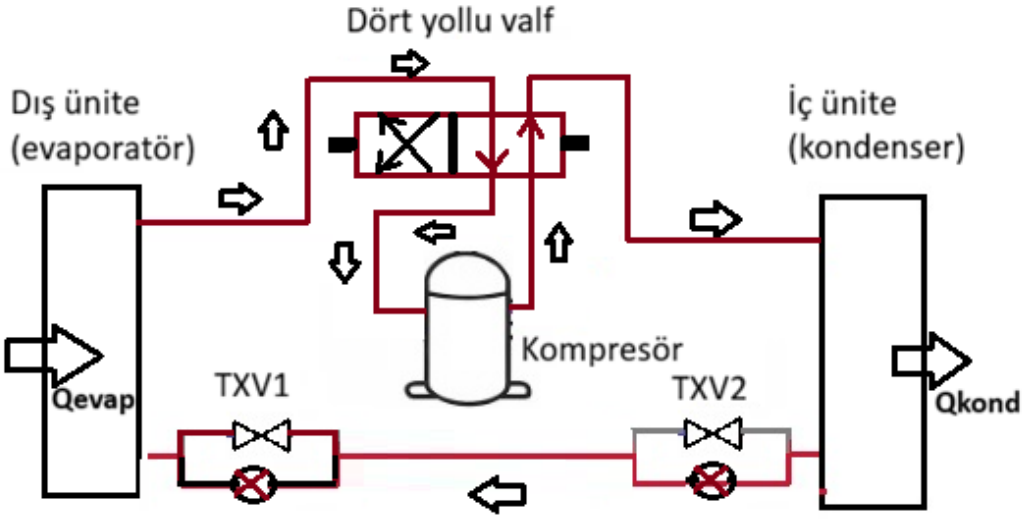
Görsel 2. Isı pompası sistemi ve laboratuvar dış duvarı fan-coil su bağlantıları

Sistem ısıtma modunda çalıştırılmasına ait şematik gösterim Görsel 3'de verilmiştir. Kompresörden çıkan kızgın buhar fazındaki soğutucu akışkan dört yollu valf ile bu durumda kondenser olarak çalışan iç üniteye gelerek ısısını atarak yoğuşur ve iç ortamın ısınmasını sağlar. İç üniteden doymuş sıvı olarak çıkan soğutucu akışkan bu durumda aktif olmayan TXV2'yi by-pass eder ve evaporatör öncesi aktif durumda olan TXV1'e gelir. TXV1'de basıncı ve sıcaklığı düşen soğutucu akışkan doymuş sıvı buhar karışımı olarak evaporatör girişine gelir. Evaporatörde dış ortamdan ısı çekerek buharlaşan soğutucu akışkan doymuş buhar fazında dört yollu valfe gelir ve daha sonra kompresöre giderek çevrimini tamamlar.

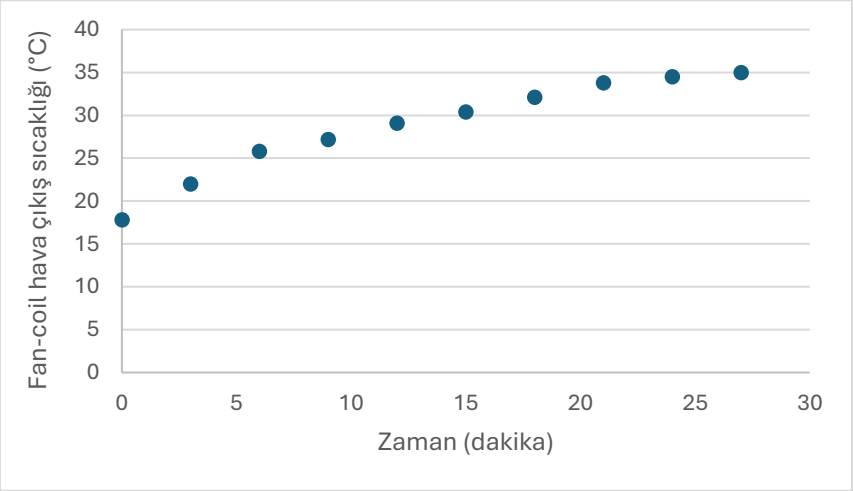


Görsel 3. Isı pompası sistemi ısıtma durumunda soğutucu akışkanın izlediği yollar

ISBN NR: 978-625-5694-92-8

3. SONUÇLAR VE DEĞERLENDİRME

Deneyler 15 °C dış hava sıcaklığı koşullarında yapılmıştır. Laboratuvar iç ortamında başka bir ısıtıcı çalıştırılmamış ve havanın ısıtılması ısı pompası ile sağlanmıştır. Isı pompası 30 dakika boyunca çalıştırılmış ve ekipmanların giriş ve çıkış noktalarından sıcaklık ve basınç değerleri ölçülmüştür. Sıcaklık ölçümü için dört kanallı CEM marka sıcaklık ölçüm cihazı kullanılmıştır. Görsel 4'de deney boyunca fan-coil hava çıkış sıcaklığı (°C) zamana bağlı olarak değişimi gösterilmiştir. Hava çıkış sıcaklığının 15 °C civarından 30 dakika sonunda 35 °C'ye ulaştığı görülmüştür.



Görsel 4. Deney boyunca fan coil-hava çıkış sıcaklığı değişimi

Isı pompası ekipmanlarının giriş çıkış noktalarında okunan sıcaklık değerleri ve manometrelerden ölçülen basınç değerleri kullanılarak entalpi değerleri hesaplanmıştır. Isı pompası sistemi kompresör gücü, ısıtma kapasitesi ve ısıtma tesir katsayısı (COP ısıtma) değerleri belirlenmiştir. Yapılan hesaplamalar sonucu ısı pompası kompresör gücü 1,02 kW, ısıtma kapasitesi 4,95 kW ve COP ısıtma değeri 4,85 olarak elde edilmiştir.

4. GENEL DEĞERLENDİRME VE SONUÇLAR

Bu çalışmada hava kaynaklı ısı pompası test sisteminin laboratuvar ısıtılması için kurulumu ve performansının değerlendirilmesi gerçekleştirilmiştir. Isı pompası test sistemi laboratuvar dış duvarına yerleştirilmiş ve fan-coil ile bağlantı hale getirilerek test edilebilir hale getirilmiştir. Su kaynaklı ısı pompası sistemi ile ısıtılan su, boru bağlantı hatları ile fan-coil sistemine gönderilmiş ve laboratuvar iç ortamının ısıtılması sağlanmıştır. Fan-coil hava üfleme bölümüne yerleştirilen sıcaklık ölüm cihazı ile 30 dakika boyunca sıcaklık ölçümü gerçekleştirilmiştir. Deney sonunda üflenen hava sıcaklık değerinin 15 °C'den 35 °C'ye ulaştığı belirlenmiştir. Yapılan hesaplamalar sonucu ısı pompası kompresör gücü 1,02 kW, ısıtma kapasitesi 4,95 kW ve COP ısıtma değeri 4,85 olarak elde edilmiştir. Bu çalışma ile hava kaynaklı ısı pompası sistemlerinin test edilmesine yönelik olarak örnek bir yaklaşım sunulmuştur.

5. TEŞEKKÜR

Bu çalışma Yalova Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimi Tarafından Desteklenmiştir. Proje Numarası: 2023/YL/0018

ISBN NR: 978-625-5694-92-8

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ISBN NR: 978-625-5694-92-8

SERA İKLİMLENDİRME İÇİN GÜNEŞ ENERJİSİ TEKNOLOJİLERİ

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ÖZET
Örtü altında yapılan tarımsal üretim, sıcak ve kurak ortamlarda gıda üretimi için sürdürülebilir bir uygulamadır. Sert iklim koşulları ve su kıtlığı, yıl boyunca süren tarımsal üretimin önündeki başlıca engellerdir. Sera tasarımı, ortam koşullarına ve tarım türüne bağlı olarak sıcaklık, bağıl nem, karbondioksit (CO_2) konsantrasyonu ve aydınlatma gibi mikro iklimin yeterli kontrolünü sağlamalıdır. Bu bildiride, sıcak ve kurak iklimlerde verimli çalışma için önemli olduğu düşünülen, boyutlar, yönelim, şekiller, kaplama ve gölgeleme malzemeleri gibi sera tasarım özellikleriyle ilgili önceki araştırmalar ayrıntılı olarak incelenmektedir. Sıcak ve kurak koşullarda tatmin edici iklim koşullarına ulaşmak ve sürdürmek için etkili sera soğutma yöntemleri ve işletme stratejileri araştırılmaktadır. Bunlar arasında doğal ve zorlamalı havalandırma, buharlaştırıcı serinletme ve sisleme sistemleri yer almaktadır. Ayrıca, iç ortam iklim değişkenlerini izlemek ve düzenlemek için sera kontrol yöntemleri değerlendirilmektedir. Son olarak, fosil yakıtlara bağımlılığı en aza indirmeye ve verimli su yönetimi sağlayan mevcut sera sürdürülebilir teknolojileri ve temiz enerji uygulamaları anlatılmaktadır. Bunlar; depolama sistemleri, nemlendirme/nem alma sistemleri ve fotovoltaik (PV) sistemlerdir. Örtü altı tarım sektörünün gelecekte karşılaşacağı zorluklar belirtilmiştir. Gelecekteki bilimsel araştırma ve geliştirme konularına ilişkin öneriler sunulmuştur.

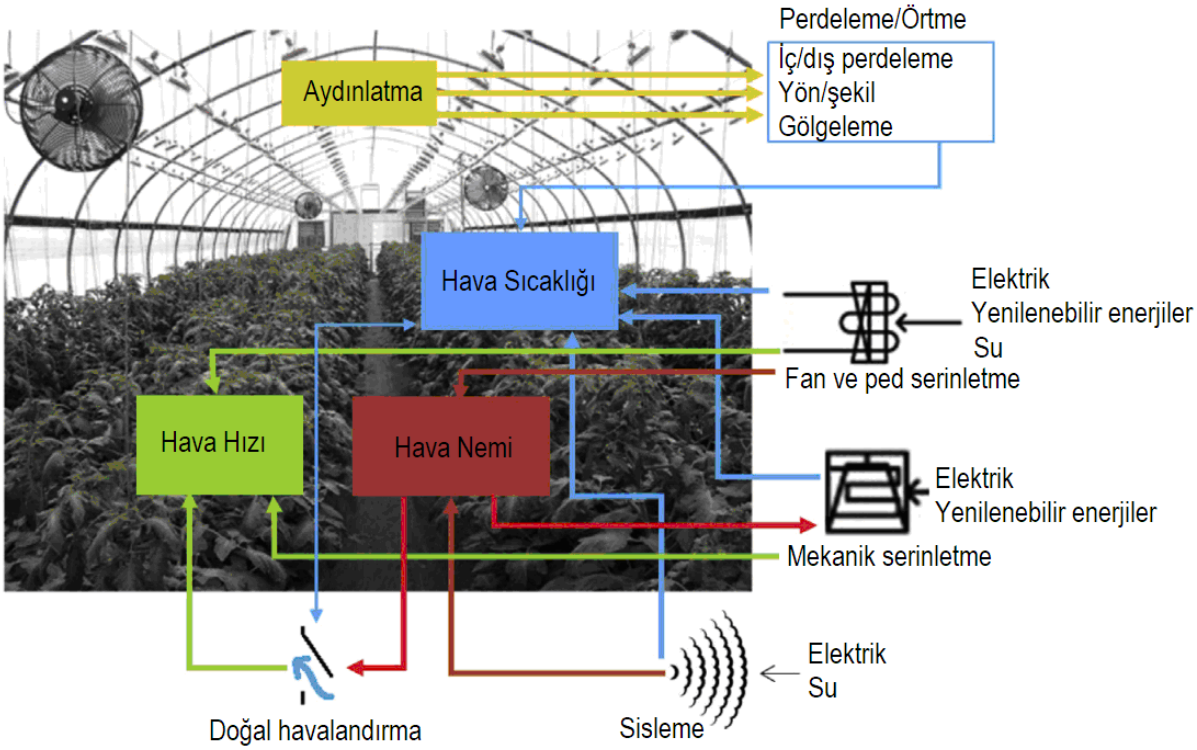
Anahtar Kelimeler: Sera, tasarım, iklim, sıcak, kurak.

1. GİRİŞ
Sera tarımı ve yetiştiriciliği, aşırı sıcaklık, bağıl nem gibi dış ortam iklim koşullarına karşı mekanik koruma ve gerekli CO_2 konsantrasyonu için daha iyi kontrol sağladığı için "korumalı" olarak tanımlanmıştır. Sera, verimli tarım için uygun bir mikro iklim ortamı yaratmak amacıyla ya "ısıyı içeride tutmaya" ya da "ısıyı dışarıda tutmaya" çalışır. Seralar, "bitki üretimi için fabrikalar" olarak kabul edilir (Russo ve Ark., 2014). Sert iklim ve su kıtlığı, tüm yıl boyunca açık havada yetiştiriciliğin önündeki başlıca engellerdir. Bu nedenle, sera tarımı, Orta Doğu ve Kuzey Afrika bölgesi (MENA) ve Körfez İşbirliği Ülkeleri (GCC) gibi sert iklim koşullarının olduğu bölgelerde etkililiğini göstermiştir. Bu bölümde, sıcak ve kurak iklimlerde faaliyet gösteren seraların tasarım zorluklarına odaklanılmaktadır. Kurak bölgeler, düşük yağış ve yüksek buharlaşma oranları ile karakterize edilir. Bu bölgelerde, yağış ve yüzey

ISBN NR: 978-625-5694-92-8

buharlaşması arasındaki fark olarak tanımlanan su dengesinin negatif olduğu ve bitki verimliliğini kısıtladığı gözlemlenmiştir.

Sıcak ve kurak ortamlarda, maksimum ortalama yağış miktarı yılda yaklaşık 150–450 mm'dir (Russo ve Ark., 2014). Ancak maksimum ortalama yağış miktarının 2 yıl boyunca 50 mm'den az olabileceği dönemler olabilir (Martin, 2006, Ghani ve Ark., 2017). Kurak bölgelerde, optimum bitki gelişimi ve artan verimlilik, tropikal bölgelerdeki yetiştirme için gerekenlerden farklı nem seviyeleri gerektirir (Alar ve Sabado, 2017). Bu nedenle, seralarda iklim kontrolü için farklı stratejiler dikkate alınmalıdır. Seraların işletme sistemleri, kapasitesine, yönelimine, malzemelerine, rüzgar ve güneş ışınımına ve iç ortam iklim değişkenlerini, diğer bir deyişle sıcaklık, bağıl nem, CO_2 konsantrasyonu ve ışınımı kontrol etme yöntemlerine bağlıdır (Görsel 1). Bu uygulamalarla ürün verimi en üst düzeye çıkarılır ve bitki zararları önlenir.



Görsel 1. Sıcak iklimlerde sera mikro iklim yönetimi için işlevler ve tasarım etmenleri (Ghoulem ve Ark., 2019)

Seraların genel tasarımında, iklim değişkenleri, ortam koşulları, finansal ve hukuki yönler dikkate alınmalıdır. Seranın iklim değişkenleri ve koşulları, ürünün her büyüme aşamasında değişerek sistemi sürekli olarak günceller. Etkili bir sera tasarımı, yüksek ısı değişim katsayısı, ticari uygulanabilirliği gösteren düşük yatırım maliyeti, düşük işletme maliyetleri, düşük bakım ve su tüketimi ile karakterize edilen yüksek soğutma verimliliğine ulaşmalıdır. Isı yalıtımlı yapı, sera boyunca eşit dağılmış bir sıcaklık profili sağlamalıdır. Sera, kum, toz ve kuvvetli rüzgarlar gibi diğer çevresel etmenlere karşı koruma sağlamalıdır. Optimum termo-higrometrik değerlerden sapma, ısı veya su stresine, bakteri ve mantar enfeksiyonuna ve üretimin azalmasına neden olabilir. Bu bölümde, sıcak ve kurak iklimlerde sera tasarımının zorlukları kapsamlı olarak incelenmektedir. İnceleme esas olarak yapısal

ISBN NR: 978-625-5694-92-8

tasarım özellikleri, soğutma teknolojileri ve mikro iklim kontrolüne ayrılmıştır. Ayrıca, seralarda sürdürülebilir yenilenebilir enerji teknolojilerinin kullanımına ilişkin araştırmalar da değerlendirilmektedir. Son olarak, sera endüstrisinin karşı karşıya olduğu gelecekteki zorluklar da incelenmiştir.

2. SERALARIN YAPISAL TASARIM ÖZELLİKLERİ

2.1. Sera Geometrisi Ve Boyutları

Sera geometrisi ve boyutları esas olarak ürün türüne, ürün miktarına ve iklim kontrolü için uygulanan yönteme bağlıdır. Sera genişlik/uzunluk (G/U) oranı, sera boyunca sıcaklık ve nem dağılım profilinin homojenliğini etkiler. G/U oranı, güneş ışınımına ve hakim rüzgara maruz kalan yüzey alanının bir göstergesidir. Yapılan araştırmalarda, farklı G/U oranlarına sahip farklı sera tasarımları incelenmiştir. Goosen ve Ark. (2003), tuzdan arındırma işlemleri için tasarlanmış seralar için, boyutların su üretimi ve enerji tüketimi üzerinde en büyük etkiye sahip olduğunu bildirmişlerdir. Genişlik/uzunluk oranları 0,25–4 aralığında incelenmiş ve oran ne kadar yüksekse, su üretiminin (65–100 m^3) o kadar yüksek, enerji tüketiminin de (4,0–1,4 kWh/m^3) o kadar düşük olduğu sonucuna varmışlardır. Umman'da, 0,27 G/U oranına sahip bir seranın tatlı su üretimi yaklaşık 297 L/gün olarak belirlenmiştir (Mahmoudi ve Ark., 2008). Seralarda maksimum güneş enerjisi toplamak için G/U oranı 0,1 olarak önerilmiştir (Çakır ve Ark., 2015). Sera soğutma enerjisi gereksinimleri güneş ışınımına bağlıdır. 0,3 G/U oranına sahip bir sera, 110 kW değerinde bir soğutma gücü gerektirir (Campiotti ve Ark., 2016). Rüzgar özelliklerinin sera mikro iklimini etkilediği, ıslah edilmiş kıyı arazileri üzerine inşa edilen ve G/U oranları 0,08 ile 0,16 arasında değişen seralarda; stabilite ve türbülans, G/U oranından ziyade sırt yüksekliğine ve eğim açısına daha fazla bağlıdır (Kwon ve Ark., 2016). Uzun bir sera, uzunluğu boyunca hava hızı ve sıcaklığın düzensiz dağılımından kaçınmak için G/U oranı 0,5'e yakın bir oranda tasarlanmalıdır (Jain ve Tiwari, 2002).

2.2. Sera Şekilleri

Seranın şekli, ürün yetiştiriciliğinde ve üretiminde önemli bir rol oynar. Sıcak ve kurak ortamlarda, optimum sera şekli yazın mümkün olan en düşük güneş ışınımını, kışın ise en yüksek güneş ışınımını almalıdır. Çatının şekli, seranın alacağı güneş enerjisi miktarını belirler. Tipik olarak, sera şekilleri beş farklı tipte karakterize edilir (Sethi, 2009). Sıcak ve kurak ortamlarda en sık kullanılan sera şekilleri Görsel 2'de verilmiştir. Eşit açıklıklı sera tasarımları en sık incelenen tip olarak kabul edilir. Hindistan'da Sethi (2009), biber yetiştiriciliği için 200 µm kalınlığında polietilen (PE) ile kaplı 24 m^2 alanına eşit açıklıklı bir serayı incelemiş ve 31 °K enlemindeki bir bölgede, eşit açıklıklı veya Quonset seraların kışın daha fazla, yazın ise daha az ışınım aldığı sonucuna varmıştır. Buna karşın, 50 °K enleminde tüm yıl boyunca yetiştiricilik için eşit açıklıklı olmayan seralar daha çok tercih edilebilirdir (Tiwari ve Ark., 2003). Gupta ve Chandra (2002) Delhi'nin soğuk ve güneşli günleri için, gotik kemer şeklindeki seraların, daha yüksek miktarda güneş ışınımı almaları nedeniyle, Quonset şekillerine kıyasla, daha düşük ısıtma gereksinimleri olduğunu bildirmişlerdir. Sıcak iklimlerde seraların soğutma gereksinimlerini azaltmak için, modifiye edilmiş kemer şekilli yapıların daha iyi performans gösterdiği kanıtlanmıştır (Tiwari ve Gupta, 2002). Standart simetrik sera çatılarına kıyasla, asimetrik sera çatıları yaz mevsiminde daha az güneş ışınımı alır (Malquori ve Ark., 1993).

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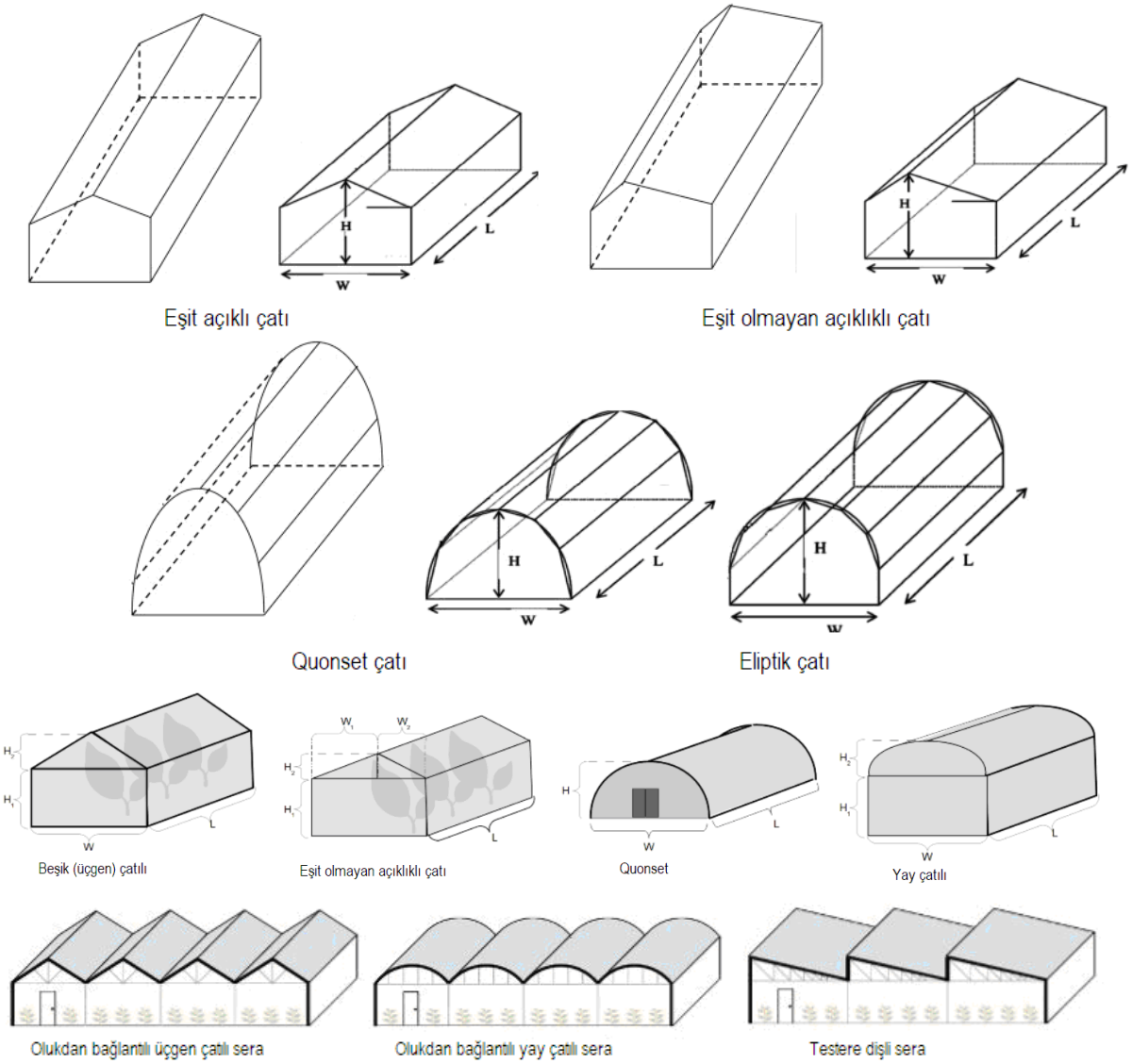
Bununla birlikte, asimetrik sera boyunca kabul edilen güneş ışınımı dağılımı eşit olmayacaktır (Fatnassi ve Ark., 2015).



Görsel 2. Yaygın olarak kullanılan sera tasarımları

Sera, bitki büyümesi için uygun bir ortam yaratmak amacıyla yaygın olarak kullanılan verimli yapılardan biridir. Bu tarım tekniğinin temel zorluğu, seralarda süregelen enerji ihtiyacıdır. Seranın tasarımı ve konumu, ısıtma ve soğutma için gereken enerji miktarını etkiler. Belirli bir bitki türü için ve belirli bir iklimde uygun bir mikro iklim sağlamak için sera tasarımının belirlenmesi önemlidir. Seraların tasarımı geliştirilmesinin ilk aşamalarında enerji optimizasyonu dikkate alınmalıdır. Şüphesiz, seranın tasarımı ve konumu ısıtma ve soğutma için ihtiyaç duyduğu enerji miktarını etkiler. Sonuç olarak, belirli bir yetiştirme sistemi için ve belirli çevre koşulları altında, seranın tasarımı mümkün olan en iyi mikro iklim koşullarını sağlayacak şekilde seçilmelidir. Chahidi ve Mechaqrane (2023) tarafından yapılan bir araştırmada, Fas'ın iklim bölgeleri için en uygun olanı seçmek amacıyla çeşitli sera tasarımları (şekil, zarf malzemesi ve yönelim) değerlendirilmiştir. Bu amaçla, dokuz farklı tasarım (düzensiz açıklık, tek eğimli çatı, standart eşit açıklık, mansart çatı, quonset, gotik kemer, modifiye edilmiş quonset ve modifiye edilmiş gotik kemer) (Görsel 3) ve dört malzeme (düşük

ISBN NR: 978-625-5694-92-8

yoğunluklu polietilen, kabarcıklı polietilen, etilenvinil asetat ve cam) olmak üzere farklı şekil/örtü malzemesi kombinasyonları dikkate alınmıştır. Uygun kombinasyonun seçilmesinin ardından, 0°, 90°, 45° ve -45° (uzun eksen ve Kuzey-Güney ekseni) olmak üzere dört farklı yönelim araştırılmıştır. Seranın enerji verimliliği, soğutma ihtiyacını azaltmak için doğal kontrollü havalandırma ve ısıtma sezonu boyunca çalışan gece ısı yalıtımı sağlanarak daha da artırılmıştır. Enerji tasarrufu potansiyelini belirlemek ve her iklim bölgesinde daha uygun tasarımı seçmek için; sera ısıtma ve soğutma yükleri, dikkate alınan bitki ihtiyaçlarına bağlı olarak sera tabanına gelen güneş ışınımı ve yıllık iklimlendirme maliyeti gibi farklı değişkenler dikkate alınmıştır. Belirlenen temel sonuçlar aşağıdaki gibi özetlenebilir:

- Dokuz farklı sera tasarımı analiz edilerek, tasarımın ısıl yükleri önemli ölçüde etkilediği belirlenmiştir. Bu nedenle, doğru tasarımın seçilmesi, ısıtma ve soğutma dönemlerinde sırasıyla, %26'ya ve %9'a varan enerji tasarrufu sağlayabilir. Böylece, yıllık enerji maliyetlerinde %20 düzeyine ulaşan azalma sağlanabilir.
- Düşük yoğunluklu polietilen (LDPE), kabarcıklı polietilen (BPE), etilenvinil asetat (EVA) ve cam olmak üzere dört zarf malzemesi araştırılmıştır. Sonuçlara göre, sera örtü malzemesi sera ısıl yüklerini önemli ölçüde etkilemektedir. Optimum seçim, ısıtma ve soğutma için enerji ihtiyaçlarını sırasıyla, %13 ve %12 oranlarına kadar azaltabilir. Böylece, yıllık enerji maliyetlerinde %10'a ulaşan bir azalma sağlanabilir.
- Gotik kemer şekli ve BPE örtü malzemesinin birleşimi, Fas'ın iklim bölgelerindeki minimum ısıl yükler, yıl boyunca bitki güneş ışınımı ihtiyaçları dikkate alındığında, domates bitkilerinin serada üretimi için iyi bir uzlaşmadır.
- Optimum sera yönünün seçimi, 0°, 90°, 45° ve –45° (uzun eksen ve Kuzey-Güney ekseni) olmak üzere dört yönün karşılaştırılmasıyla gerçekleştirilmiştir. Uygun seçim, ısıtma ve soğutma enerjisi gereksinimlerinde sırasıyla, %8,6 ve %13,4 düzeyine kadar tasarruf sağlayabilir. Böylece, yıllık enerji maliyetlerinde %4,5 oranına ulaşan bir azalma sağlanır. Fas için optimum sera yönünün 2 ve 3. bölgeler için 0°, diğer iklim bölgeleri için ise 90° olduğu bulunmuştur.
- Altı iklim bölgesinde, sera ısıtma yüklerini en aza indirmek için seralarda gece yalıtımı uygulanmıştır. Yıllık olarak, 1. bölgede (Agadir) ve 4. bölgede (Infran) ısıtma yüklerinde sırasıyla, 6,18 kWh/m^2 ile 21 kWh/m^2 arasında değişen azalmalar sağlanmıştır. Bu değerler iklim bölgesine bağlı olarak %13 ile %17 arasında değişen enerji tasarrufu potansiyeline eşdeğerdir.
- Soğutma yüklerini en aza indirmek için kontrollü doğal havalandırma incelenmiştir. Yıllık olarak, 6. bölgede (Errachidia) ve 2. bölgede (Tangier) soğutma yüklerinde sırasıyla, 54,17 kWh/m^2 ile 85,48 kWh/m^2 arasında değişen azalmalar sağlanmıştır. Bu değerler, iklim bölgesine bağlı olarak, %10,3 ile %21,8 arasında değişen bir enerji tasarrufu potansiyeline eşdeğerdir.
- Önerilen tasarım (şekil, örtü malzemesi, yönlendirme, ısı yalıtım örtüleri ve açılabilir pencereler) birleştirildiğinde, domates serası iklimlendirmesinin yıllık enerji maliyeti, 1. bölge (Agadir), 2. bölge (Tanca), 3. bölge (Fes), 4. bölge (İfran), 5. bölge (Marakeş) ve 6. bölge (Errachidia) için sırasıyla, 142,88, 143,32, 174,25, 194,67, 170,14 ve 185,66 MAD/yıl/m^2 olarak belirlenmiştir.

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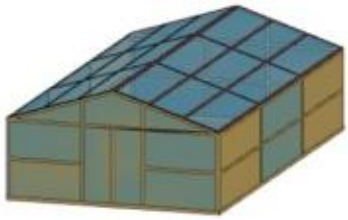		
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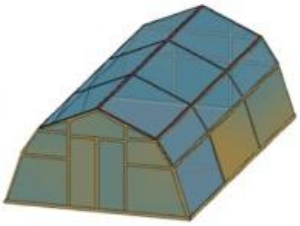
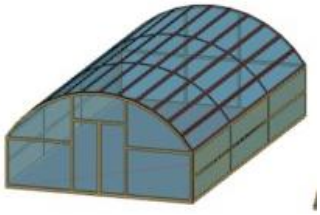
		
Mansart çatı	Modifiye edilmiş IARI	Quonset
		
Modifiye edilmiş quonset	Gotik kemer	Modifiye edilmiş gotik kemer

Görsel 3. Farklı tip sera tasarımları (Chahidi ve Mechaqrane, 2023)

2.3. Sera Örtü Malzemeleri

Örtü malzemeleri, ürünü dış ortamdaki olumsuz koşullardan koruyan ve ışınım geçirgenliğini, ısı yayılımını ve seraya giren ışınım miktarını kontrol eden kaplama malzemeleridir. Örtü malzemeleri, güneş ışınımının seraya girmesine izin verirken aynı zamanda uzak kızılötesi ışınımı engelledikleri için iki işlevli bir rol oynar. Seranın içindeki aktarılan ve yayılan ışınım dengesi, fotosentez ve buharlaşma-transpirasyon sürecini olumlu yönde kontrol ederek yüksek ürün kalitesi sağlayabilir. Diğer taraftan, aşırı gelen ışınım ürün hastalıklarına ve düşük üretime neden olabilir. Tipik bir serada enerji değişimleri Görsel 4'de gösterilmiştir.

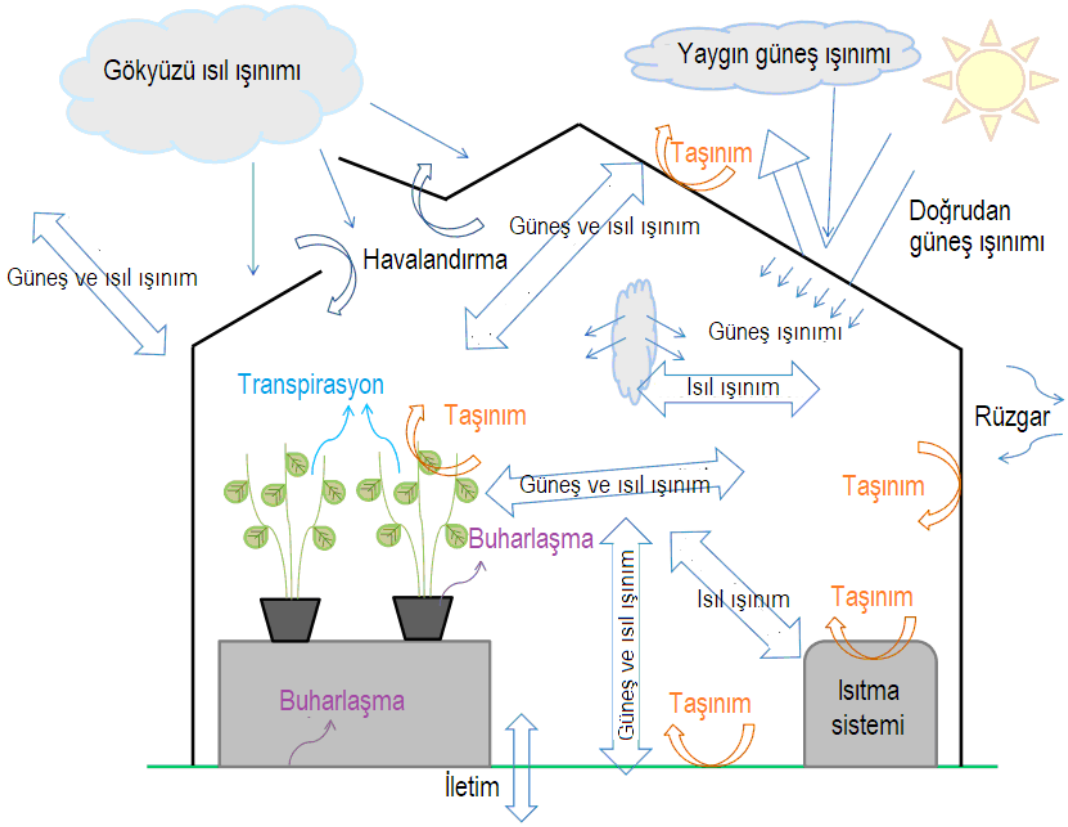
Sera örtü malzemelerinin seçimi, ürünün enerji ihtiyaçlarına ve mevcut bütçeye bağlıdır. Sera örtü malzemesi olarak tek veya çift katlı cam veya plastik malzemeler kullanılabilir. Cam malzeme fotosentez için aktif ışınım (PAR) iletimini desteklerken, polietilen (PE) plastik yakın kızılötesi ışınım (NIR) iletimini destekler (Kittas ve Ark., 1999). NIR yansıtıcı malzemenin seranın enerji dengesini %8 oranında azalttğı kanıtlanmıştır (Stanghellini ve Ark., 2011).

PE örtülerinin iletim oranları 0,7 (García ve Ark., 2011a,b; Sethi ve Sharma, 2007c), 0,73 (Hanson, 1963), 0,8 (Sethi ve Dubey, 2011), 0,85 (Mongkon ve Ark., 2013, 2014), 0,9 (Berroug ve Ark., 2011) ve 0,92–0,93 (Cemek ve Ark., 2006) arasında değişmektedir. Cam örtü geçirgenliğinin 0,88 (Hanson, 1963), 0,89 (Pollet ve Pieters, 2000) ve 0,90 (Dos Reis Benatto ve Ark., 2017) olduğu bulunmuştur. Camın gece IR ışınımına karşı en yüksek (%93) oranda, PE örütünün ise en düşük (%26) oranda ısı koruması sağladığı bulunmuştur (Hanson, 1963). Fiberglas levhalar, beş farklı malzeme arasında en düşük ışınım geçirgenliği göstermiştir.

ISBN NR: 978-625-5694-92-8

Fiberglas, PE, polikarbonat (PC), pleksiglas ve polipropilen (PP) dokusuz kumaş, 0,87'nin üzerindeki geçirgenlik oranıyla en iyi performansı göstermiştir (Fadel ve Ark., 2016). Ayrıca, sıcak ve kurak ortamlarda sera örtü malzemesi olarak fiberglas kullanılması, PE malzemeye kıyasla soğutma sisteminin verimini %8,70 oranında artırmıştır (Al-Amri ve Ark., 1999). Tropik bölgelerde üretimi artırmak için, Endonezya'daki bir sera için 200 µm kalınlığında bir plastik film örtü malzemesi kullanılmıştır (Hemming ve Ark., 2006). Plastik film örtü malzemesinde UV bloke edici bir pigment kullanılmıştır ve gelişmiş ışınım yayma özellikleri sağlarak bitki üretim alanında önemli bir soğutma etkisi sağlamıştır. Birleşik Arap Emirlikleri gibi kurak ortamlarda, Hesaplamalı Akışkanlar Dinamiği (CFD) çalışmaları, Kuzey-Güney yönlü seralarda, yeşil veya beyaz boyalı diğer malzemeler yerine PC levhalar örtü malzemesi olarak kullanıldığında hıyar üretiminin daha yüksek olduğunu vurgulamıştır (Subin ve Ark., 2018). Hindistan'ın tropikal ikliminde, hıyar üretimi için bir sera inşa etmek amacıyla duvar olarak alüminat perdeler kullanılmıştır (Singh ve Ark., 2018).

Sera örtü malzemesinin kalınlığı, seranın ömrünü belirleyen önemli bir faktördür. Malzemelerin bozulması, seranın içindeki ve dışındaki ortam ve mikro iklim koşullarına bağlıdır. Sera örtü malzemelerinin kalınlık, sertlik, dayanım ve geçirgenlik özellikleri malzemeler arasında farklılık gösterir. Genellikle 0,14 mm ile 0,20 mm arasında değişen kalınlıktaki PE levhaların ömrü yaklaşık 3–4 yıldır (Scarascia Mugnozza ve Ark., 2012). 0,15 mm kalınlığında PE örtülerle örtülü seralarda birçok araştırma yapılmıştır. Bununla birlikte, araştırmalarda 0,10 mm ve 0,20 mm kalınlığında PE örtüler de kullanılmıştır. Cam seralarda yaygın olarak 4 mm kalınlığında cam kullanılmakla birlikte, 3 mm (Marucci ve Cappuccini, 2016) ve 7 mm (Yang ve Ark., 2016a,b) kalınlığında cam malzemeler de kullanılmıştır.



Görsel 4. Serada enerji dengesi

ISBN NR: 978-625-5694-92-8

Ek örtü malzemeleri arasında silika cam, polivinilklorür (PVC) ve düşük yoğunluklu polietilen (LDPE), polimetil metakrilat (PMMA), polikarbonat (PC) ve polivinil florür (PVF) filmler veya cam-film kombinasyonları bulunmaktadır. İki katmanlı sera örtü malzemelerinin etkileri, Ahmed ve Ark. (2011) tarafından Sudan Eyaleti, Hartum'da ve Villarreal-Guerrero ve Ark. (2012a,b) tarafından Arizona'da tünel tipi seralarda test edilmiştir. Abbouda ve Ark. (2012), domates üretimi için 9 cm iç hava boşluğu olan iki kat örtü uygulamışlar ve buharlaştırmalı serinletmenin boşluksuz olana kıyasla daha yüksek verim sağladığı belirlenmiştir. Optimum iç koşullar, domates verimini %76'dan fazla artırmıştır. Birden fazla malzeme katmanı, gelen ışınımı ve dolayısıyla seradaki enerji dengesini değiştirerek yüksek işletme maliyetlerine neden olabilir (Sanford, 2011). Endonezya gibi tropikal iklimlerde, örtü malzemeleri seranın iç ortam iklimini önemli ölçüde etkilemez. Çünkü sera mikro iklimi, havalandırma ve yaprak alanı indeksindeki değişikliklere daha duyarlıdır (Impron ve Ark., 2008).

Chahidi ve Mechaqrane (2023) Fas'ın 6 farklı iklim bölgesi için yaptıkları çalışmada, tüm sera tasarımları ve iklim bölgeleri için, kabarcıklı polietilen (BPE) örtü hem ısıtma hem de soğutma dönemlerinde en etkili malzeme olarak belirlenmiştir. Bu durum, PBE malzemesinin hava kabarcıkları içeren geliştirilmiş bir polietilen (PE) film türü olmasıyla açıklanabilir. Hava bir yalıtkan görevi gördüğünden, PBE malzemesinin yüksek ısıl dirence sahip olmasını ve böylece sera ile dış ortam arasındaki ısı transferini azaltmasını sağlar. Ayrıca, incelenen malzeme özelliklerine göre, PBE malzemesi diğerlerine kıyasla en düşük ısıl iletkenliğe (0,22 W/mK) ve PAR (%63) ve NIR (%68) ışınım geçirgenliğine sahiptir. Bu durum, bitkinin ihtiyaçlarını dikkate alarak örtü malzemesinden geçen güneş ışınımı miktarının analiz edilmesini gerekli kılar. Isıtma gerektiğinde, EVA malzemesi daha yüksek yükler oluşturur, ardından LDPE malzemesi, ardından cam ve son olarak BPE malzemesi gelir. Soğutma gerektiğinde, en yüksek yüklere neden olan malzeme camdır, ardından EVA ve LDPE gelir. BPE malzemesi en etkili örtü malzemesidir. BPE malzemesiyle sera geometrik tasarımının birlikte etkisi incelendiğinde, gotik kemer tasarımı ve BPE örtünün birlikte kullanımı, altı bölge için en uygun kombinasyon olarak belirlenmiş olup, yıllık iklimlendirme maliyetlerinde %23–27 aralığında değişen oranlarda azalma sağlanmıştır. Sera şeklinin seçimi, yıllık iklimlendirme maliyetlerini %16–20 oranında azaltabilirken, dış örtü malzemesi bu maliyeti %8–10 oranında azaltmıştır. Isıtma periyodu boyunca çalışan gece ısı yalıtım perdeleri ısıtma gereksinimini, bölgelere göre %13–17 aralığında değişen bir oranda azaltmıştır.

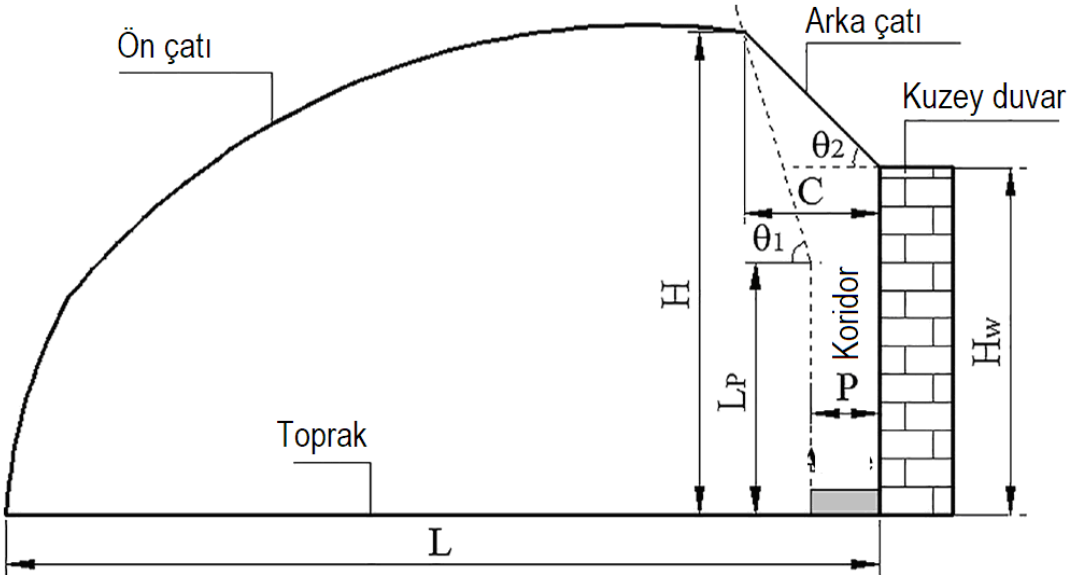
Sera şekli ve örtü malzemesinin seçimi, gelen güneş enerjisinden etkilenen sera ortamında istenen sıcaklık profiline bağlıdır. Bu durum, sera şeklinin, boyutlarının, çatı tasarımının ve örtü malzemelerinden kaynaklanan kayıpların bir fonksiyonudur (Connellan, 2002; Papadakis ve Ark., 2000). Örtü malzemelerinin seçimi, verim türüne ve seranın konumuna göre ayarlanmalıdır. Genellikle, istenen malzeme geçirgenliğinin 0,7'den fazla olduğu kabul edilir. Önerilen malzeme kalınlığı, UV katkılı PE için 0,10 ile 0,20 mm, PC levhalar için 6–10 mm, fiberglas için 0,80 mm ve cam için 4 mm arasında değişebilir (Al-Amri, 2000).

2.4. Sera Yönlendirmesi

ISBN NR: 978-625-5694-92-8

Bir seranın yönünü, en uzun kenarına paralel olarak hizalanmış ana eksen belirler. Yönlendirme, verimli bir fotosentez süreci için seraya ulaşan ışınım miktarıyla bağlantılıdır. Sıcak ve kurak bölgelerde faaliyet gösteren seralar için araştırmacılar tarafından ağırlıklı olarak Doğu-Batı (D-B) ve Kuzey-Güney (K-G) iki ana yönelim incelenmiştir Sera yöneliminin optimum seçimi, coğrafi konuma, mevcut parsel büyüklüğüne, planlamaya ve yetiştirilen ürüne bağlıdır.

D-B yönelimli bir serada, tüm enlemlerde ve tüm yıl boyunca, eşit açıklıklı seralar, sahip oldukları en büyük güney duvarı nedeniyle, en fazla miktarda güneş ışınımı toplar (Sethi, 2009). D-B yönelimli seraların kuzey duvarı (Görsel 5); ürün büyümesini etkili bir şekilde destekler ve verim miktarını artırır (Sethi ve Dubey, 2011). Sera mikro iklimini etkilememek ve ısı yükünü en aza indirmek için kuzey duvarının betondan yapılması önerilmiştir (Santamouris, 1993; Singh ve Tiwari, 2000). D-B yöneliminin, tüm enlemlerdeki seralar (Sethi, 2009) ve cam seralar (Edwards ve Lake, 1965) için daha uygun olduğu bulunmuştur. Çünkü alınan toplam ışınım miktarının kışın yaz mevsimine kıyasla daha fazla olduğu belirlenmiştir. Mevcut bir doğu-batı yönelimli seranın saat yönünde 45° döndürülmesi, kışın en düşük ışınım kaybına, yazın ise en yüksek ışınım kaybına neden olmuştur (Gupta ve Ark., 2012).



Görsel 5. Serada kuzey duvar tasarımı

Yaz döneminde K-G yönelimli seralar daha fazla miktarda güneş enerjisi alır. Bu durum iklim kontrolü için enerji gereksinimini arttırır (Chandra, 1976). 37°K enlemlerinde, 10° çatı eğimine sahip D-B yönelimli seralar, K-G veya eğimli seralara kıyasla, biraz daha yüksek iletim oranları sunarken, 30° çatı eğimlerinde iletim farkı %13 oranına kadar çıkmıştır (FAO, 2013). Çatı eğiminden bağımsız olarak, aynı enlem (37° 58° K) için D-B yönlendirmesi (Papadakis ve Ark., 1998) tarafından önerilmiştir. Bunun aksine (Rosa ve Ark., 1989), tüm yıl boyunca daha verimli olabilecek daha düzgün bir ışınım dağılımı için K-G yönelimini önermiştir. Işık homojenliği açısından, oluk ve sırt gölgeleri gün içinde güneşin yörüngesine göre konumlarını değiştirdiğinden, K-G yönelimi önerilmiştir (FAO, 2013). Bazı Akdeniz bölgelerinde sera yöneliminin D-B, ancak ürün sıralarının K-G yönelimli olduğu gözlemlenmiştir (FAO, 2013).

Seranın yönü, ısıtma ve soğutma yapılan dönemlerde ısıtma ve soğutma yükleri arasında denge sağlayacak şekilde seçilmelidir. Sonuç olarak, kurak ve yarı kurak alanlarda seracılık

ISBN NR: 978-625-5694-92-8

için, D-B yönelimi, K-G yönelimine kıyasla, daha az ışınım ve güneş enerjisi aldığı için tercih edilir. Kabul edilen güneş enerjisi farkı, Chandra (1976) tarafından yaklaşık %7 olarak belirlenmiştir. Sonuç olarak, D-B yöneliminde yaz döneminde enerji gereksinimi düşüktür. Bu durum iklim kontrol yöntemlerini daha uygun fiyatlı hale getirme potansiyeline sahiptir. D-B yönelimi gün içinde daha az gölge sağlar ve bu nedenle büyüme oranları etkilenmez (Sanford, 2011).

4. GENEL DEĞERLENDİRME VE SONUÇLAR

Örtü altında yapılan tarımsal üretim, sıcak ve kurak ortamlarda gıda üretimi için sürdürülebilir bir uygulamadır. Sert iklim koşulları ve su kıtlığı, yıl boyunca süren tarımsal üretimin önündeki başlıca engellerdir. Sera tasarımı, ortam koşullarına ve tarım türüne bağlı olarak sıcaklık, bağıl nem, karbondioksit (CO_2) konsantrasyonu ve aydınlatma gibi mikro iklimin yeterli kontrolünü sağlamalıdır. Bu bölümde, sıcak ve kurak iklimlerde verimli çalışma için önemli olduğu düşünülen, boyutlar, yönelim, şekiller, kaplama ve gölgeleme malzemeleri gibi sera tasarım özellikleriyle ilgili önceki araştırmalar ayrıntılı olarak incelenmiştir. Sıcak ve kurak koşullarda tatmin edici iklim koşullarına ulaşmak ve sürdürmek için etkili sera soğutma yöntemleri ve işletme stratejileri araştırılmaktadır. Bunlar arasında doğal ve zorlamalı havalandırma, buharlaştırmalı serinletme ve sisleme sistemleri yer almaktadır. Ayrıca, iç ortam iklim değişkenlerini izlemek ve düzenlemek için sera kontrol yöntemleri değerlendirilmektedir. Son olarak, fosil yakıtlara bağımlılığı en aza indirmeye ve verimli su yönetimi sağlayan sürdürülebilir teknolojiler ve temiz enerji uygulamaları anlatılmaktadır. Bunlar; depolama sistemleri, nemlendirme/nem alma sistemleri ve fotovoltaik (PV) sistemlerdir. Örtü altı tarım sektörünün gelecekte karşılaşacağı zorluklar belirtilmiştir. Gelecekteki bilimsel araştırma ve geliştirme konularına ilişkin öneriler sunulmuştur.

Çalışmaların sonuçları, modern tarımın en düşük enerji talebiyle çalışmak için sıcak ve kurak ortamlarda uygulayabilecek serinletme yöntemlerinin yararlarını vurgulamaktadır. Aynı zamanda, yüksek kaliteli ürün üretimi ve teknolojinin uygulanabilirliği, önerilen yöntemlerin temel taşı olmaya devam etmektedir. Açık tarla tarımıyla karşılaştırıldığında, örtü altı tarımı yüksek bağıl nem değerleri nedeniyle, sulama suyunda %60–80 oranında azalma sağlayabilir (Fernandes ve Ark., 2003). Bu durum, su kıtlığı olan bölgelerde önemli bir faktördür. Seranın iklim değişkenleri ve koşulları, ürünün her büyüme aşamasında değişerek sistemi sürekli güncellemeye tabi tutar. Sera serinletme teknolojileri, iç ortam iklim koşullarını doğrudan etkileyen mevcut yerel çevresel değişkenler tarafından belirlenir. Seranın optimum yönelimi, ortam ışınımı ve rüzgar hızı gibi yerel iklim verilerine uygun olmalıdır. Seranın yaza göre kışın daha fazla ışınım alması nedeniyle doğu-batı yönelimi önerilir. Sera doğu-batı yönelimliyse, ısı yüklerini sınırlamak için tuğladan tasarımlanan kuzey duvarı önerilir.

Sera (genişlik:/uzunluk) oranı, sera boyunca sıcaklık ve nem dağılım profilinin homojenliğini etkiler. Sera boyunca homojen hava ve sıcaklık dağılımı sağlamak için (genişlik:uzunluk) oranı 0,5'e yakın olan seralar tasarımlamak tercih edilir (Jain ve Tiwari, 2002). Standart çatılarla karşılaştırıldığında, asimetrik sera çatıları yaz aylarında daha az güneş ışınımı alma konusunda mükemmel performansa sahiptir. Bu nedenle, seranın serinletilmesi daha az enerji gerektirecektir (Malquori ve Ark., 1993). Ancak, asimetrik sera boyunca gelen güneş ışınımı eşit olmayan bir şekilde dağılır (Hicham Fatnassi ve Ark., 2015).

Örtü malzemelerinin seçimi, ürün türüne ve seranın konumuna bağlı olarak yapılmalıdır. Genellikle, istenen malzemenin geçirgenliğinin 0,7'den fazla olduğu kabul edilir. Önerilen malzeme kalınlıkları, Ultraviyole katkılı polietilen için 0,10 ile 0,20 mm, polikarbonat levhalar için 6–10 mm ve cam için 4 mm arasında değişebilir. 0,80 mm kalınlığında fiberglas da kullanılabilir. Çatı ve yan duvarlar, yuvalar ve ek gölgeleme mekanizmasıyla donatılmış doğal havalandırma için açıklıklara sahip olmalıdır. Yaz aylarında güneş yükünün yüksek olduğu ülkelerde, sera gölgelemesi öncelikle beyaz boyalı çatılar, dış siyah gölgeleme filesi ve iç alüminyum katkılı perdelerle sağlanabilir. Yansıtıcı malzemeler de düşünülebilir.

İklim kontrol yöntemleri, ürün hasarını veya kaybını önlemek için yetiştirilen ürüne uygun olarak seçilmeli ve yerel iklim koşullarıyla uyumlu olmalıdır. Kurak bölgelerde sera iklimini kontrol etmek için yaygın olarak buharlaştırıcı serinletme pedleri kullanılmadır. Sera uzunsa, sıcaklık farklarını azaltmak için ikinci bir ped kurulumu önerilir.

Sera mikro iklimini kontrol etmek için, seranın boyutuna bağlı olarak, doğal havalandırma, zorlamalı havalandırma ve dış gölgeleme uygulanabilir. Büyük ölçekli üretim için, kurak bölgelerde sera kurulumu, yüksek sıcaklık ve düşük bağıl nem sorununu çözmek için mekanik gölgeleme mekanizmalarının kullanımını ve daha fazla sayıda buharlaştırmalı serinletme ve egzoz fanı ünitesini bir araya getirebilir. Yüksek su tüketimi nedeniyle sisleme veya püskürtmeli serinletme tekniklerinden kaçınılmalıdır.

Sera mikro iklim verileri mobil, doğrudan ve uzaktan yöntemlerle izlenebilir. Sıcaklık, nem ve gaz konsantrasyonlarının ölçümlerinin, merkezi veri ünitelerine bağlı sensörler ve düğümler aracılığıyla kaydedilmesi önerilir. Ağın sermaye maliyeti kısmen yüksek olsa da, sistem özellikle uzak bölgelerde faydalıdır. Ek enerji üretimi için yeşil uygulamalar, seranın yapısına yerleştirilen PV sistemler ile gerçekleştirilebilir. Gömülü borular ve kaya yatağı kanalları gibi sığ toprak ısı değiştiricileri aracılığıyla enerji depolama, sera işletmesi için sürdürülebilir çözümler sağlayabilir. Birleştirilmiş sürdürülebilir teknolojiler, uygulanabilir enerji çözümleri sağlayabilir. Sıcak ve kurak bölgeler için ideal su yönetimi yöntemlerinde, yoğuşturucular ve dahili boruları kullanılabilir. Mikro iklim soğutma stratejisi yöntemlerinin seçimi ve uygulanması, ürüne, ölçüm türüne ve maliyete uygun olmalıdır. Sera, düşük karmaşıklıkta sağlam bir tasarıma sahip olmalıdır. Böylece uygulamaların daha fazla yaygınlaştırılması, seranın uygulanabilirliğini artırarak maliyet optimizasyonu sağlayabilir. Yüksek su ve enerji verimliliği ile en düşük zararlı tehditlerini gösteren alternatif üretim sistemlerinin geliştirilmesi, sera endüstrisinin "temiz ve yeşil" hale gelmesini sağlayarak, minimum karbon ayak iziyle sağlıklı bir yaşam tarzını teşvik edecektir.

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ISBN NR: 978-625-5694-92-8

SERA İKLİMLENDİRME İÇİN GÜNEŞ ENERJİSİ TEKNOLOJİLERİ

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ÖZET
Sera yetiştiriciliği, daha yüksek verim ve daha iyi ürün kalitesi elde etmek için ürünlerin kontrollü bir ortamda yetiştirildiği modern bir tarım biçimidir. Sera üretiminde güneş enerjisi teknolojilerinden yararlanmak, enerji tüketimi bakımından sürdürülebilirlik artışı sağlayacaktır. Bu çalışmada, enerji açısında sürdürülebilir seralar için fotovoltaik (PV), güneş teknolojisinden yararlanma konusu tartışılmıştır. PV modüller, elektrik taleplerini karşılamak ve yeterli ürün üretimini sağlamak için ümit verici sonuçlar göstermektedir. Ancak, statik geleneksel PV modülleriyle ilgili temel sorun, sera ürünlerinin fotosentez verimliliğinde azalmaya neden olan gölgeleme etkisidir. Sabit PV modül uygulamalarının %1'inin domates ürününün verimini yaklaşık %0,66 oranında azalttığı bildirilmektedir. Bu olumsuzluğu önlemek için dinamik gölgeleme ve yoğunlaştırıcı güneş teknolojileri olmak üzere iki olası çözüm bildirilmektedir. Ayrıca, yarı saydam PV güneş teknolojilerinin entegrasyonu seralar için olası bir uygulamadır. Sera iç ortamını ısıtmak ve fosil yakıt ihtiyacını azaltmak için yoğunlaştırma ve depolama teknolojileri de değerlendirilmiştir. Fotovoltaik/ısıl (PV/T) sistemler, sera uygulaması için, PV/T modüllerin yüksek verimlilikleri ve tek bir panelden elektrik ve ısı enerjisi üretmeleri nedeniyle önem ve ilgi kazanmaktadır. Son olarak, güneş enerjisi teknolojilerinin seralarda kullanılmasıyla ürün verimi ve kalitesinin artırılabileceği ve sürdürülebilir ve çevre dostu enerji üretiminin sağlanabileceği sonucuna varılmıştır. Bununla birlikte güneş enerjisi teknolojilerinin daha çekici hale getirilmesi için daha da optimize edilmesi gerekmektedir.

Anahtar Kelimeler: Sera, Fotovoltaik, Güneş ısıl toplaçları, Fotovoltaik/ısıl toplaçlar,

1. GİRİŞ

Genel olarak, enerji, Dünya'da bulunan kömür, ham petrol, doğal gaz vb. gibi doğal kaynaklardan üretilir. Bu kaynaklar sınırlıdır ve sürekli kullanımları nedeniyle birkaç yıl içinde tükenecektir. Geleneksel enerji kaynaklarının yanı sıra, jeotermal, gel-git, hidrolik ve güneş enerjisi gibi yenilenebilir enerji kaynakları, yenilenebilir yeşil enerji kaynaklarıdır. Tüm yenilenebilir enerjiler arasında güneş enerjisi, her yerde bulunması ve serbestçe erişilebilir olması nedeniyle en yaygın enerji kaynaklarından biridir. Güneş enerjisi, güneş ocakları, güneş enerjili su ısıtıcıları, güneş enerjili ısıtma ve sera etkisi, güneş enerjili ısı pompaları, fotovoltaik (PV) paneller ve tuzdan arındırma gibi çeşitli ısıl sistemlerde kullanılabilir. Güneş enerjisi, mekanik, elektrik, kimyasal vb. diğer enerji biçimlerine doğrudan veya dolaylı olarak dönüştürülebilir. Güneş enerjisinin mekanik enerjiye dönüştürülmesi, elektrik üretimi için

ISBN NR: 978-625-5694-92-8

güneş ısıl santrallerinde gerçekleşir. Güneş enerjisinin kimyasal enerjiye dönüştürülmesi ise fotosentez süreciyle yeşil bitkilerde gerçekleşir. Bununla birlikte, güneş enerjisinin faydalı enerjiye dönüştürülmesinin esas olarak iki yaygın yöntemle gerçekleşmektedir (Görsel 1):

1) Güneş ısıl toplaçları ile güneş ışınımı-ısı enerjisi dönüşümü
2) Fotovoltaik (PV) hücreler kullanılarak güneş ışınımı-elektrik dönüşümü

Görsel 1. Güneş enerjisi teknolojileri: Sol: Fotovoltaik (PV) teknoloji ve Sağ: Isıl teknoloji

Seralarda yapılan deneysel ve sayısal çalışmalar, yetiştirilen ürün, iklim ve seranın yapısı dahil olmak üzere, çeşitli faktörlerin bir seranın yıllık enerji taleplerine katkıda bulunduğunu göstermektedir. Bu nedenle, bu tüketim değerleri doğrudan karşılaştırılamaz. Ayrıca, iklim kontrol cihazları olarak ısıtma, soğutma ve aydınlatma cihazları çoğunlukla kömür, petrol, odun ve doğal gaz gibi karbon esaslı kaynaklar kullanılarak çalıştırılır. Bu durum da küresel ısınmaya ve çevre sorunlarına katkıda bulunur. Küresel ısınmayla mücadele etmek ve sera enerjisi talepleri için sürdürülebilir bir enerji kaynağı sağlamak için, rüzgar, güneş, hidrolik ve biyokütle gibi alternatif çevre dostu yeşil enerji kaynakları enerji üretmek için kullanılabilir. Sera uygulamaları için yenilenebilir enerji kaynaklarından biri güneş enerjisidir. Bir sera genellikle açık bir alana inşa edilir. Bu nedenle ürünün fotosentez için temel ihtiyacını karşılamak için bol miktarda güneş ışınımına sahiptir. Bu nedenle, bu tür yerler güneş enerjisi teknolojisi için uygundur ve enerji üretimi için faydalıdır. Ayrıca, güneş enerjisi teknolojileri sera uygulamalarında çok aktif ve kapsamlıdır. Birçok araştırmacı seraya farklı türde güneş teknolojilerini entegre etmeye çalışmıştır. Bu bildiride, sera iklimlendirme uygulamalarında güneş fotovoltaik/ısıl sistemlerin kullanılması araştırılmıştır.

2. SERALARDA FOTOVOLTAİK UYGULAMALAR

Fotovoltaik (PV) teknoloji, güneş ışınımını fotovoltaik etki yoluyla doğrudan elektriğe dönüştürür. PV teknolojiler, sera uygulamaları için kullanılan geleneksel PV modüller ve yarı saydam modüller olarak sınıflandırılır (Görsel 2). Çoğu geleneksel PV modül silikon, monokristal ve polikristal silikondan yapılırken, yarı saydam PV modüller organik PV hücrelerden, boya duyarlı PV hücrelerden veya diğer yeni teknolojilerden yapılır. Farklı tipteki PV modüllerin elektriksel verimi son birkaç yılda iyileşmiştir. 1950'lerde geleneksel PV

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modüllerin maksimum verimi %15 düzeylerinde iken (Tyagi ve Ark., 2013), yıllar içinde sürekli olarak artmış ve günümüzde %25'e yükselmiştir (Ahmad ve Ark., 2020). Buna karşılık, son 30 yılda, PV modüllerin fiyatı önemli ölçüde azalmıştır. Sonuç olarak, güneş enerjisinden elektrik üretmek için PV teknoloji küresel ölçekte hızla gelişmiştir. Kurulum kapasitesi 2009 yılındaki 23 GW'tan 2019 yılında 627 GW düzeyine yükselmiştir (REN21, 2020).

Görsel 2. Sera çatısında fotovoltaik (PV) sistemler

2.1. Fotovoltaik/Isıl Toplaçlar

Günümüz dünyası çevrenin bozulması ve enerjinin tükenmesi olmak üzere iki önemli sorunla karşı karşıyadır. İnşaat sektörü dünyanın toplam enerjisinin %40'ını tüketmekte ve inşaat sektörünün yaydığı sera gazları (GHG) dünyanın toplam GHG emisyonunun üçte birini oluşturmaktadır (Abdelrazik ve Ark., 2022). Fosil yakıt rezervleri giderek tükenmektedir, fiyatları istikrarsızdır ve çevreye zararlıdırlar. Bu durum küresel enerjinin üretim şeklini değiştirmiştir. Güneş enerjisi en umut verici yenilenebilir enerji kaynaklarından biri olarak kabul edilmektedir. Güneş enerjisini kullanmanın başlıca iki temel yöntemi vardır. Bunlardan biri güneş fotovoltaik (PV) güç üretimi, diğeri ise güneş ısıl güç üretimidir. Ancak, güneş ısıl güç üretimi ile sadece düşük kaliteli ısı enerjisi elde edilebilmiştir. Bu durum güneş ısıl güç uygulamalarını sınırlandırmıştır. PV kullanımı yüksek maliyet ve düşük verimlilik sorunlarıyla karşı karşıyadır. Bu nedenle, PV modülleri ve güneşten ısı enerjisi kazanma teknolojisini birleştiren fotovoltaik/ısıl (PV/T) teknoloji geliştirilmiştir (Görsel 3).

PV ünitelerin sıcaklıklarının yüksek olması durumunda, elektrik üretimi azalır ve hücrelerin yaşlanması hızlanır. Bu durum PV elektrik üretimi için en büyük sorun olarak kabul edilir. Yüksek sıcaklıklar, soğurulan güneş ışınımının bir kısmının elektrik yerine ısıya

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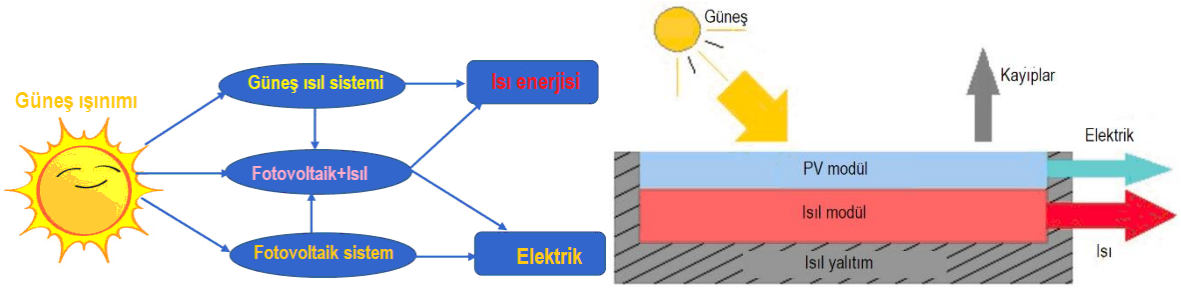
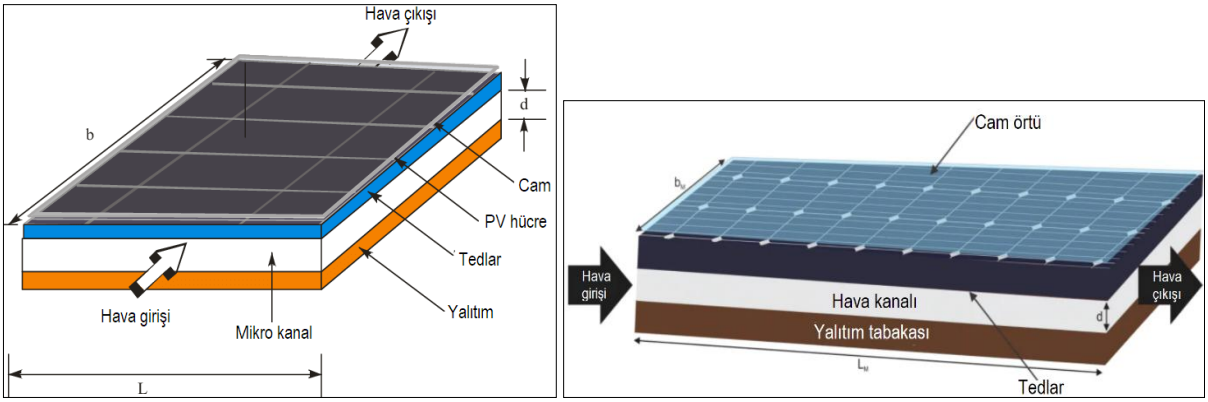
dönüştürülmesinden kaynaklanır. Sonuç olarak, biriken ısı enerjisi PV modülün çalışma sıcaklığını artırır ve dolayısıyla elektrik veriminde azalmaya neden olur. Standart Test Koşulları (STC) altında, PV modülün dönüşüm verimi bir birim sıcaklık artışı başına yaklaşık %0,40–0,50 oranında azalır (Abdelrazik ve Ark., 2022).



Görsel 3. Fotovoltaik/ısıl (PV/T) toplacın enerji üretimi

Çoğu PV hücrenin (örneğin silikon hücreler), artan hücre sıcaklıklarıyla birlikte elektrik üretme verimleri azalır. Bu nedenle, PV hücrelerden ısının uzaklaştırılması sıcaklıklarını azaltabilir ve böylece hücrelerin verimleri artırılabilir. Daha düşük çalışma sıcaklıklarının bir diğer faydası da PV hücre ömürlerinin uzamasıdır. Bu uygulama, sistemin toplam verimini ve güvenilirliğini en üst düzeye çıkarmak için etkili bir yöntemdir. Ancak, ısıl bileşenin sadece güneş ısıl toplacıyla sağlanabilecek performansa kıyasla düşük performans göstermesine neden olur. Diğer bir deyişle, çoğu PV/T sistem için max. çalışma sıcaklıkları, max. hücre sıcaklığından daha düşüktür (tipik olarak 85 °C'nin altında). Bununla birlikte, hücre verimine ve sistem tasarımına bağlı olarak, her birim elektrik üretimi için 2 veya daha fazla birim ısı enerjisi üretilir (Cao ve Ark., 2023).

PV modülün elektrik verimi, sıcaklığı arttıkça azalır. Sonuç olarak, PV hücrenin sıcaklığı PV modülün verimliliğini önemli düzeyde etkiler. PV modülü bir ısı transfer akışkanıyla soğutmak, elektrik verimini artırmak etkili yöntemdir (Görsel 4). Isı transfer akışkanı, PV modülün sıcaklığını azaltmaya yardımcı olur ve düşük sıcaklıklarda ısı enerjisi sağlayabilir. Bu nedenle, PV bileşenlerinin geleneksel bir ısıl toplaçla birleştirilmesi, sistemin genel enerji verimini artırabilir. PV/T modüller (Görsel 5), PV etki ile elektrik ve aynı anda güneş ısıl toplaçları gibi işlev yaparak ısı enerjisi üretir. Bu nedenle, PV/T modüllerin kullanımı, seranın elektrik ve ısıtma taleplerini önemli düzeyde karşılayabilir.

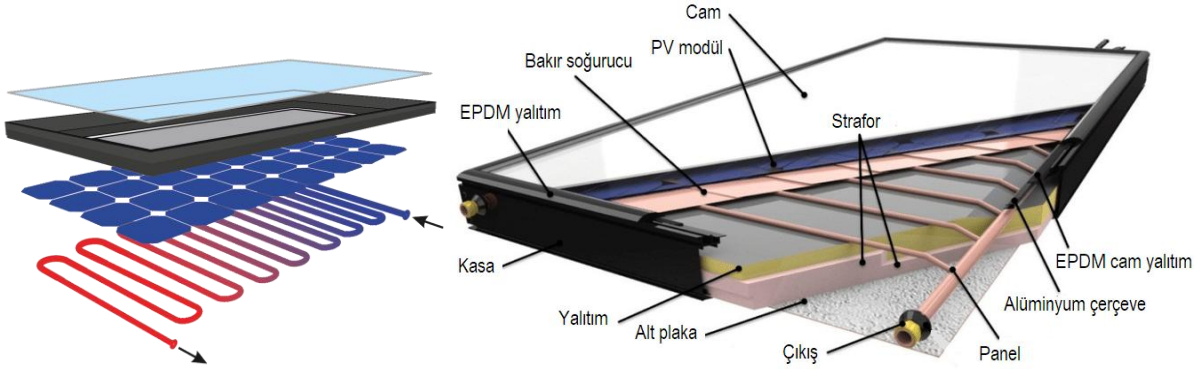


Görsel 4. Fotovoltaik/ısıl (PV/T) toplacın soğutulması

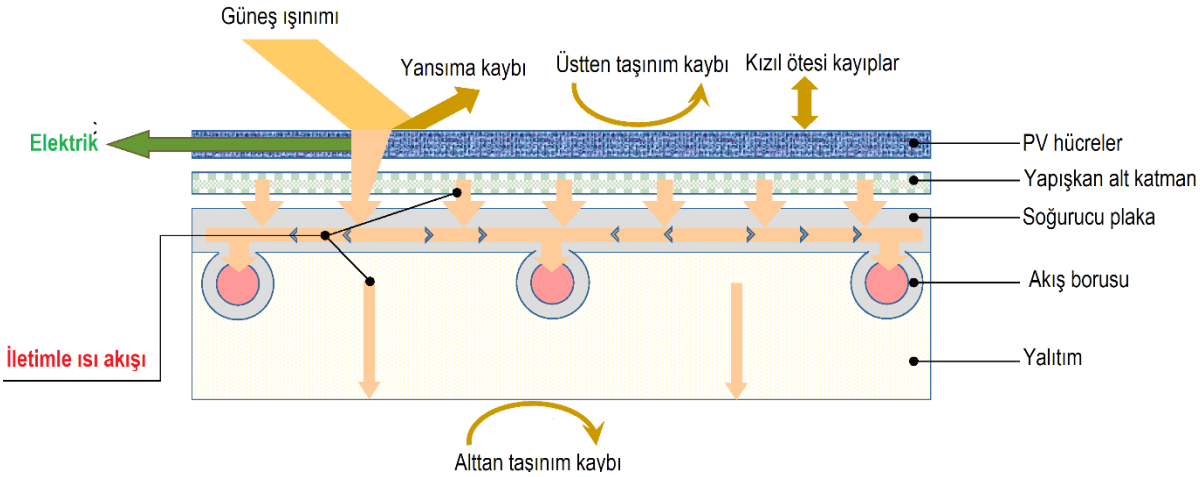
Güneş enerjisi, temiz ve verimli özellikleri nedeniyle geleneksel enerjinin yerini almak için yaygın olarak kullanılmaktadır. Güneş enerjisinin binaların enerji tasarrufunda büyük uygulama potansiyeli vardır. Güneş enerjisini binalarla birleştirmek maliyetleri azaltırken, daha

ISBN NR: 978-625-5694-92-8

yüksek verim sağlayabilir ve sistemin ömrü daha uzun olur. PV/T teknolojisi güneş fotovoltaik ve fototermal teknolojiyi birleştirir ve aynı anda sürdürülebilir elektrik ve ısı enerjisi üretilir. PV/T sistemler (Görsel 6) binalara kolayca entegre edilebilir. PV/T sistem tarafından üretilen elektrik ve ısı, ısı toplama işlemi, katı/sıvı nem alma işlemi ve foto/termal katalitik arıtma işlemi gibi çeşitli fiziksel ve kimyasal işlemlerde kullanılabilir. Bu nedenle, binaya entegre PV/T sistemin iç ortam hava sıcaklığı, hava nemi ve gaz kirleticilerin kontrolü gibi, bina ortamı kontrolünde etkin uygulama potansiyeli vardır. Son yıllarda PV/T üzerine yapılan çok sayıda araştırmanın temel olarak geliştirme süreci, ekipman ve malzemelere odaklanmıştır. Mevcut araştırmalarda, çevre kontrolü sıcaklık, nem ve hava kalitesi olmak üzere temel olarak üç noktaya odaklanmıştır. PV/T teknolojisi bu üç açıdan yaygın olarak kullanılmıştır. Örneğin, mevcut uygulama biçimleri arasında güneş enerjili sıcak su sistemi, güneş enerjili ısıtma sistemi, güneş enerjili kurutma ekipmanı ve güneş enerjili havalandırma yer almaktadır.



Görsel 5. Fotovoltaik/ısıl (PV/T) toplacın başlıca bileşenleri



Görsel 6. Fotovoltaik/ısıl (PV/T) toplacın çalışma ilkesi

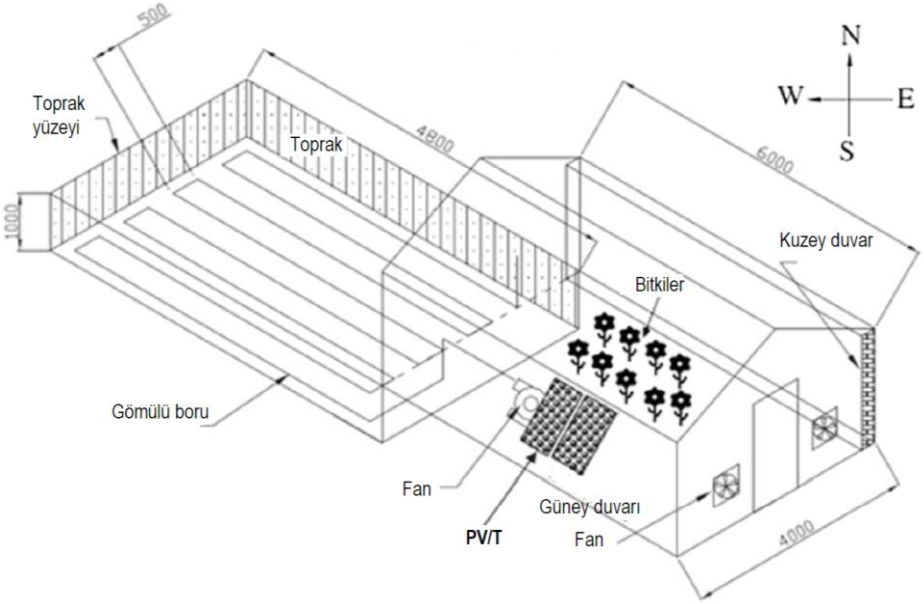
3. SERALARDA FOTOVOLTAİK/ISIL TOPLAÇ UYGULAMALARI

3.1. Düzlem Plakalı Fotovoltaik/Isıl Toplaç

Düzlem plakalı fotovoltaik/ısıl (PV/T) toplaç, PV hücrelerin arkasında bütünleşik durumda ısı üreten sıvı kanalları bulunan plaka tipi soğuruculardan oluşur. Enerji verimliliği terimi, PV/T toplacın performansını değerlendirmek için kullanılabilir. Ancak, enerji verimliliği açısından, elektrik ve ısı enerjisi eşit değerde kabul edilir. Gerçekte, elektrik yüksek kalitedeyken, ısı enerjisi düşük kalitededir. Sonuç olarak, PV/T sistemlerin performansını doğru bir şekilde değerlendirmek ve hem ısı hem de elektrik üretimini ayrı ayrı hesaba katmak için

ISBN NR: 978-625-5694-92-8

ekserji analizi yapmak tercih edilir. Yazdanifard ve Ameri (2018), PV/T toplaçlar için ayrıntılı bir ekserji ve enerji modeli geliştirmişlerdir. Nayak ve Tiwari (2008), Hindistan, Yeni Delhi'deki bir sera çatısı için PV/T toplacın performansını değerlendirmiştir. Bulgularına göre, 9,68 m^2 PV/T sistemin ürettiği yıllık ısı enerjisi ve elektrik sırasıyla, 21291 kWh ve 716 kWh düzeylerindedir. PV/T entegre seranın ekserji verimi %4 olarak belirlenmiştir. Ayrıca, ısıtma ve soğutma taleplerini karşılamada PV/T ve toprak hava ısı değiştiricilerinin yıllık etkinliğini izlemek için bir model geliştirmişlerdir. Bir kış gecesinde hava sıcaklığının 7 ˚C'den 8 ˚C'ye yükseldiği belirlenmiştir. Seraya entegre edilen PV/T sistemin ekserji veriminin %5,5 olduğu bulunmuştur (Nayak ve Tiwari, 2009). Mahdavi ve Ark. (2019), matematiksel hesaplamalarda tesisi hesaba katan kapsamlı ısıl modellemeyle benzer bir çalışma yapmışlardır. Sistem, Görsel 7'de gösterildiği gibi sera, topraktan havaya ısı değiştirici ve PV/T toplaç olmak üzere, üç bileşenden oluşmuştur. Bulgularına göre, seranın zemin yüzeyinde bir ısı değiştirici olan PV/T toplaçların önemli bir etkisi vardır.



Görsel 7. Isı değiştiricili seranın şematik görünümü (Mahdavi ve Ark., 2019)

Chaysaz ve Ark. (2019), cam, plastik ve polikarbonat olmak üzere, üç farklı çatı örtüsüne sahip prototip bir serada seri olarak iki PV/T toplacı değerlendirmişlerdir. PV/T toplacın en yüksek verimi, 0,03 kg/s kütle akış hızında ve serada ürün olmaması koşulunda, cam örtü için %59,9, plastik örtü için %54,56 ve polikarbonat örtü için %47,58 düzeylerindedir. Sajid ve Bicer (2021), kendi kendine yeten bir sera tasarımı için elektrik, tatlı su ve buhar sıkıştırmalı bir sistemle soğutma sağlamak için PV/T sistemin yaşam döngüsü analizini yapmışlardır. Entegre tuzdan arındırma sistemi ile tatlı su üretmek için PV/T toplaçtan üretilen ısı enerjisi kullanılmıştır. Seviyelendirilmiş elektrik, soğutma ve tatlı su maliyetleri sırasıyla, 0,033 $/kWh, 0,015 $/kWh ve 1,45 $/$m^3$ olarak belirlenmiştir.

3.2. Yoğunlaştırmalı Fotovoltaik/Isıl Toplaç

Yoğunlaştırmalı PV/T toplaçlar, seranın enerji gereksinimlerini karşılamak ve performansını artırmak için sera uygulamalarında kullanılmıştır. Örneğin, Sonneveld ve Ark., (2010), Görsel 8(a)'da gösterildiği gibi, ısıtma yükünü elektrik üretimiyle azaltmak için, bir seraya yoğunlaştırmalı PV/T toplaçlar ekleyerek yeni bir tasarım geliştirmişlerdir. Bitki

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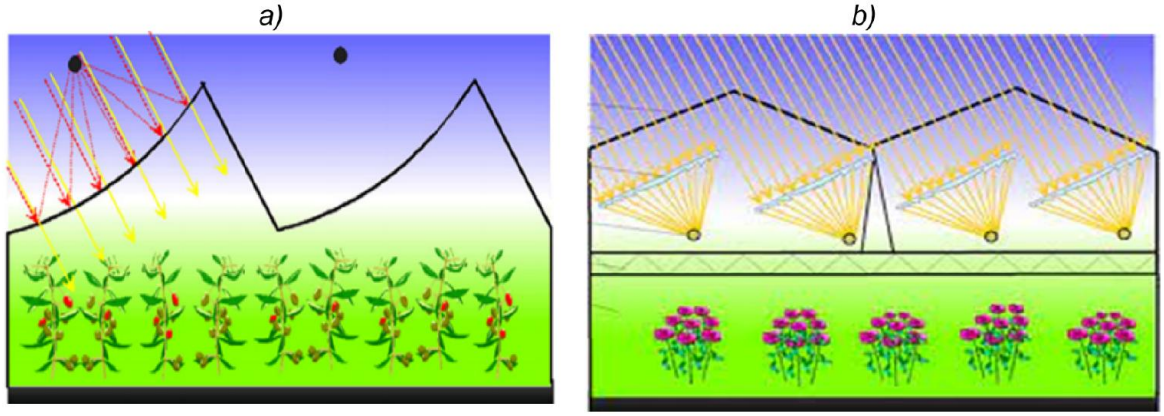
büyümesi için yararlı ışınımın geçmesine olanak sağlamak ve kalan ışınımı 30 yoğunlaştırma oranına sahip bir PV/T modüle yönlendirmek için seçici bir yansıtıcı örtü kullanılmıştır. Sonuç olarak, PV/T toplacın gölgeleme etkisi sadece %3,3 ile sınırlanmıştır. Yıllık ısı ve net elektrik üretimi sırasıyla, 32,5 kWh/m^{2}yıl ve 18 kWh/m^{2}yıl olarak gerçekleşmiştir. Başka bir çalışmada, Sonneveld ve Ark. (2011), doğrudan ışınımı PV/T toplacın odak çizgisine 25 kat yoğunlaştıran doğrusal *Fresnel* mercek refraktörlü CPV/T sistemleri kullanmayı önermişlerdir. Yer seviyesindeki ışınım enerjisi %75 oranında azalmış ve iklimlendirme ve sulama ihtiyacını sınırlamıştır. Bu yeni tasarımdan yıllık ısı enerjisi ve elektrik üretimi sırasıyla 29 kWh/m^{2}yıl ve 144 kWh/m^{2}yıl olarak belirlenmiştir. Sonneveld ve Ark. (2017) ayrıca, Görsel 8(b)'de gösterildiği gibi, Hollanda'nın Wageningen kentinde daha yüksek güç üretmek için, üç eklemli PV hücreye sahip başka bir *Fresnel* sera tasarımının sayısal simülasyonunu gerçekleştirmişlerdir. Sayısal değerler, maksimum yıllık elektrik ve ısı enerjisi üretiminin sırasıyla, 120 kWh/m^{2}yıl ve 180 kWh/m^{2}yıl olacağını öngörmüştür. Hemming ve Ark. (2014), elektrik ve ısı enerjisi üretmek için PV/T toplaçları olan Hollanda iklimi için iki yeni sera tasarımı (*Fresnel* ve lamel aynalar) geliştirmişlerdir. İki tasarımın karşılaştırılması sonucunda, *Fresnel* serasının lamel serasından iki kat daha fazla enerji ürettiği belirlenmiştir.



Görsel 8. *Fresnel* yoğunlaştırma sistemlerine örnekler: (a) Reflektör (Sonneveld ve Ark., 2010) ve (b) Refraktör (Sonneveld ve Ark., 2017)

Bazı araştırmalarda enerji üretimi için sera çatılarına parabolik oluk PV/T toplaçlar yerleştirilmiştir. Örneğin, Wu ve Ark. (2020) fazla ışınımı elektrik ve ısı enerjisine dönüştürmek için, Çin'deki bir güneş serasının üretim yapılmayan alanında parabolik bir yoğunlaştırıcı çatı tasarımlamıştır. Sıcaklık dağılımlarını ve seranın elektriksel ve ısıl verimini Monte Carlo ışınım izleme yöntemini kullanarak test etmişlerdir. Maksimum elektriksel ve ısıl verimler sırasıyla, %18 ve %45 olarak belirlenmiştir.

4. GENEL DEĞERLENDİRME VE SONUÇLAR

Dünyanın çeşitli bölgelerindeki sera uygulamaları için PV/T teknolojilerin (düzlem plaka ve yoğunlaştırıcı PV/T) kullanılması konusunda birçok araştırma yapılmıştır. Çoğu temsili çalışmanın, eşit açıklıklı bir sera yapısına sahip küçük boyutlu seralardan oluşan prototip seralar olduğu bildirilmektedir. Ek olarak, bu çalışmalardaki seraların üretim alanları 5,8 ile 100 m^2 arasında değişmektedir. Sera uygulamalarında esas olarak iki tip PV/T toplacın, düzlem plaka ve yoğunlaştırmalı doğrusal *Fresnel* (LFC) PV/T toplacın kullanıldığı belirlenmiştir.

Ayrıca, PV/T toplaç kullanılan çoğu serada domates ürünü yetiştirildiği gözlemlenirken, bazı araştırmalar ürün olmayan koşullarda yapılmıştır.

Düzlem plakalı PV/T toplaçların seraların ısı ve elektrik taleplerini karşılayabileceği bildirilmektedir. Bazı araştırmalarda, daha fazla elektrik ve ısı enerjisi sağlayabilen yeni bir sera tasarımında yoğunlaştırıcı LFC PV/T ve PTC PV/T toplaçlar kullanılmıştır. Örneğin, Sonneveld ve Ark (2017), maksimum elektrik ve ısı enerjisi üretiminin sırasıyla, 120 kWh/m^{2}yıl ve 180 kWh/m^{2}yıl olduğunu bildirmiştir. Ancak bu çalışmalarda, yoğunlaştırıcı PV/T toplaçları seralara entegre etmek için belirli bir tasarım stratejisi uygulanmamaktadır. Bu nedenle, uygulanabilir sera yapılarına sahip bu toplaçların kullanımını yaygınlaştırmak için daha fazla araştırma gereklidir.

Sera uygulamalarında, düzlem plakalı toplaçların seranın içine etkili bir şekilde ısı dönüşümü ve transferi nedeniyle dikkat çektiği belirtilmiş ve seranın ısıtma gereksinimlerini kısmen karşılamıştır. Bazı çalışmalar, bu toplayıcıların ısı depolama (TES) ile eşleştirildiğinde bir seranın tüm ısıtma taleplerini karşılayabileceğini bildirmektedir. Buna karşılık, hibrit PV/T modül, yüksek verimliliği nedeniyle sabit PV ve güneş ısıl toplaçlarına kıyasla, sera uygulamalarında önemli ölçüde ilgi görmektedir. Bu modüller aynı anda elektrik ve ısı enerjisi üretebilir. Sera çatısına kurulan düzlem plakalı PV/T, esas olarak çıkarılan ısının serada alan ısıtması için kullanıldığı su soğutmalı bir sisteme dayanmaktadır.

Güneş ışınımı yoğunlaştırıcılar, seralar için bir başka araştırma teknolojisidir. Daha az alıcı yüzey alanıyla daha fazla faydalı güç üretirler. Bu durumda ışınım alma verimi artar ve daha az gölgeleme oluşur. PV modüldeki yoğunlaştırıcın olumsuzluğu, panelin aşırı ısınmasıdır. Bu durum verimi önemli ölçüde azaltır ve bazen PV hücrelere zarar verir. Bu nedenle, sera uygulamaları için ısıl toplaç veya PV/T modüller ile birlikte yoğunlaştırıcı teknolojilerin kullanılması tercih edilir. Güneş ışınımı yoğunlaştırıcılar durumunda, paneller aşırı ısınmaz ve bu da sistemin dayanıklılığını sağlar. Bu nedenle, yoğunlaştırmalı PV/T modül sera uygulamaları için daha uygun görünmektedir. PV/T, güneş ışınımını daha küçük bir yüzey alanına alır. Böylece daha az gölgeleme yaratır ve sera ortamına daha fazla güneş ışınımının girmesine olanak tanır.

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ISBN NR: 978-625-5694-92-8

A DATA-DRIVEN APPROACH FOR FORECASTING AIRCRAFT EMISSIONS BASED ON LTO OPERATIONS

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ABSTRACT

This study aims to forecast aircraft-related emissions based on airport operational data. The research focuses specifically on Landing-Takeoff (LTO) activities and examines the change in emission values over time using operational data from previous years. A data-driven prediction model was developed, taking into account operational indicators such as the number of LTOs, traffic density, and fleet structure.

Us0ing the developed model, the potential future trends of airport-related emissions were assessed. The primary objective of the study is to predict the possible future values of emission levels based on changes in operational activities. The results obtained are expected to provide supportive information for airport management and relevant stakeholders in monitoring emissions and planning processes.

Keywords: Emission estimation, aviation emissions, LTO cycle, estimation model, airport operations.

INTRODUCTION

The aviation sector, one of the most dynamic components of the global transport system, is rapidly increasing its energy consumption and greenhouse gas emissions in parallel with the rapid growth in both passenger and freight transport. Particulate emissions such as carbon dioxide (CO_2) and black carbon, particularly from aircraft engines, not only contribute to global climate change but also adversely affect local air quality and public health around airports (Grewe et al., 2021).

ISBN NR: 978-625-5694-92-8

Scenarios are being developed in which global aviation CO_2 emissions could increase by 2–3.6 times between 2000 and 2050; the magnitude depends on economic growth, demand growth and technology assumptions (Owen et al., 2010).

Despite sector targets that appear consistent with the Paris Agreement goals, it is highly likely that aviation's total climate impact (CO_2 + contrails + NOx) will not be fully aligned with these targets(Grewe et al., 2021b).

Modelling specific to China shows that fleet carbon efficiency could increase by 2 per cent per year through technology, operational improvements and SAF integration, but that 2035 emissions would still be approximately 50 per cent higher than 2019 levels. (Zhang et al., 2025).

This study examines three different airports in Turkey:

- Ankara Esenboğa Airport
- İstanbul Sabiha Gökçen Airport
- Konya Airport

The main objective of the study is to estimate CO_2 emissions from aircraft operations at these airports and to reveal future emission trends.

A two-stage modelling approach was developed. In the first stage, operational variables were estimated using the SARIMA time series model. In the second stage, CO_2 emissions were estimated using machine learning algorithms.

2. EXPERIMENTAL STUDIES

2.1 Data Set

The data set used in the study consists of monthly operational data from three airports between 2014 and 2023. Variables used include the number of LTOs, freight traffic, fuel consumption (FUEL), and calculated CO_2 emissions using the IPCC Tier 2 methodology.

Variables used in the model:

- Number of LTOs
- cargo baggage mail freight traffic
- Fuel consumption (FUEL)
- Carbon dioxide emissions (CO_2)

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These variables were used to analyse the impact of airport operations on emissions production.

3. Methodology

The study utilised monthly operational data from 2014 to 2023. The model inputs were defined as the number of LTOs, freight traffic (cargo + baggage + mail) and fuel consumption; the output variable was the calculated CO_2 emission values. Missing data were completed using linear interpolation, a logarithmic transformation was applied for variance stability, and moving average (MA) filters were used to clean up short-term noise. Fuel consumption values were derived from aircraft activity data using the IPCC Tier 2 methodology for LTO cycle emission estimation.

Modelling Flow

- Stage 1 (Input Projection): The optimal parameters for each input variable were determined using the SARIMA(p,d,q)(P,D,Q)$_{12}$ models with the 'Grid Search' method, and a 120-month future forecast was made using the Optimal SARIMA parameters with the Akaike Information Criterion (AIC) procedure.
- Stage 2 (Machine Learning): Machine learning models were trained using an 80-20 training-test split. Hyperparameters were optimised through cross-validation, and overfitting analysis was performed by comparing training and test errors.SARIMA input forecasting: Model definition and preprocessing summary. To ensure the stability of the model when dealing with large volumes of operational data, Z-score normalisation was applied to both the input and output variables.

Projecting future CO_2 estimates based on the history and seasonality of inputs using SARIMA(p,d,q)(P,D,Q)s is a common and valid approach in the literature. General form of the SARIMA model In many studies, SARIMA is defined as SARIMA(p,d,q)×(P,D,Q)s, which includes seasonal and non-seasonal AR and MA components; here, s is the seasonal period (e.g., s=12 for monthly data) (Jalloh et al., 2025).

Noise reduction and pre-processing The idea of 'pre-processing' the data before SARIMA is seen in many studies in a similar way:

Missing data interpolation/synthetic generation: Resampling or interpolating missing or sparse series in a way that preserves their statistical properties can reduce estimation error (Al Mobin & Kamrujjaman, 2023)

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Moving average/smoothing: Moving averages or related filters are used to produce a smoother series by reducing short-term noise (Marcilio et al., 2013)

Logarithmic or Box-Cox transformation: Log/Box-Cox transformations are common to stabilise variance and approximate SARIMA assumptions (approximate stationarity, constant variance). Following these pre-processing steps, stationarity is achieved and the model residuals are verified to be white noise using Ljung–Box-like tests(Perez-Guerra et al., 2023)

3. RESULTS AND EVALUATION

3.1. Input Forecast Performance

In the first phase of the study, 120-month forward projections covering the period 2024–2033 for the variables LTO count, fuel consumption and freight traffic which form the basis of the emission projection models—were carried out using SARIMA models. The optimal parameters for each variable were optimised using the grid search method.

Below is an evaluation of all input projection results obtained from your work within an academic framework: A Metric-Based Comparative Analysis of Input Forecasting Performance. The forecasting of input variables (LTO, Fuel, Cargo) for airport emission projections was carried out using SARIMA models with high statistical reliability. The analysis results indicate that the model's performance varies depending on operational volume, data stability and airport characteristics, but generally remains within the limits of the current literature.

- Sabiha Gökçen (SAW) Performance: Due to high traffic density and a regular seasonal cycle, SAW achieved excellent results in LTO (4.12% MAPE) and Fuel (4.10% MAPE) forecasts. This demonstrates that the model effectively captures the seasonal pattern at high-traffic airports.
- Esenboğa (ESB) Stability: R^2 values of 0.868 and 0.891 for Ankara Esenboğa indicate that the model explains the uncertain post-pandemic recovery process with approximately 90% accuracy and demonstrates high resilience in medium-scale operations.
- Konya (KYA) and Scale Effect: The MAPE values reaching the 30% band at Konya airport are a mathematical situation caused by low operational volume rather than model error; although small deviations in numerically small data increase the percentage error, the R^2 values between 0.64 and 0.80 indicate the trend.

3.2 CO_2 Emission Prediction Performance (Machine Learning)

ISBN NR: 978-625-5694-92-8

Table 1. Airport-Based CO_2 Emission Prediction Model Performance Metrics

Airport	Algorithm	Test RMSE	Test MAPE (%)
Ankara (ESB)	Decision Tree	1.400.947	%7,03
Ankara (ESB)	LSBoost	1.383.829	%6,85
Ankara (ESB)	SVR (RBF Kernel)	601.072	%2,99
Sabiha Gökçen (SAW)	Decision Tree	3.866.410	%6,14
Sabiha Gökçen (SAW)	LSBoost	4.650.304	%1,21
Sabiha Gökçen (SAW)	SVR (RBF Kernel)	1.881.334	%3,10
Konya (KYA)	Decision Tree	48.470	%2,86
Konya (KYA)	LSBoost	70.045	%3,14
Konya (KYA)	SVR (RBF Kernel)	43.175	%1,98

An examination of Table 2 reveals that, for all three airports, the Support Vector Regression (SVR) model yields the most consistent results in terms of error metrics. The fact that the Mean Absolute Percentage Error (MAPE) values remain at 2.99% in Ankara, 3.10% in Sabiha Gökçen and 1.98% in Konya demonstrates that the developed models possess a considerably high prediction accuracy compared to similar studies in the literature. In particular, the MAPE value of 1.98% obtained for emissions at Konya Airport demonstrates that the model successfully captures the strong correlation between operational variables and emission outputs.

Table 2. Airport-Based CO_2 Emission Prediction Model Performance Metrics

Airport	Algorithm	Test RMSE	Test MAPE (%)
Ankara (ESB)	SVR (RBF Kernel)	601.072	%2,99
Sabiha Gökçen (SAW)	LSBoost	4.650.304	%1,21
Konya (KYA)	SVR (RBF Kernel)	43.175	%1,98

An examination of Table 2 reveals that the SVR method performs better at medium-sized and local airports (ESB, KYA), whilst the LSBoost method achieves the highest accuracy at high-traffic airports (SAW). R^2 values ranging from 0.945 to 0.984 demonstrate that the machine learning model accurately reflects the emissions inventory despite the uncertainties in the input data.

ISBN NR: 978-625-5694-92-8

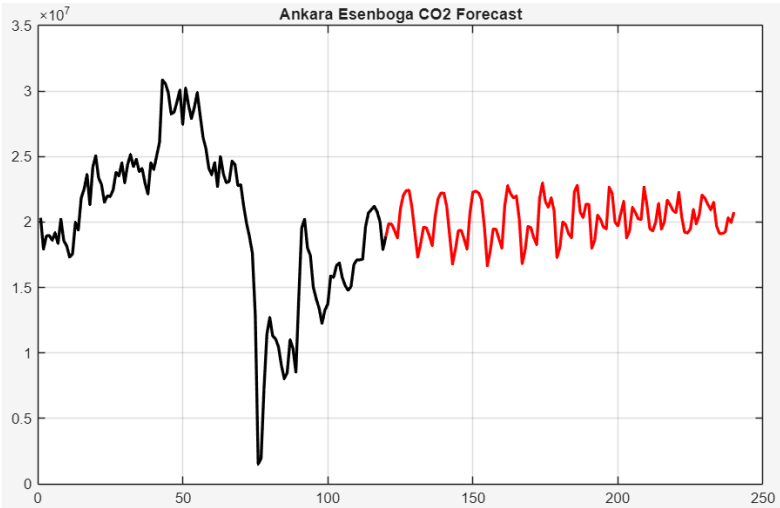

Figure 1. Ankara Esenboğa Airport (ESB) CO_2 Emission Time Series 2014-2033 Projection

The SVR model selected for the ESB demonstrates high resilience to structural disruptions, such as the sharp decline observed around the 80th month due to the pandemic. The model accurately captures the subsequent rapid recovery phase, explaining the variability in emissions with an R^2 value of 0.945. Furthermore, the constant width of the confidence intervals (CI) throughout the 120-month projection confirms a stable forecast variance and demonstrates that the ESB's medium-scale operational structure can be forecast within a very narrow error margin (MAPE: 2.99%).

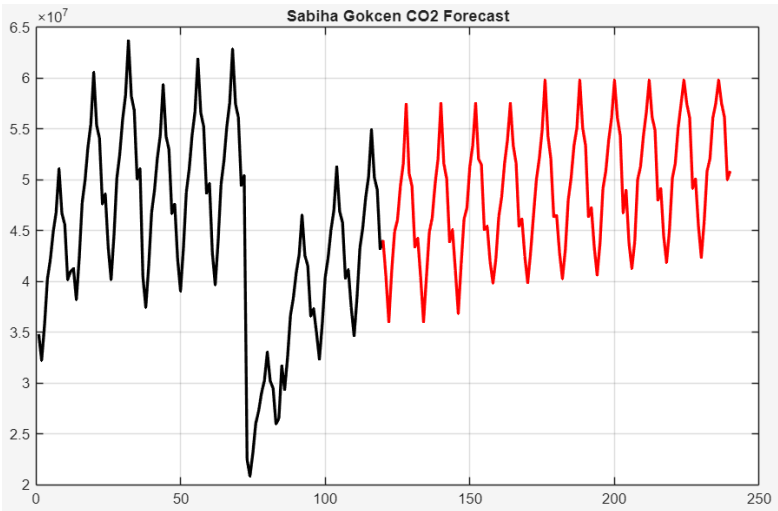

Figure 2. Sabiha Gökçen Airport (SAW) CO_2 Emission Time Series 2014-2033 Projection

The time series for Istanbul Sabiha Gökçen (SAW) shows the highest volume of emissions and the most pronounced seasonal cycle among the airports examined. The regular zigzag pattern

ISBN NR: 978-625-5694-92-8

in the graph reflects a strong seasonal trend driven by high traffic and stable operational demand. Although the pandemic caused a significant decline at SAW, the recovery rate was much higher, enabling the airport to return rapidly to pre-pandemic levels. The LSBoost (Least Squares Boosting) algorithm performed exceptionally well in this variable data environment, achieving an R^2 value of 0.984 and a very low MAPE of 1.21%. Although there is some margin of error in cargo traffic forecasts, the model's ability to provide a precise final CO_2 forecast demonstrates its strong capability in filtering and prioritising Fuel and LTO data—the key factors influencing total emissions. Furthermore, seasonal amplitude has been well preserved throughout the 120-month (10-year) forecast period. The narrow confidence intervals (CI) observed during this period indicate that the model's stability and predictive power remain very high, even in high-traffic areas such as SAW. This ensures a reliable long-term emissions trajectory by effectively managing operational noise.

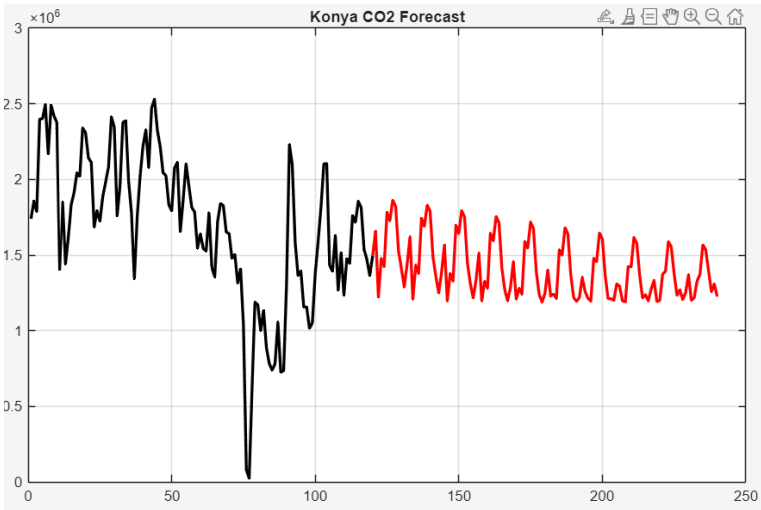

Figure 3. Konya Airport (KYA) CO_2 Emission Time Series 2014-2033 Projection

The Istanbul Sabiha Gökçen (SAW) time series shows the highest emission volume and the strongest seasonal cycle among the airports examined. The regular pattern in the graph indicates that the Konya Airport (KYA) time series yields the most stable results, despite having a lower operational volume than the other two airports. Although absolute emission levels are much lower, the hybrid model has effectively captured Konya's unique 'micro-seasonality' with a high degree of accuracy. With an R^2 value of 0.977 and a MAPE of 1.98%, the results obtained for Konya represent the highest level of success in this study. This clearly demonstrates the effectiveness of the SVR (Support Vector Regression) algorithm when working with low-volume but trending data. An NRMSE of 0.0172 further confirms that the model's error margin is very low relative to the operational scale. The red forecast line indicates a stable long-term trend for Konya. Whilst the forecast maintains seasonal peaks, it shows a slight downward trend towards the end of the 120-month projection. This minor change, coupled with the gradual

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widening of the confidence intervals (CI), should be viewed as a natural increase in uncertainty arising from low-volume market forecasts. This reflects scientific integrity rather than indicating a failure of the model; as the model takes into account data limitations and potential saturation in smaller-scale transactions.

CONCLUSION AND DISCUSSION

This study examined CO_2 emissions from aircraft at three major airports in Turkey (Ankara Esenboğa, Istanbul Sabiha Gökçen and Konya). These airports differ in terms of size and operations. The research employed a hybrid approach to provide 120-month forecasts extending to 2033. The results demonstrate that a two-stage modelling framework (SARIMA and Machine Learning) achieves high forecasting accuracy in the aviation sector, which is influenced by various external factors. The study reveals that different algorithms perform better depending on the unique traffic patterns at each airport. Sabiha Gökçen Airport (SAW), which has the highest traffic volume, achieved an exceptional success rate rarely seen in the current literature, with an R^2 of 98.4% and a MAPE of 1.21% using the LSBoost (Least Squares Boosting) algorithm.

This demonstrates LSBoost's ability to filter out 'operational noise' and resolve complex seasonality at high-traffic hub airports. At Ankara Esenboğa (ESB) and Konya (KYA) airports, however, the Support Vector Regression (SVR) model yielded the most consistent results. The R^2 values of 94.5% in Ankara and 97.7% in Konya demonstrate how effective SVR's kernel-based learning capacity is on medium and boutique-scale datasets.

Ten-year projections indicate that airports will follow different emission trajectories depending on their strategic roles:

The steady upward trend observed at Sabiha Gökçen, coupled with its sustained high seasonal variation, suggests that the airport's potential for growth as an international hub will continue.

Whilst a more stable trajectory has been observed at Ankara Esenboğa following the post-pandemic recovery, it has been noted that emissions at Konya Airport have stabilised as they approach a slight saturation point. This suggests that local traffic volume is operating within physical capacity limits.

The NRMSE values obtained (0.0172–0.0205) confirm the scientific reliability of the study by demonstrating that the model's margin of error amounts to only 2% of the total operational

scale. This study combines the IPCC Tier 2 methodology with modern data science techniques to provide airport authorities with a precise decision-support mechanism that can be utilised in processes such as carbon pricing, green airport certification and sustainable fleet planning.

In future studies, the integration of variables such as Sustainable Aviation Fuels (SAF) and electric aircraft operations into this model will contribute to measuring the effectiveness of emission reduction strategies.

ACKNOWLEDGEMENT

This work has been supported by Necmetttin Erbakan University Scientific Research Projects Coordination Unit under project number #25YL16001

(Bu çalışma, 25YL16001 numaralı proje kapsamında Necmettin Erbakan Üniversitesi Bilimsel Araştırma Projeleri (NEÜ BAP) Koordinatörlüğü tarafından desteklenmektedir.

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BALKAN 15th INTERNATIONAL CONFERENCE ON APPLED SCIENCES
March 20 – 22, 2026 – SKOPJE
ISBN NR: 978-625-5694-92-8

AHŞAP YAPI VE ATIK KÖKENLİ DOĞAL YALITIM MALZEMELERİNİN EMİSYON PERFORMANSININ SİMÜLASYON ANALİZİ

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ÖZET

Bu çalışmada, Kayseri ilinde konumlanan 150 m² büyüklüğünde bir hayvan barınağı için farklı ahşap yapı malzemeleri ve atık kökenli doğal yalıtım levhalarının enerji, emisyon ve maliyet performansları simülasyon tabanlı olarak değerlendirilmiştir. Bina modeli, üç boyutlu enerji analizine imkân tanıyan Energy3D yazılımı kullanılarak oluşturulmuştur. Yapı kabuğunda dört farklı ahşap türü (Abies bornmuelleriana – Uludağ Köknarı, Fagus orientalis – Doğu Kayını, Populus nigra – Kara Kavak ve Cedrus libani – Toros Sediri) kullanılmıştır. Dıştan yalıtımlı olarak modellenen binada ise tavuk tüyü, atık insan saçı ve hurma ağacı liflerinden üretilmiş doğal yalıtım malzemeleri değerlendirilmiştir.

Toplamda 12 farklı malzeme kombinasyonu oluşturulmuştur. Her senaryo için yapı kabuğuna ait ısı iletkenlik katsayısı, yoğunluk değerleri belirlenmiştir. Daha sonra U-değerleri hesaplanmıştır. Simülasyon sonuçları doğrultusunda yıllık enerji tüketimi, CO_2 emisyonu ve toplam maliyet değerleri karşılaştırılmıştır. Elde edilen sonuçlar, malzeme seçimlerinin enerji performansı ve çevresel etki üzerinde belirleyici olduğunu göstermiştir. Özellikle düşük ısı iletkenliğine sahip doğal yalıtım malzemeleri ile yoğunluğu dengeli ahşap türlerinin birlikte kullanıldığı senaryolarda enerji tüketimi ve karbon salınımının önemli ölçüde azaldığı tespit edilmiştir.

Çalışma, Kayseri'nin karasal iklim koşullarında sürdürülebilir ve düşük karbonlu yapı tasarımı için uygun malzeme kombinasyonlarını ortaya koyarak, kırsal ve tarımsal yapıların çevresel performansının iyileştirilmesine yönelik bilimsel bir karar destek yaklaşımı sunmaktadır.

Anahtar Kelimeler : Ahşap yapı malzemeleri; Atık bazlı yalıtım; Enerji simülasyonu; CO_2 emisyonu; Sürdürülebilir yapı tasarımı

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1. GİRİŞ

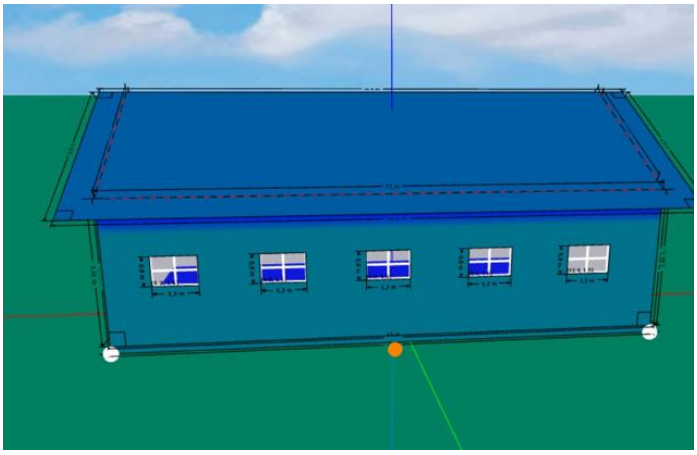
Küresel enerji kullanımı ve sera gazı emisyonlarının azaltılması, sürdürülebilir mimari tasarımın en önemli hedefleri arasında yer almaktadır. Bina sektöründe operasyonel enerji tüketimi, toplam küresel enerji kullanımı içinde önemli bir paya sahiptir ve binada dış kabuğun termal performansı bu tüketimin doğrudan belirleyicisidir [1]. Geleneksel yapı malzemelerinin üretiminde kullanılan yüksek miktarda fosil yakıt, CO_2 emisyonuna önemli katkı sağlarken, sürdürülebilir malzeme çözümleri gelişmekte olan bu etkiye alternatifler sunmaktadır [2].
Sürdürülebilir bina tasarımı, yalnızca kullanım enerji verimliliğini değil aynı zamanda malzemelerin yaşam döngüsü çevresel etkilerini de kapsamaktadır [3]. Bu kapsamda düşük ısı iletkenliğine sahip yalıtım malzemeleri, hem enerji talebini hem de işletme aşamasındaki CO_2 salınımını azaltarak daha çevre dostu yapılar inşa edilmesine katkı sağlayabilir [4]. Doğal lifler ve biyolojik kökenli atık malzemelerden üretilen yalıtım sistemleri, döngüsel ekonomi ilkeleriyle inşa edildiğinde hem çevresel hem de ekonomik açıdan avantaj sunmaktadır [5].
Ahşap, yenilenebilir, karbon depolayan ve gömülü enerji gereksinimi nispeten düşük bir yapı malzemesi olarak sürdürülebilir inşaat pratiğinde giderek yaygınlaşmıştır [6]. Kayın, sedir ve köknar gibi ağaç türleri, hem yapısal performans hem de termal davranış açısından değerlendirildiğinde bio-bazlı yapı elemanları olarak önemli alternatifler sunmaktadır [7]. Buna ek olarak, bina kabuğunun ısı kaybını azaltmak için yalıtım malzemelerinin performansı, yapıların toplam enerji tüketimini doğrudan etkilediği için U-değeri gibi termal parametreler kritik öneme sahiptir [8].
Son literatürde, doğal bazlı izolasyon malzemelerinin termal performansı, karbon ayak izi ve çevresel etkileri üzerine artan sayıda çalışma bulunmaktadır [9]. Özellikle bitkisel lifler, hammadde atıkları ve organik materyallerin bina yalıtımında kullanımı, konvansiyonel sentetik izolasyonlara kıyasla daha düşük enerji ve CO_2 değerleri ile ilişkilendirilmiştir [10]. Bununla birlikte, doğal izolasyon malzemelerinin uzun vadeli performansı, nem yönetimi, mekanik dayanım gibi ilave faktörler üzerine çalışmalar devam etmektedir [11].
Kayseri gibi soğuk iklim bölgelerinde ısıtma enerjisi ihtiyacı, bina kabuğu performansına olan duyarlılığı artırmaktadır [12-14]. Bu nedenle, farklı ahşap yapı malzemeleri ile atık kökenli doğal yalıtım malzemelerinin kombinasyonlarına dayalı simülasyon çalışmaları, hem enerji tüketimi hem de CO_2 emisyonu açısından bilinçli malzeme seçiminin önemini ortaya koymaktadır. Bu çalışmada, simülasyon temelli değerlendirmelerle yapı kabuğu alternatifleri karşılaştırılmış ve sürdürülebilir uygulama stratejileri geliştirilmiştir.

2. METODOLOJİ

Görsel 1'de, Kayseri ilinde konumlanan 150 m² büyüklüğündeki hayvan barınağının Energy3D yazılımı kullanılarak oluşturulan üç boyutlu dijital modeli gösterilmektedir. Modelleme sürecinde binanın geometrik özellikleri, yönlenmesi, çatı formu ve yapı kabuğu bileşenleri detaylı şekilde tanımlanmıştır. Dış duvar katmanlarında farklı ahşap türleri ve doğal yalıtım malzemeleri ayrı ayrı tanımlanarak her senaryo için termofiziksel özellikler (ısı iletkenlik katsayısı, yoğunluk ve kalınlık) sisteme girilmiştir. Böylece yapı kabuğuna ait U-değerleri

ISBN NR: 978-625-5694-92-8

otomatik olarak hesaplanmış ve yıllık enerji tüketimi, CO_2 emisyonu ile maliyet analizleri simülasyon tabanlı olarak elde edilmiştir. Bu model, farklı malzeme kombinasyonlarının enerji performansı üzerindeki etkilerini karşılaştırmalı olarak değerlendirmeye imkân sağlamaktadır.



Görsel 1. Binanın Energy 3D yazılımı bünyesinde modellenmesi

Çizelge 1'de, çalışmada değerlendirilen farklı yapı kabuğu alternatiflerine ait malzeme kombinasyonları ve bu kombinasyonlara karşılık gelen uygulama tipleri sunulmaktadır. Dört farklı ahşap yapı malzemesi (Uludağ Köknarı, Kara Kavak, Doğu Kayını ve Toros Sediri) ile üç farklı atık kökenli doğal yalıtım malzemesi (atık insan saçı, tavuk tüyü ve hurma lifi) bir araya getirilerek toplam 12 farklı senaryo oluşturulmuştur. Her bir tip, ahşap taşıyıcı katman ile dıştan uygulanan yalıtım levhasının kombinasyonunu temsil etmektedir. Bu sınıflandırma sayesinde malzeme değişiminin yapı kabuğu ısıl performansı, yıllık enerji tüketimi, CO_2 emisyonu ve ilk yatırım maliyeti üzerindeki etkileri karşılaştırmalı olarak analiz edilmiştir. Tablo, çalışmanın metodolojik çerçevesini oluşturan senaryo sistematiğini açık ve düzenli biçimde ortaya koymaktadır.

Çizelge 1. Çalışmada kullanılan malzeme kombinasyonlarına göre belirlenmiş tipler

Uygulama Tipi	Malzeme Kombinasyonu
Tip 1	Köknar + Atık İnsan Saçı
Tip 2	Köknar + Tavuk Tüyü
Tip 3	Köknar + Hurma Lifi
Tip 4	Kara Kavak + Atık İnsan Saçı
Tip 5	Kara Kavak + Tavuk Tüyü
Tip 6	Kara Kavak + Hurma Lifi
Tip 7	Doğu Kayını + Atık İnsan Saçı
Tip 8	Doğu Kayını + Tavuk Tüyü

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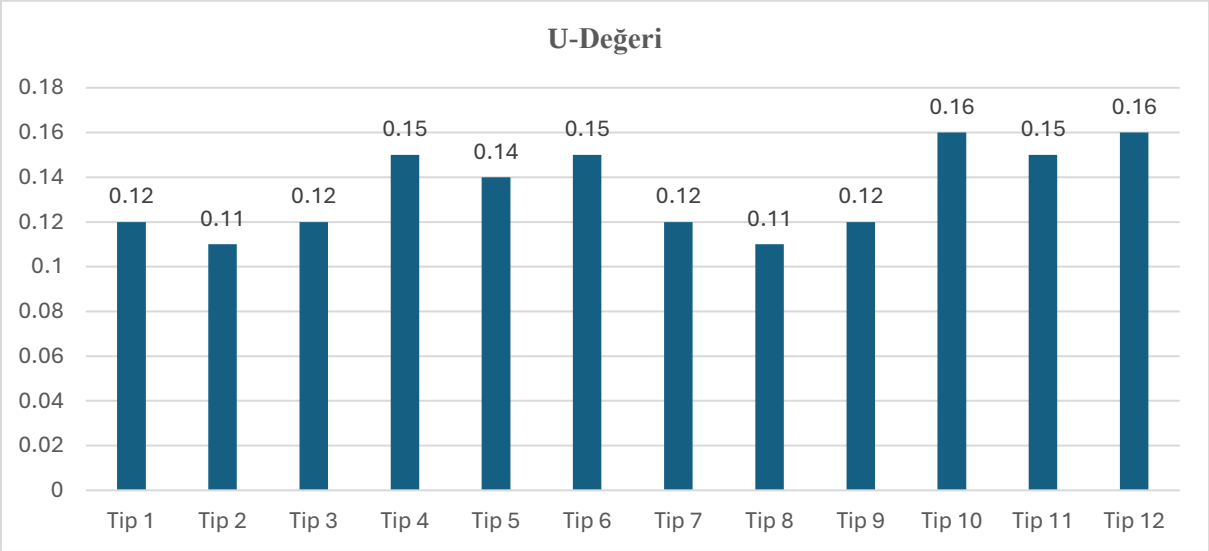
Tip 9	Doğu Kayını + Hurma Lifi
Tip 10	Toros Sediri + Atık İnsan Saçı
Tip 11	Toros Sediri + Tavuk Tüyü
Tip 12	Toros Sediri + Hurma Lifi

Görsel 2'de, çalışmada oluşturulan 12 farklı malzeme kombinasyonuna ait yapı kabuğu toplam ısı geçiş katsayısı (U-değeri) grafiksel olarak sunulmaktadır. Grafik incelendiğinde, en düşük U-değerlerinin 0,11 W/m²K ile tavuk tüyü yalıtımı kullanılan senaryolarda (Tip 2 ve Tip 8) elde edildiği görülmektedir. Bu durum, tavuk tüyünün düşük ısı iletkenlik katsayısına bağlı olarak ısı kayıplarını daha etkin şekilde sınırlandırdığını göstermektedir. Buna karşılık en yüksek U-değerleri 0,16 W/m²K ile Toros Sediri + atık saç ve Toros Sediri + hurma lifi kombinasyonlarında (Tip 10 ve Tip 12) belirlenmiştir. Kara Kavak ve Toros Sediri kullanılan senaryolarda U-değerlerinin nispeten daha yüksek bulunmuştur. Köknar ve Doğu Kayını içeren kombinasyonlarda ise daha düşük değerlerin elde edildiği anlaşılmaktadır. Bu sonuçlar, yapı kabuğunda kullanılan ahşap türü ile yalıtım malzemesinin birlikte değerlendirilmesinin ısıl performans açısından kritik öneme sahip olduğunu ortaya koymaktadır.



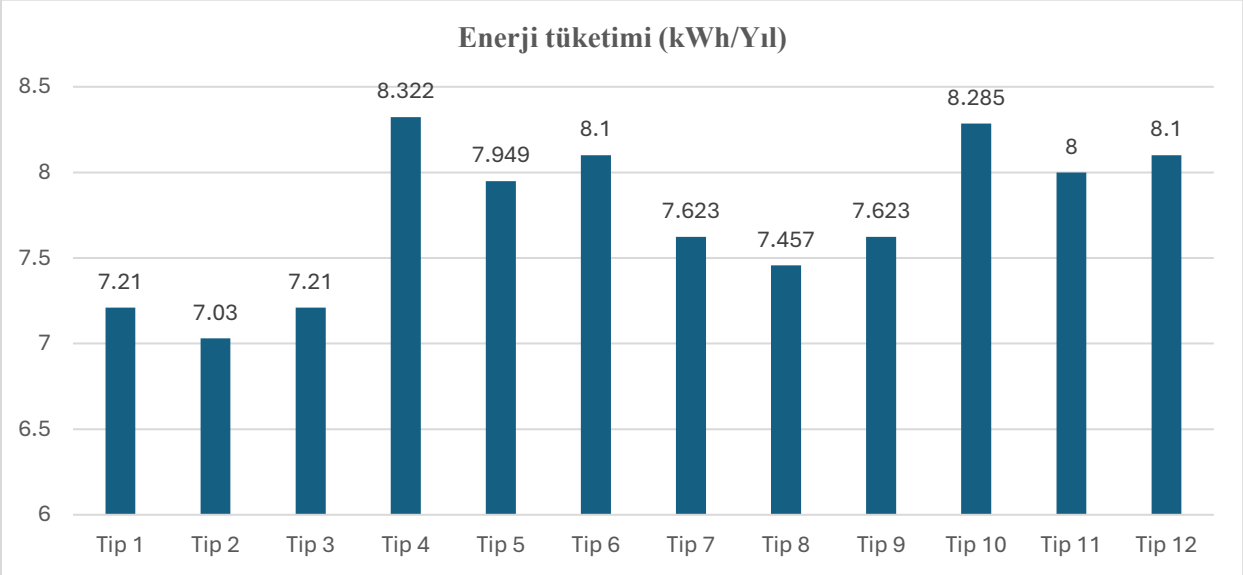
Görsel 2. Farklı Malzeme Kombinasyonlarına Ait Yapı Kabuğu U-Değerlerinin Karşılaştırılması

3. ANALİZ SONUÇLARI VE DEĞERLENDİRMELER

Görsel 3'te, oluşturulan 12 farklı yapı kabuğu senaryosuna ait yıllık toplam enerji tüketimi (kWh/yıl) değerleri grafiksel olarak sunulmaktadır. Şekil 3'te, en düşük enerji tüketiminin 7.030 kWh/yıl ile Köknar + Tavuk Tüyü kombinasyonunda (Tip 2) elde edildiği görülmektedir. Bu sonucu 7.457 kWh/yıl ile Doğu Kayını + Tavuk Tüyü (Tip 8) takip etmektedir. Bu durum, düşük U-değerine sahip kombinasyonların enerji tüketimini doğrudan azalttığını göstermektedir.

ISBN NR: 978-625-5694-92-8

En yüksek enerji tüketimi ise 8.322 kWh/yıl ile Kara Kavak + Atık Saç kombinasyonunda (Tip 4) belirlenmiştir. Benzer şekilde Toros Sediri kullanılan senaryolarda da enerji tüketiminin görece yüksek olduğu dikkat çekmektedir. Yapı kabuğu ısıl performansı iyileştikçe yıllık enerji tüketiminin azaldığı görülmektedir. Görsel 3 malzeme seçimlerinin enerji performansı üzerindeki belirleyici rolünü ortaya koymaktadır. Özellikle tavuk tüyü yalıtımı kullanılan senaryoların Kayseri'nin karasal iklim koşullarında daha enerji verimli bir çözüm sunduğunu göstermektedir.



Görsel 3. Farklı Malzeme Kombinasyonlarına Ait Yıllık Enerji Tüketimi Değerlerinin Karşılaştırılması

Görsel 4'te, çalışmada değerlendirilen 12 farklı yapı kabuğu senaryosuna ait yıllık CO_2 emisyonu değerleri (kg/yıl) grafiksel olarak sunulmaktadır. Görsel 4'te, en düşük CO_2 salınımının 3.409,5 kg/yıl ile Köknar + Tavuk Tüyü kombinasyonunda (Tip 2) elde edildiği görülmektedir. Bu sonucu 3.616,6 kg/yıl ile Doğu Kayını + Tavuk Tüyü (Tip 8) izlemektedir. Bu durum, düşük U-değerine sahip ve enerji tüketimi az olan senaryoların karbon emisyonu açısından da avantaj sağladığını göstermektedir.

En yüksek CO_2 emisyonu ise 4.036,1 kg/yıl ile Kara Kavak + Atık Saç kombinasyonunda (Tip 4) belirlenmiştir. Toros Sediri kullanılan ve U-değeri görece yüksek olan senaryolarda da karbon salınımının arttığı dikkat çekmektedir.

Enerji tüketimi ile CO_2 emisyonu arasında doğrudan bir ilişki olduğu açıkça görülmektedir. Isı kayıplarının azaltıldığı ve yıllık enerji ihtiyacının düştüğü senaryolarda karbon salınımı da paralel şekilde azalmaktadır. Bu sonuçlar, yapı kabuğunda yapılacak doğru malzeme seçiminin yalnızca enerji verimliliği değil, aynı zamanda çevresel sürdürülebilirlik açısından da kritik öneme sahip olduğunu ortaya koymaktadır.

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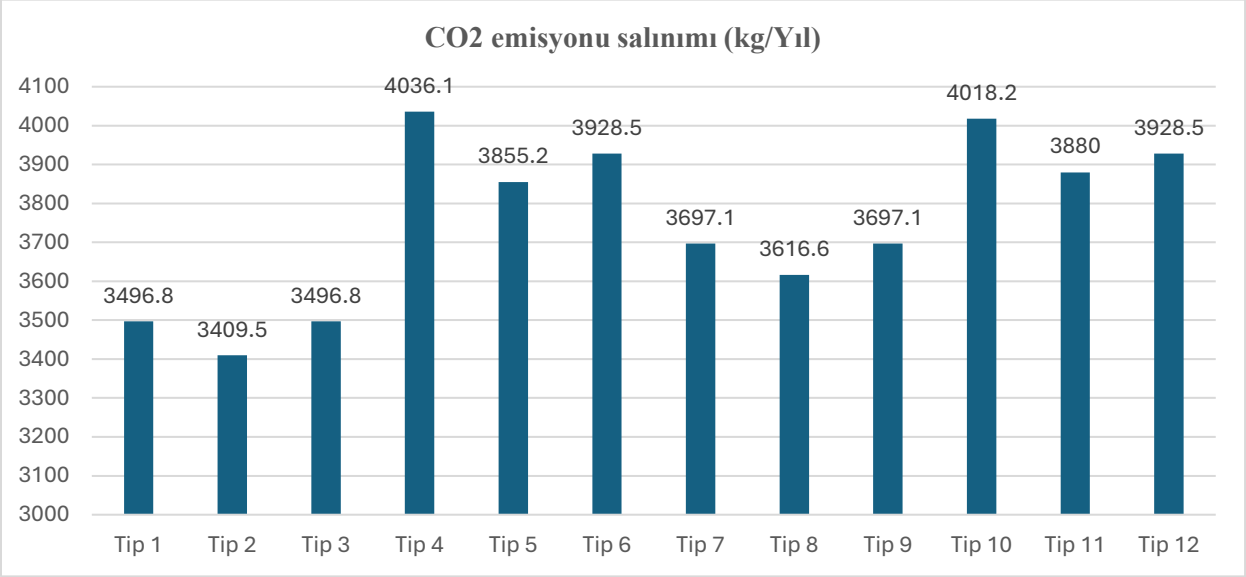

Görsel 4. Farklı Malzeme Kombinasyonlarına Ait Yıllık CO_2 Emisyonu Değerlerinin Karşılaştırılması

Görsel 5'te, çalışmada oluşturulan 12 farklı yapı kabuğu senaryosuna ait ilk inşaat maliyeti ($) değerleri grafiksel olarak gösterilmektedir. Şekil 5'te, en düşük ilk yatırım maliyetinin 176.399 $ ile Kara Kavak + Atık Saç kombinasyonunda (Tip 4) elde edildiği görülmektedir. Benzer şekilde Toros Sediri kullanılan bazı senaryolarda da maliyet değerlerinin görece düşük olduğu dikkat çekmektedir.

Buna karşılık en yüksek ilk inşaat maliyeti 184.187 $ ile Köknar + Tavuk Tüyü kombinasyonunda (Tip 2) belirlenmiştir. Düşük U-değerine ve daha yüksek enerji performansına sahip senaryolarda ilk yatırım maliyetinin bir miktar arttığı gözlemlenmektedir. Bu durum, yüksek performanslı doğal yalıtım malzemelerinin ve bazı ahşap türlerinin maliyet üzerindeki etkisinden kaynaklanmaktadır.

Sonuç olarak Şekil 5, ilk yatırım maliyeti ile enerji ve emisyon performansı arasında bir denge bulunduğunu ortaya koymaktadır. Düşük maliyetli seçenekler kısa vadede ekonomik avantaj sağlarken, enerji tüketimi ve CO_2 emisyonu açısından daha verimli alternatifler uzun vadede işletme maliyetlerini azaltarak toplam yaşam döngüsü maliyetinde avantaj sunabilir. Bu nedenle malzeme seçiminin yalnızca ilk yatırım maliyeti değil, bütüncül sürdürülebilirlik kriterleri çerçevesinde değerlendirilmesi gerekmektedir.

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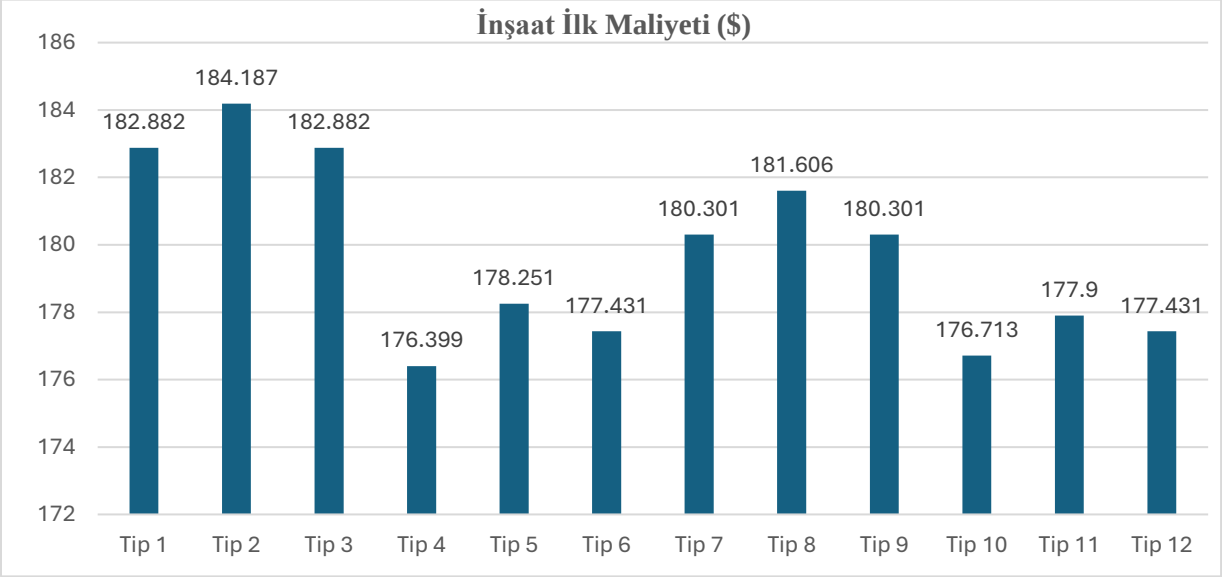

Görsel 5. Farklı Malzeme Kombinasyonlarına Ait İlk İnşaat Maliyeti ($) Değerlerinin Karşılaştırılması

Görsel 6'da, yıllık toplam enerji tüketimi ve CO_2 emisyonu açısından en iyi performansı gösteren Tip 2 (Köknar + Tavuk Tüyü) senaryosuna ait bir yıllık enerji tüketim dağılımı grafiksel olarak sunulmaktadır. Grafik, enerji tüketiminin yıl içerisindeki aylara göre değişimini ortaya koymakta ve özellikle kış aylarında belirgin bir artış olduğunu göstermektedir. Bu durum, Kayseri'nin karasal iklim özellikleri nedeniyle ısıtma yükünün yılın soğuk dönemlerinde yoğunlaşmasından kaynaklanmaktadır.

Yaz aylarında ise enerji tüketiminin önemli ölçüde azaldığı ve daha dengeli bir seyir izlediği görülmektedir. Bu sonuç, düşük U-değerine sahip yapı kabuğu bileşiminin ısı kayıplarını minimize ederek özellikle kış döneminde enerji talebini azaltmada etkili olduğunu göstermektedir.

Tip 2 senaryosunun hem yıllık toplam enerji tüketimi hem de CO_2 emisyonu açısından en düşük değerlere ulaşması, tavuk tüyü yalıtım malzemesinin ve Köknar ahşap kombinasyonunun Kayseri iklim koşullarında yüksek enerji verimliliği sağladığını ortaya koymaktadır. Şekil 6, optimum malzeme seçiminin mevsimsel enerji performansına olan katkısını açık bir şekilde göstermektedir.

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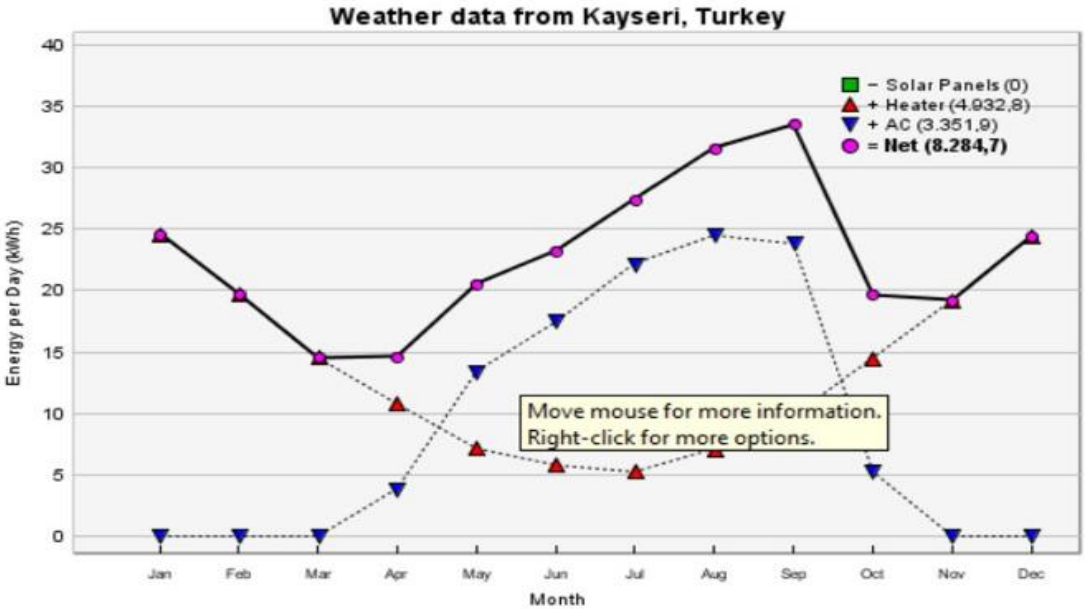

Görsel 6. Minimum enerji tüketimi ve CO_2 emisyonunun elde edildiği Tip 2 senaryosu için 1 yıllık enerji tüketim dağılımı

Görsel 2'de, yapı kabuğu performansında en belirgin değişimin U-değeri parametresinde gerçekleştiği görülmektedir. En düşük U-değeri (0.11 W/m²K) ile en yüksek U-değeri (0.16 W/m²K) arasında yaklaşık %45,5 oranında fark bulunmaktadır. Bu durum, malzeme kombinasyonlarının ısıl geçirgenlik üzerinde ciddi bir etkiye sahip olduğunu göstermektedir.
Enerji tüketimi açısından değerlendirildiğinde, en düşük değer olan 7.030 kWh/yıl (Tip 2) ile en yüksek değer olan 8.322 kWh/yıl (Tip 4) arasında %18,4 oranında bir artış söz konusudur. CO_2 emisyonu değerlerinde de aynı oranda (%18,4) artış gözlemlenmiştir. Bu paralellik, enerji tüketimi ile karbon salınımı arasında doğrudan ve güçlü bir ilişki bulunduğunu açıkça ortaya koymaktadır.
İlk yatırım maliyetlerinde ise maksimum ve minimum senaryolar arasında yalnızca %4,4 oranında bir fark bulunması dikkat çekicidir. Bu sonuç, enerji ve emisyon performansında yaklaşık %18'e varan iyileşmeler sağlanırken maliyet artışının oldukça sınırlı kaldığını göstermektedir.
Genel değerlendirme yapıldığında, Tip 2 senaryosu enerji ve emisyon açısından en avantajlı alternatif olarak öne çıkarken, Tip 4 en düşük ilk yatırım maliyetini sunmaktadır. Ancak enerji–emisyon kazanımları ile maliyet farkı birlikte değerlendirildiğinde, uzun vadeli sürdürülebilirlik açısından yüksek performanslı alternatiflerin daha rasyonel bir tercih olduğu söylenebilir.

Çizelge 2. Senaryolar Arası Max–Min Değerler ve Performans (%) Karşılaştırması

Performans Kriteri	Minimum Değer (Tip)	Maksimum Değer (Tip)	Mutlak Fark	% Fark (Min'e Göre)
U-Değeri (W/m²K)	0.11 (Tip 2–8)	0.16 (Tip 10–12)	0.05	%45.5
Enerji (kWh/Yıl)	7,030 (Tip 2)	8,322 (Tip 4)	1,292	%18.4
CO_2 (kg/Yıl)	3,409.5 (Tip 2)	4,036.1 (Tip 4)	626.6	%18.4
İlk Maliyet ($)	176,399 (Tip 4)	184,187 (Tip 2)	7,788	%4.4

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4. SONUÇ

Bu çalışmada, Kayseri ili karasal iklim koşullarında konumlanan 150 m² büyüklüğündeki bir hayvan barınağı için dört farklı ahşap yapı malzemesi (Uludağ Köknarı, Kara Kavak, Doğu Kayını ve Toros Sediri) ile üç farklı atık kökenli doğal yalıtım malzemesinin (atık insan saçı, tavuk tüyü ve hurma lifi) kombinasyonları Energy3D yazılımı aracılığıyla simülasyon temelli olarak analiz edilmiştir. Toplam 12 farklı senaryo enerji tüketimi, CO_2 emisyonu, U-değeri ve ilk yatırım maliyeti açısından karşılaştırılmıştır.

Elde edilen sonuçlara göre, yapı kabuğunun ısıl performansını temsil eden U-değeri 0.11–0.16 W/m²K aralığında değişmiştir. En düşük U-değeri 0.11 W/m²K ile tavuk tüyü yalıtımı kullanılan Tip 2 (Köknar + Tavuk Tüyü) ve Tip 8 (Doğu Kayını + Tavuk Tüyü) senaryolarında elde edilmiştir. En yüksek U-değeri ise 0.16 W/m²K ile Toros Sediri kullanılan bazı kombinasyonlarda belirlenmiştir. U-değerindeki yaklaşık %45'lik değişim, malzeme seçiminin ısı kayıpları üzerinde belirleyici bir rol oynadığını göstermektedir.

Yıllık enerji tüketimi 7.030–8.322 kWh/yıl aralığında değişmiş olup en düşük enerji tüketimi Tip 2 senaryosunda elde edilmiştir. En yüksek enerji tüketimi ise Kara Kavak + Atık Saç kombinasyonunda (Tip 4) belirlenmiştir. Enerji tüketiminde maksimum ve minimum senaryolar arasında yaklaşık %18 oranında fark bulunmuştur. CO_2 emisyonu değerleri de enerji tüketimi ile paralel şekilde 3.409,5–4.036,1 kg/yıl aralığında değişmiş ve yine yaklaşık %18'lik bir fark ortaya çıkmıştır. Bu durum enerji tüketimi ile karbon salınımı arasında doğrudan bir ilişki olduğunu göstermektedir.

İlk yatırım maliyetleri 176.399–184.187 $ aralığında değişmiş ve maksimum–minimum farkın yalnızca %4,4 seviyesinde olduğu belirlenmiştir. Bu sonuç, enerji ve emisyon performansında yaklaşık %18'e varan iyileşmeler sağlanırken maliyet artışının oldukça sınırlı kaldığını ortaya koymaktadır.

Genel olarak, Köknar + Tavuk Tüyü (Tip 2) kombinasyonu hem en düşük enerji tüketimi hem de en düşük CO_2 emisyonu değerleri ile en sürdürülebilir alternatif olarak öne çıkmıştır. Buna karşılık Kara Kavak + Atık Saç (Tip 4) senaryosu en düşük ilk yatırım maliyetine sahip olmakla birlikte enerji ve emisyon performansı açısından en zayıf alternatif olmuştur.

Sonuç olarak, Kayseri iklim koşullarında doğal ve atık kökenli yalıtım malzemelerinin uygun ahşap türleri ile birlikte kullanılması, yapı kabuğu performansını önemli ölçüde iyileştirmekte ve düşük karbonlu yapı tasarımı için uygulanabilir bir çözüm sunmaktadır.

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BETON VE YÜN ESASLI MALZEME KOMBİNASYONLARIYLA TASARLANMIŞ BİR KÖY OKULU BİNASI İÇİN ENERJİ PERFORMANSININ FİZİBİLİTESİ

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ÖZET

Bu çalışmada, Ankara ilinde yer alan 250 m² büyüklüğünde bir köy okulu projesinin yapı kabuğu enerji performansı incelenmiştir. Bina modeli Energy 3D yazılımı kullanılarak oluşturulmuştur. Yapı kabuğunda dört farklı beton esaslı yapı malzemesi (Gaz Beton, Kuvvetlendirilmiş Beton, Beton Tuğla ve Dökme Beton) kullanılmıştır. Yapı dıştan yalıtımlı sistemde ve altı farklı yün esaslı yalıtım malzemesi (Ağaç Yünü, Kül Yünü, Cam Yünü, Keçe Yünü, Mineral Yünü ve Taş Yünü) ile değerlendirilmiştir. Bu kapsamda toplam 24 farklı malzeme kombinasyonu senaryosu oluşturulmuştur.

Her bir senaryo için yapı kabuğuna ait U değerleri, malzemelerin ısı iletkenlik katsayısı ve yoğunluk değerleri dikkate alınarak hesaplanmıştır. Energy 3D simülasyonları sonucunda her alternatif için ilk inşaat maliyeti, yıllık enerji tüketimi ve yıllık enerji maliyeti verileri elde edilmiştir. Analiz sonuçları karşılaştırmalı olarak değerlendirilmiş ve enerji tüketimi açısından en verimli ve en zayıf performans gösteren senaryolar belirlenmiştir.

Elde edilen bulgular, Ankara iklim koşullarında inşa edilecek eğitim yapılarında sürdürülebilirlik hedefleri doğrultusunda en uygun beton ve yün esaslı yalıtım malzemesi kombinasyonlarının belirlenmesine katkı sağlamaktadır. Çalışma, malzeme seçiminin enerji performansı üzerindeki etkisini simülasyon destekli olarak ortaya koymaktadır.

Anahtar Kelimeler : Enerji performansı, Köy okulu binaları, Beton esaslı yapı malzemeleri, Yün esaslı yalıtım malzemeleri, Energy 3D simülasyonu, Sürdürülebilir yapı tasarımı

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ISBN NR: 978-625-5694-92-8

1. GİRİŞ

Küresel enerji tüketimi ve buna bağlı sera gazı emisyonları, 21. yüzyılın en önemli çevresel ve ekonomik sorunları arasında yer almaktadır. Özellikle yapı sektörü, dünya genelinde toplam enerji tüketiminin yaklaşık %30–40'ından ve karbon emisyonlarının önemli bir kısmından sorumludur [1, 2]. Bu nedenle binalarda enerji verimliliğinin artırılması, sürdürülebilir kalkınma hedefleri doğrultusunda kritik bir öneme sahiptir.

Binalarda enerji tüketiminin büyük bölümü ısıtma ve soğutma yüklerinden kaynaklanmakta olup, bu yükler doğrudan yapı kabuğunun termofiziksel özellikleriyle ilişkilidir [3]. Duvar, çatı ve döşeme sistemlerinin ısı iletim katsayıları (U değeri), iç ortam konfor koşullarının sağlanmasında belirleyici rol oynamaktadır. Yapı kabuğunda kullanılan malzemelerin ısı iletkenlik katsayısı ve yoğunluk gibi özellikleri, hem enerji performansını hem de yaşam döngüsü maliyetini etkilemektedir [4].

Beton esaslı yapı malzemeleri, dayanıklılık, yangın direnci ve ekonomik avantajları nedeniyle dünya genelinde yaygın olarak kullanılmaktadır. Bununla birlikte betonun yüksek ısı iletkenliğe sahip olması, uygun yalıtım uygulamaları yapılmadığında enerji kayıplarını artırabilmektedir [5]. Bu nedenle betonarme yapılarda dıştan yalıtım sistemleri enerji performansının iyileştirilmesinde etkili bir çözüm olarak önerilmektedir [6].

Isı yalıtım malzemeleri arasında mineral esaslı ve lifli yapıdaki yün malzemeler (cam yünü, taş yünü vb.), düşük ısı iletkenlik katsayıları ve yangın dayanımları nedeniyle yaygın olarak tercih edilmektedir [7]. Literatürde, farklı yalıtım malzemelerinin bina enerji performansına etkisini inceleyen birçok çalışma bulunmaktadır [8]. Ancak bu çalışmaların büyük kısmı tek bir yapı tipi veya sınırlı sayıda malzeme kombinasyonuna odaklanmıştır.

Son yıllarda bina enerji performansının değerlendirilmesinde simülasyon tabanlı yöntemler ön plana çıkmıştır. Dinamik enerji modelleme yazılımları, tasarım aşamasında farklı malzeme ve sistem alternatiflerinin karşılaştırılmasına olanak sağlamaktadır [9-12]. Bu tür analizler, özellikle eğitim yapıları gibi kamu binalarında, uzun vadeli enerji maliyetlerinin azaltılmasında önemli avantajlar sunmaktadır.

Türkiye'de farklı iklim bölgelerinde inşa edilen eğitim yapılarının enerji performansına yönelik çalışmalar artmakla birlikte, Ankara gibi karasal iklim özelliklerine sahip bölgelerde beton esaslı taşıyıcı sistemler ile yün esaslı yalıtım malzemelerinin birlikte değerlendirilmesine yönelik kapsamlı ve karşılaştırmalı analizler sınırlıdır. Bu amaçla, bu çalışmada Ankara ilinde tasarlanan bir köy okulu binasında farklı beton ve yün esaslı yalıtım malzemesi kombinasyonlarının enerji performansı simülasyon destekli olarak analiz edilmiştir. Yün esaslı yalıtım malzemelerinin bir binanın enerji performansına etkileri güncel beton esaslı malzemelerle birlikte Energy 3D yazılımı yardımıyla değerlendirilmiştir.

2. METODOLOJİ

Tablo 1'de, Ankara ilinde tasarlanan 250 m² büyüklüğündeki köy okulu binası için oluşturulan 24 farklı yapı kabuğu senaryosu sunulmaktadır. Senaryolar, dört farklı beton esaslı yapı

ISBN NR: 978-625-5694-92-8

malzemesi (Gaz Beton, Kuvvetlendirilmiş Beton, Beton Tuğla ve Dökme Beton) ile altı farklı yün esaslı yalıtım malzemesinin (Ağaç Yünü, Kül Yünü, Cam Yünü, Keçe Yünü, Mineral Yünü ve Taş Yünü) sistematik kombinasyonu ile oluşturulmuştur.
Bu yaklaşım ile her bir taşıyıcı duvar malzemesinin farklı yalıtım türleri ile birlikte değerlendirilmesi sağlanmış ve toplamda 4 × 6 kombinasyon üzerinden karşılaştırmalı bir analiz altyapısı oluşturulmuştur. Böylece yapı kabuğunda kullanılan beton esaslı malzemenin ve yalıtım türünün enerji performansı üzerindeki etkisi ayrı ayrı ve birlikte incelenebilmiştir.
Oluşturulan senaryo matrisi, çalışmanın metodolojik temelini oluşturmakta olup, sonraki analiz aşamalarında U-değeri, yıllık enerji tüketimi ve maliyet parametrelerinin karşılaştırılmasına olanak sağlamaktadır. Bu sistematik senaryo kurgusu sayesinde malzeme seçimlerinin enerji performansına etkisi objektif ve karşılaştırılabilir bir biçimde değerlendirilmiştir.

Çizelge 1. Ankara İklim Koşullarında 24 Farklı Beton ve Yün Esaslı Malzeme Kombinasyonu ile örnek bina için oluşturulan senaryolar

Senaryo	**Yapı malzemesi**	**Yalıtım Malzemesi**
1	Gaz Beton	Ağaç Yünü
2	Gaz Beton	Kül Yünü
3	Gaz Beton	Cam Yünü
4	Gaz Beton	Keçe Yünü
5	Gaz Beton	Mineral Yünü
6	Gaz Beton	Taş Yünü
7	Kuvvetlendirilmiş Beton	Ağaç Yünü
8	Kuvvetlendirilmiş Beton	Cam Yünü
9	Kuvvetlendirilmiş Beton	Kül Yünü
10	Kuvvetlendirilmiş Beton	Keçe Yünü
11	Kuvvetlendirilmiş Beton	Mineral Yünü
12	Kuvvetlendirilmiş Beton	Taş Yünü
13	Beton Tuğla	Ağaç Yünü
14	Beton Tuğla	Cam Yünü
15	Beton Tuğla	Kül Yünü
16	Beton Tuğla	Keçe Yünü
17	Beton Tuğla	Mineral Yünü
18	Beton Tuğla	**Taş Yünü**
19	Dökme Beton	**Ağaç Yünü**
20	Dökme Beton	Cam Yünü
21	Dökme Beton	Kül Yünü
22	Dökme Beton	Keçe Yünü
23	Dökme Beton	Mineral Yünü
24	Dökme Beton	Taş Yünü

Görsel 1’de, 24 farklı yapı kabuğu senaryosu için hesaplanan toplam ısı geçirgenlik katsayısı (U-değeri) sonuçları grafiksel olarak sunulmaktadır. U-değeri, yapı kabuğunun birim alanından

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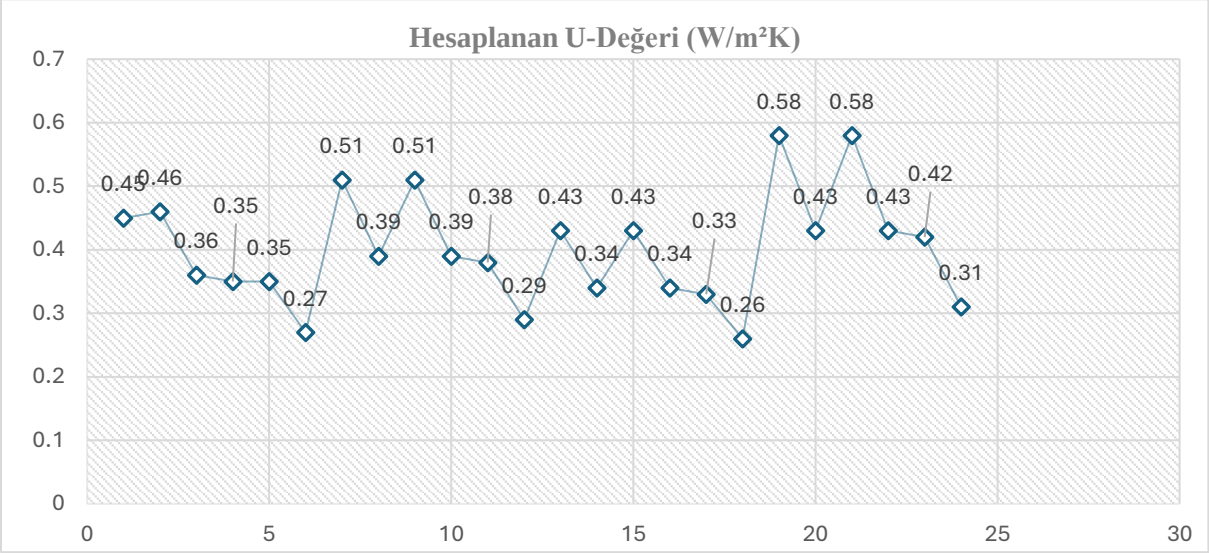
birim zamanda geçen ısı miktarını ifade etmekte olup, düşük değerler daha yüksek ısı yalıtım performansını göstermektedir.
Tüm beton türlerinde taş yünü kullanılan senaryoların en düşük U-değerlerine sahip olduğu görülmektedir. Özellikle beton tuğla–taş yünü ve gaz beton–taş yünü kombinasyonları en yüksek ısıl performansı sağlamıştır. Buna karşılık dökme beton ile ağaç yünü ve kül yünü kombinasyonlarında en yüksek U-değerleri elde edilmiş olup, bu durum daha yüksek ısı kaybına işaret etmektedir.
Aynı yalıtım malzemesi kullanıldığında beton türüne bağlı olarak U-değerlerinde değişim gözlenmesi, taşıyıcı malzemenin ısıl iletkenlik katsayısının toplam duvar performansı üzerindeki belirleyici etkisini ortaya koymaktadır. Bununla birlikte, yalıtım malzemesi değişiminin U-değerleri üzerinde daha baskın bir etkiye sahip olduğu dikkat çekmektedir. Bu durum, dıştan yalıtım uygulamalarında doğru yalıtım malzemesi seçiminin enerji verimliliği açısından kritik olduğunu göstermektedir.



Görsel 1 Farklı Beton ve Yün Esaslı Yalıtım Malzemesi Kombinasyonlarına Ait Hesaplanan U-Değerlerinin Karşılaştırılması

3. ANALİZ SONUÇLARI VE DEĞERLENDİRMELER

Görsel 2'de, 24 farklı yapı kabuğu senaryosu için hesaplanan ilk inşaat maliyeti değerleri grafiksel olarak sunulmaktadır. İlk yatırım maliyeti, yapı kabuğunda kullanılan beton esaslı taşıyıcı malzeme ve yün esaslı yalıtım türüne bağlı olarak değişkenlik göstermektedir.
En düşük ilk inşaat maliyetlerinin genellikle dökme beton kombinasyonlarında elde edildiği görülmektedir. Buna karşılık taş yünü kullanılan senaryolarda maliyetlerin diğer yalıtım türlerine kıyasla daha yüksek olduğu belirlenmiştir. Bu durum, taş yününün yüksek performans özellikleri ile birlikte nispeten daha yüksek birim maliyetine sahip olmasından kaynaklanmaktadır.
Beton türleri arasında maliyet farklarının sınırlı düzeyde olduğu, ancak yalıtım malzemesi değişiminin toplam yatırım maliyetini daha belirgin şekilde etkilediği gözlemlenmektedir.

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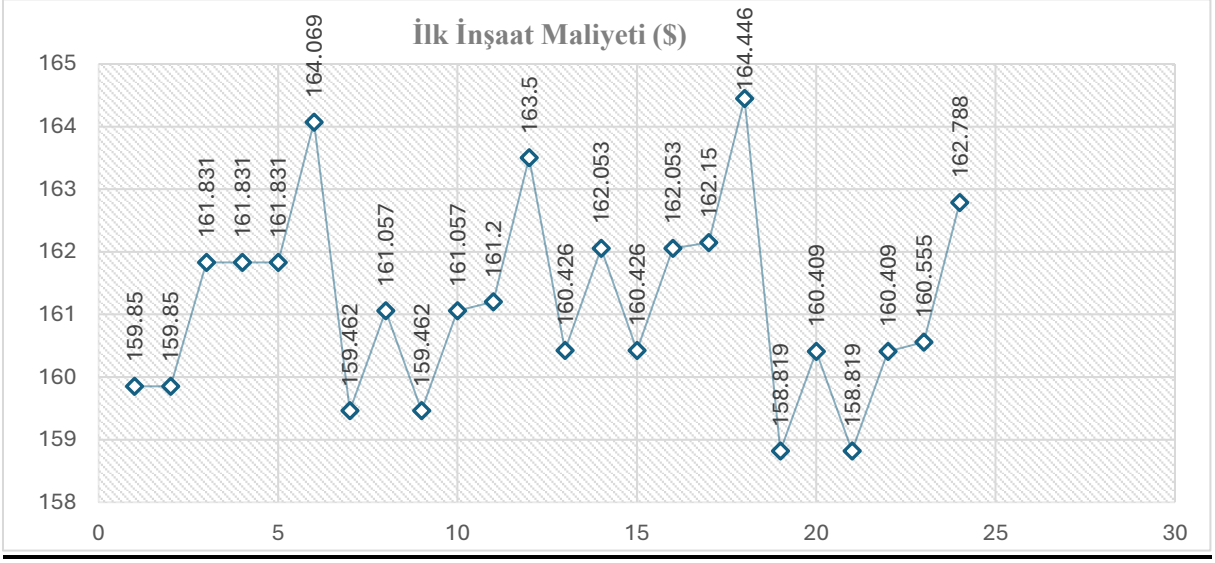
Özellikle cam yünü, keçe yünü ve mineral yünü kullanılan senaryoların orta maliyet bandında yer aldığı, ağaç yünü ve kül yünü kombinasyonlarının ise nispeten daha düşük başlangıç maliyetine sahip olduğu görülmektedir.
Sonuçlar, yapı tasarımında yalnızca ilk yatırım maliyetinin değil, aynı zamanda enerji performansı ve işletme giderlerinin de birlikte değerlendirilmesi gerektiğini ortaya koymaktadır. İlk yatırım maliyeti düşük olan alternatiflerin uzun vadede daha yüksek enerji giderlerine yol açabileceği göz önünde bulundurulmalıdır.



Görsel 2 Farklı Beton ve Yün Esaslı Yalıtım Malzemesi Kombinasyonlarına Ait İlk İnşaat Maliyeti Değerlerinin Karşılaştırılması

Görsel 3'te, Ankara iklim koşullarında modellenen köy okulu binası için oluşturulan 24 farklı yapı kabuğu senaryosuna ait yıllık enerji tüketimi (kWh) değerleri grafiksel olarak sunulmaktadır. Yıllık enerji tüketimi, yapı kabuğunun ısıl performansına doğrudan bağlı olup, U-değeri ile ters orantılı bir eğilim göstermektedir.
Görsel 3'te, en düşük yıllık enerji tüketimi değerlerinin taş yünü kullanılan senaryolarda elde edildiği görülmektedir. Özellikle beton tuğla–taş yünü ve gaz beton–taş yünü kombinasyonları enerji performansı açısından en avantajlı alternatifler olarak öne çıkmaktadır. Buna karşılık, dökme beton ile ağaç yünü ve kül yünü kombinasyonlarında en yüksek enerji tüketim değerleri belirlenmiştir.
Beton türleri karşılaştırıldığında, gaz beton ve beton tuğla kullanılan senaryoların genel olarak daha düşük enerji tüketim değerlerine sahip olduğu; dökme beton ve kuvvetlendirilmiş beton kombinasyonlarının ise daha yüksek tüketim değerleri ürettiği gözlemlenmektedir. Bu durum, taşıyıcı malzemenin ısı iletkenlik katsayısının toplam enerji performansı üzerindeki etkisini ortaya koymaktadır.
Yalıtım malzemesi değişiminin enerji tüketimi üzerindeki etkisinin daha belirgin olduğu görülmekte olup, düşük U-değerine sahip kombinasyonların enerji talebini önemli ölçüde azalttığı anlaşılmaktadır. Sonuç olarak, uygun yalıtım malzemesi seçimi yıllık enerji tüketimini düşürerek hem ekonomik hem de çevresel sürdürülebilirliğe katkı sağlamaktadır.

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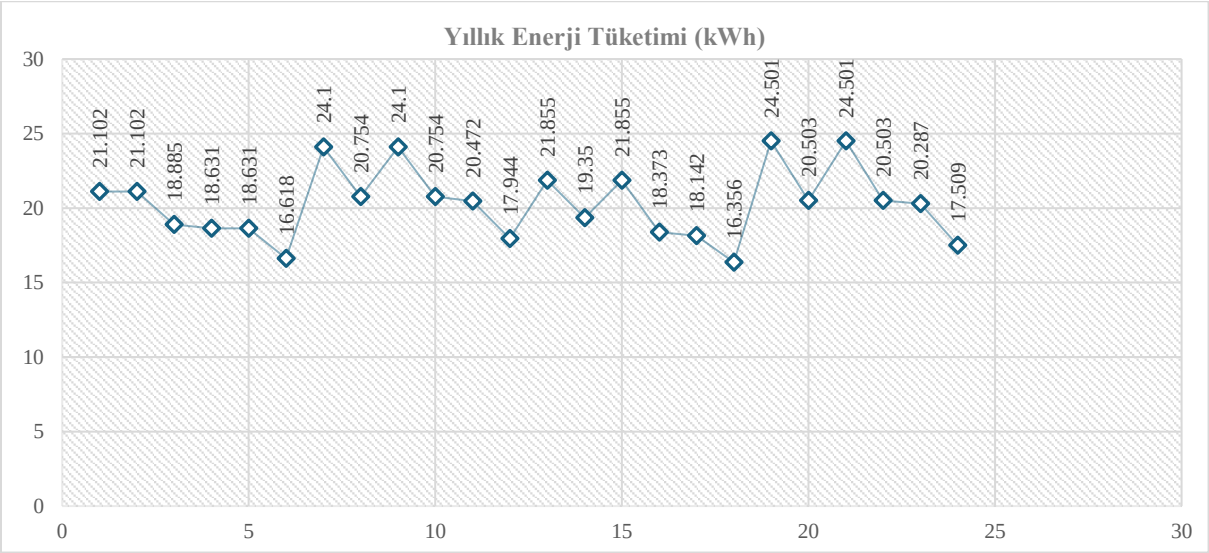

Görsel 3 Farklı Beton ve Yün Esaslı Yalıtım Malzemesi Kombinasyonlarına Ait Yıllık Enerji Tüketimi Değerlerinin Karşılaştırılması

Görsel 4'te, Ankara iklim koşullarında modellenen örnek köy okulu binası için oluşturulan 24 farklı senaryoya ait yıllık enerji faturası ($) değerleri grafiksel olarak sunulmaktadır. Yıllık enerji maliyeti, doğrudan yıllık enerji tüketim miktarına bağlı olarak değişmekte olup, yapı kabuğunun ısıl performansı ile güçlü bir ilişki göstermektedir.

En düşük yıllık enerji faturası değerleri taş yünü kullanılan senaryolarda elde edilmiştir. Özellikle beton tuğla–taş yünü ve gaz beton–taş yünü kombinasyonları ekonomik açıdan en avantajlı alternatifler olarak öne çıkmaktadır. Buna karşılık, dökme beton ile ağaç yünü ve kül yünü kombinasyonlarında en yüksek yıllık enerji faturası değerleri belirlenmiştir.

İlk yatırım maliyeti daha yüksek olan bazı yüksek performanslı yalıtım kombinasyonlarının, yıllık enerji faturasında önemli düşüş sağladığı görülmektedir. Bu durum, yapı tasarımında yalnızca başlangıç maliyetine odaklanmanın yeterli olmadığını; yaşam döngüsü maliyeti perspektifinin dikkate alınması gerektiğini ortaya koymaktadır. Uzun vadede enerji giderlerindeki azalma, başlangıçta daha yüksek yatırım gerektiren alternatifleri ekonomik olarak daha avantajlı hale getirebilmektedir.

Sonuç olarak, enerji verimliliği yüksek yapı kabuğu tasarımı hem işletme maliyetlerini azaltmakta hem de sürdürülebilir yapı yaklaşımına katkı sağlamaktadır.

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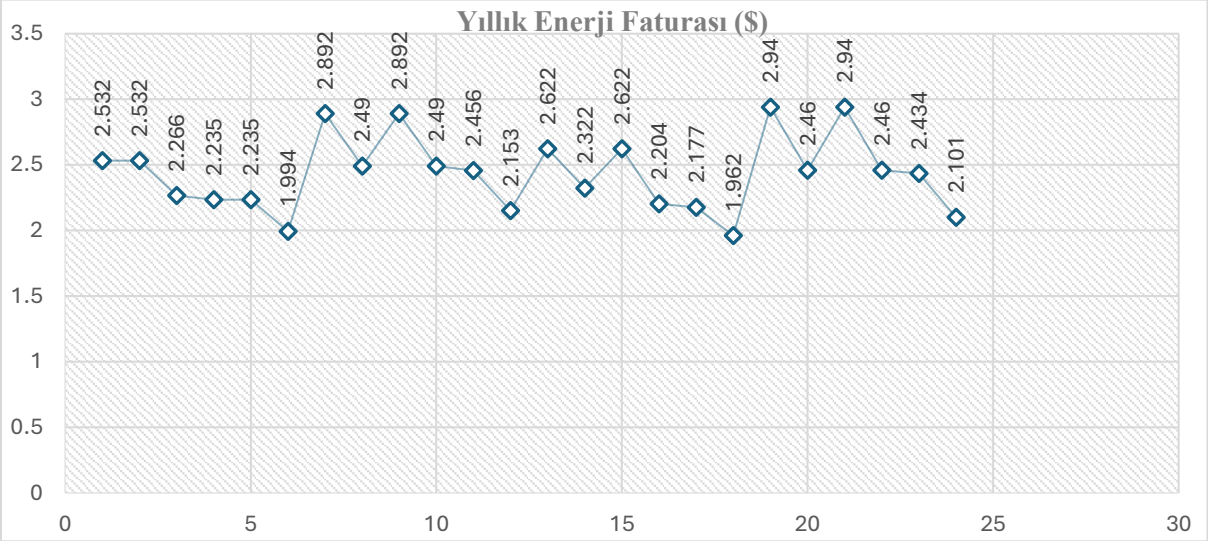

Görsel 4 Farklı Beton ve Yün Esaslı Yalıtım Malzemesi Kombinasyonlarına Ait Yıllık Enerji Faturası Değerlerinin Karşılaştırılması

Senaryoların sayısal karşılaştırması incelendiğinde, en düşük U-değeri 0,26 W/m²K ile Beton Tuğla–Taş Yünü kombinasyonunda, en yüksek U-değeri ise 0,58 W/m²K ile Dökme Beton–Ağaç Yünü ve Dökme Beton–Kül Yünü kombinasyonlarında elde edilmiştir. Bu durum, maksimum ve minimum U-değerleri arasında yaklaşık %55 oranında bir iyileşmeye karşılık gelmektedir. Yıllık enerji tüketimi açısından değerlendirildiğinde, en düşük tüketim değeri 16.356 kWh (Beton Tuğla–Taş Yünü), en yüksek tüketim değeri ise 24.501 kWh (Dökme Beton–Ağaç Yünü/Kül Yünü) olarak belirlenmiştir. Bu iki uç senaryo arasında yaklaşık %33 oranında enerji tasarrufu potansiyeli bulunmaktadır. Benzer şekilde yıllık enerji faturası değerleri incelendiğinde, en düşük maliyet 1.962 $ iken en yüksek maliyet 2.940 $ olarak hesaplanmış ve maksimum–minimum senaryolar arasında yaklaşık %33'lük bir maliyet farkı ortaya çıkmıştır. İlk inşaat maliyeti açısından ise en düşük değer 158.819 $, en yüksek değer 164.446 $ olup, yatırım maliyetleri arasındaki fark yaklaşık %3,5 düzeyinde kalmıştır. Bu sonuçlar, başlangıç maliyetindeki sınırlı artışa karşılık işletme maliyetlerinde önemli oranlarda düşüş sağlanabildiğini ve enerji performansı yüksek yapı kabuğu tasarımının uzun vadede ekonomik açıdan avantaj sunduğunu açıkça göstermektedir.

4. SONUÇ

Bu çalışmada, Ankara iklim koşullarında tasarlanan 250 m² büyüklüğündeki bir köy okulu binası için dört farklı beton esaslı yapı malzemesi ve altı farklı yün esaslı yalıtım malzemesinin kombinasyonu ile oluşturulan toplam 24 farklı yapı kabuğu senaryosu Energy 3D yazılımı kullanılarak analiz edilmiştir. Çalışma kapsamında U-değerleri hesaplanmış; ilk inşaat maliyeti, yıllık enerji tüketimi ve yıllık enerji maliyeti parametreleri karşılaştırmalı olarak değerlendirilmiştir.

Elde edilen sonuçlar, yapı kabuğunun ısıl performansının yıllık enerji tüketimi üzerinde doğrudan belirleyici olduğunu ortaya koymuştur. U-değeri azaldıkça yıllık enerji tüketimi ve buna bağlı enerji maliyetlerinde anlamlı düşüşler gözlenmiştir. Özellikle taş yünü kullanılan senaryolar tüm beton türlerinde en düşük U-değerlerini ve buna bağlı olarak en düşük yıllık

enerji tüketimlerini sağlamıştır. Buna karşılık dökme beton ile ağaç yünü ve kül yünü kombinasyonları en yüksek ısı geçirgenliği ve enerji tüketimi değerlerini üretmiştir.
Beton türleri karşılaştırıldığında, gaz beton ve beton tuğla kullanılan senaryoların genel olarak daha avantajlı enerji performansı sunduğu belirlenmiştir. Bununla birlikte, yalıtım malzemesi seçiminin toplam enerji performansı üzerindeki etkisinin, taşıyıcı beton türüne kıyasla daha belirgin olduğu görülmüştür. Bu durum, dıştan yalıtım uygulamalarında uygun yalıtım malzemesi seçiminin kritik bir tasarım parametresi olduğunu göstermektedir.
İlk inşaat maliyeti açısından değerlendirildiğinde, yüksek performanslı yalıtım malzemelerinin başlangıç yatırım maliyetini artırdığı; ancak yıllık enerji faturasında sağladığı düşüş sayesinde uzun vadede ekonomik avantaj sunduğu belirlenmiştir. Bu sonuç, yapı tasarımında yalnızca ilk yatırım maliyetinin değil, yaşam döngüsü maliyet yaklaşımının dikkate alınması gerektiğini ortaya koymaktadır.
Sonuç olarak, Ankara iklim koşullarında inşa edilecek eğitim yapılarında enerji verimliliği yüksek yapı kabuğu tasarımı için taş yünü ile birlikte gaz beton veya beton tuğla kombinasyonlarının daha uygun alternatifler olduğu belirlenmiştir.

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ISBN NR: 978-625-5694-92-8

KATI YAKITLI BACALARDA YALITIMIN BACA PERFORMANSINA ETKİSİNİN SİMÜLASYONLA ANALİZİ; AFYON ÖRNEĞİ

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Özet
Bu çalışmada, Afyon ilinin iklim koşullarında faaliyet gösteren ve 140.000 kcal/h kapasiteli katı yakıtlı ısıtma kazanı bulunan bir şekerleme üretim tesisine ait baca sistemlerinin enerji ve emisyon davranışı açısından performansı incelenmiştir. Çalışmada kare kesitli, çift cidarlı baca tasarımları oluşturulmuş; yalıtım parametresi olarak yalıtımsız durum ile birlikte 30 mm, 35 mm, 40 mm, 45 mm ve 50 mm olmak üzere altı farklı taş yünü yalıtım kalınlığı değerlendirilmiştir. Yalıtım malzemesi olarak taşyünü kullanılmıştır. Ayrıca hafif beton (orta), hafif boş beton (orta) ve hafif dolu beton (orta) olmak üzere üç farklı baca malzemesi kullanılarak çok sayıda alternatif senaryo geliştirilmiştir. Oluşturulan tüm senaryoların performans değerlendirmesi KesaAladin simülasyon programı aracılığıyla gerçekleştirilmiştir. Simülasyon sonuçları, yalıtım kalınlığının artmasıyla birlikte baca gazı sıcaklık kayıplarının azaldığını ve sistemin çekiş veriminin iyileştiğini ortaya koymaktadır. Bununla birlikte, baca malzemesinin ısıl özelliklerinin emisyon seviyeleri üzerinde önemli bir rol oynadığı belirlenmiştir. Çalışma, Afyon ili özelinde endüstriyel tesislerde uygun baca malzemesi ve yalıtım kalınlığı seçiminin çevresel etkileri azaltma ve enerji verimliliğini destekleme potansiyelini vurgulamaktadır.
Anahtar kelimeler*:* Baca yalıtımı, katı yakıtlı kazanlar, enerji verimliliği, emisyon analizi, KesaAladin simülasyonu, endüstriyel tesisler

1 Giriş

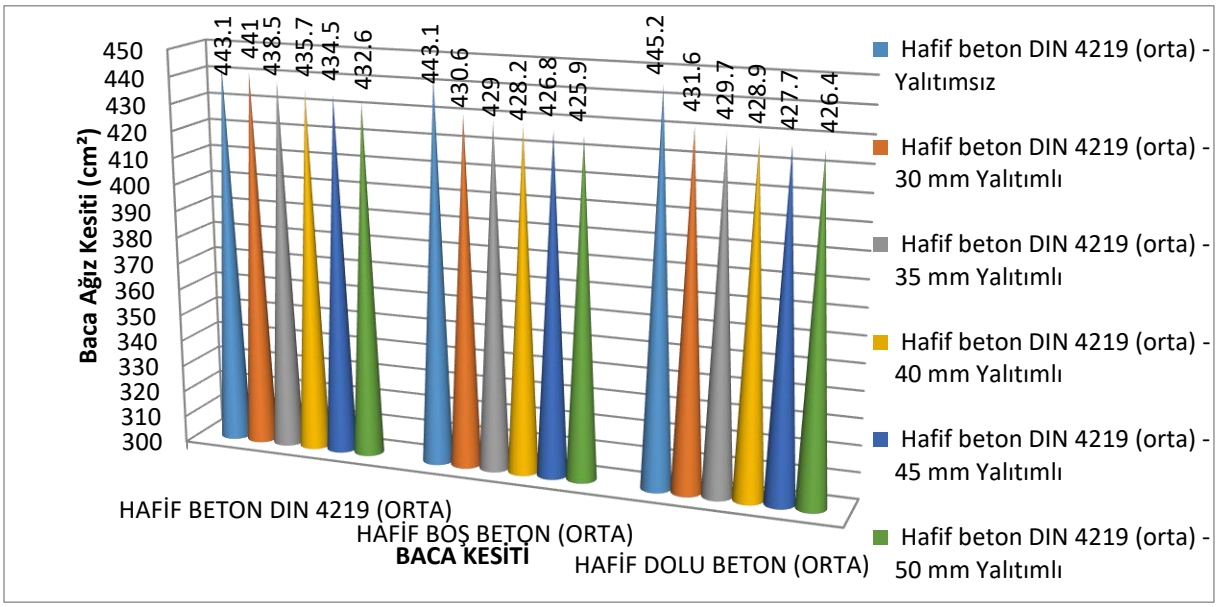
Endüstriyel tesislerde kullanılan katı yakıtlı kazan sistemleri, özellikle ısı ihtiyacının yüksek olduğu bölgelerde enerji tüketiminin önemli bir bölümüne neden olmaktadır. Bu sistemler yanma verimi, baca gazı kayıpları ve çekiş karakteristiği toplam sistem performansı tasarımdan direkt etkilenir [1]. Katı yakıtlı ısıtma sistemlerinde yanma sonucu oluşan yüksek sıcaklıktaki baca gazlarının atmosfere iletilmesi sırasında meydana gelen ısı kayıpları, hem enerji verimliliğini düşürür hem de emisyon değerlerini artırabilir [2]. Bu yüzden baca sistemlerinin tasarımı ve özellikle yalıtım özellikleri, kazan sistemlerinin sürdürülebilir ve çevreye duyarlı işletimi açısından dikkate alınması gereken bir durumdur. Baca yalıtımı, baca gazı sıcaklığının korunmasını sağlayarak yoğuşma riskini azaltmır, çekiş kuvvetini iyileştirir ve yanma stabilitesini destekler [3]. Yetersiz yalıtım olduğunda baca gazı sıcaklığı düşebilir, doğal çekiş azalabilir dolayısıyla yanma verimi olumsuz bir şekilde etkilenebilir [4]. Bunların yanında düşük sıcaklık bölgelerinde oluşabilecek yoğuşma, baca iç yüzeylerinde korozyon ve yapısal hasar riskini artırabilir [5]. Bu sebeplerle baca mekanizmalarında uygun yalıtım kalınlığının belirlenmesi, sadece enerji tasarrufu açısından değil, aynı zamanda sistem ömrü ve emisyon kontrolü açısından da önemlidir.

Katı yakıtlı sistemlerde emisyon oluşumu; yakıt türü, yanma koşulları, fazla hava oranı ve baca tasarım parametrelerine bağlı olarak değişkenlik gösterebilir [6]. Literatürde baca gazı kayıplarının azaltılması ve yanma veriminin artırılması amacıyla farklı yalıtım stratejilerinin değerlendirildiği çalışmalar mevcuttur [7, 8]. Bunun yanında, baca malzemesinin ısıl iletkenlik katsayısı ve ısıl depolama kapasitesi gibi özellikleri, sistemin sıcaklık dağılımı ve emisyon karakteristiği üzerinde etkili karakteristiklerdir [9, 10]. Hafif beton türevleri gibi farklı baca malzemelerinin ısıl performans açısından karşılaştırılması, endüstriyel uygulamalar için önemli tasarım verileri sunmaktadır.

ISBN NR: 978-625-5694-92-8

Enerji sistemlerinin performans analizinde simülasyon tabanlı yöntemler günümüzde yaygın olarak kullanılmaktadır. Sayısal modelleme araçları farklı yalıtım kalınlıkları ve malzeme alternatiflerinin, uygulama öncesinde karşılaştırmalı olarak değerlendirilebilmesine olanak tanır. Bu sayede optimum tasarım parametreleri kısa sürede belirlenebilir [11-13]. Bu çerçeve, özellikle bölgesel iklim verilerinin dikkate alındığı çalışmalarda daha gerçekçi sonuçlar elde edilmesini sağlayabilir [14-16].
Afyon ili, karasal iklim özellikleri ve uzun ısıtma sezonu nedeniyle katı yakıtlı kazan kullanımının yaygın olduğu bir bölgedir. Bu bağlamda, baca yalıtım kalınlığının ve malzeme türünün sistem performansına etkisinin simülasyon yöntemiyle incelenmesi, hem enerji verimliliği hem de emisyon kontrolü açısından önemli bir araştırma alanı oluşturmaktadır. Bu çalışma, Afyon iklim koşullarında faaliyet gösteren bir şekerleme üretim tesisine ait katı yakıtlı kazan sisteminde farklı yalıtım kalınlıkları ve baca malzemeleri için performans analizleri gerçekleştirerek, endüstriyel tesisler için uygulanabilir tasarım önerileri sunmayı amaçlamaktadır.

2. Analiz sonuçları ve değerlendirmeler



Şekil 1. Yalıtım Kalınlığına Bağlı Olarak Baca Ağız Kesitindeki Değişim

Artan yalıtım kalınlığı ile birlikte baca iç kesit değerlerinde küçük fakat düzenli bir azalma eğilimi gözlenmiştir. Bu durum, çift cidarlı yapı ve yalıtım tabakasının sistem geometrisi üzerindeki etkisini göstermektedir. Bununla birlikte kesit değişimi baca performansını olumsuz etkileyecek düzeyde değildir.

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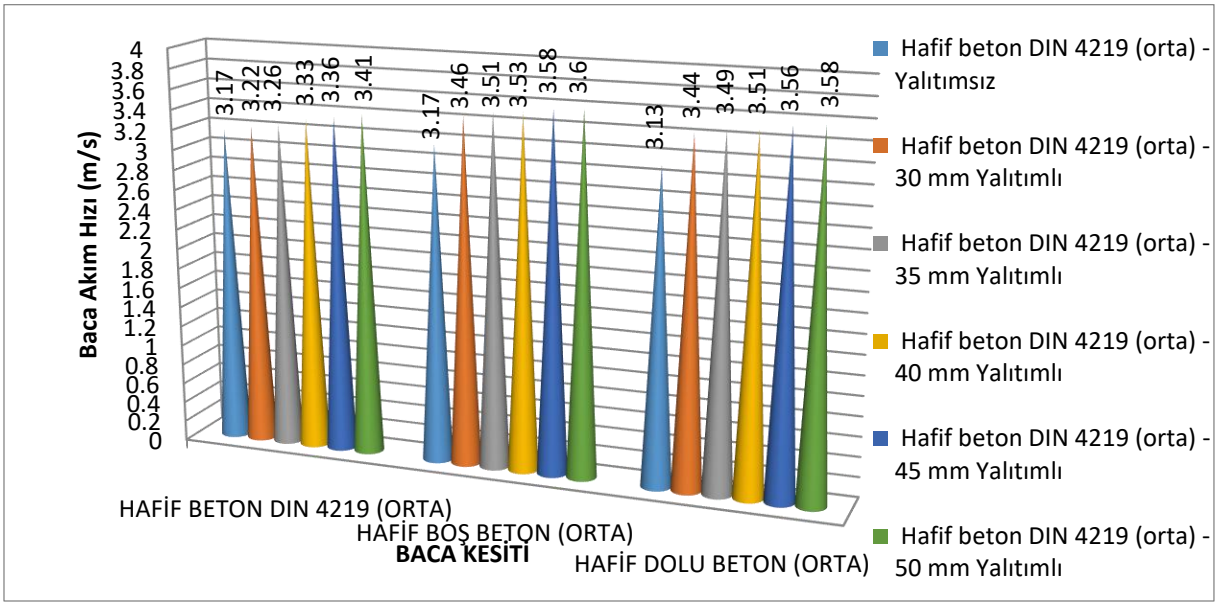
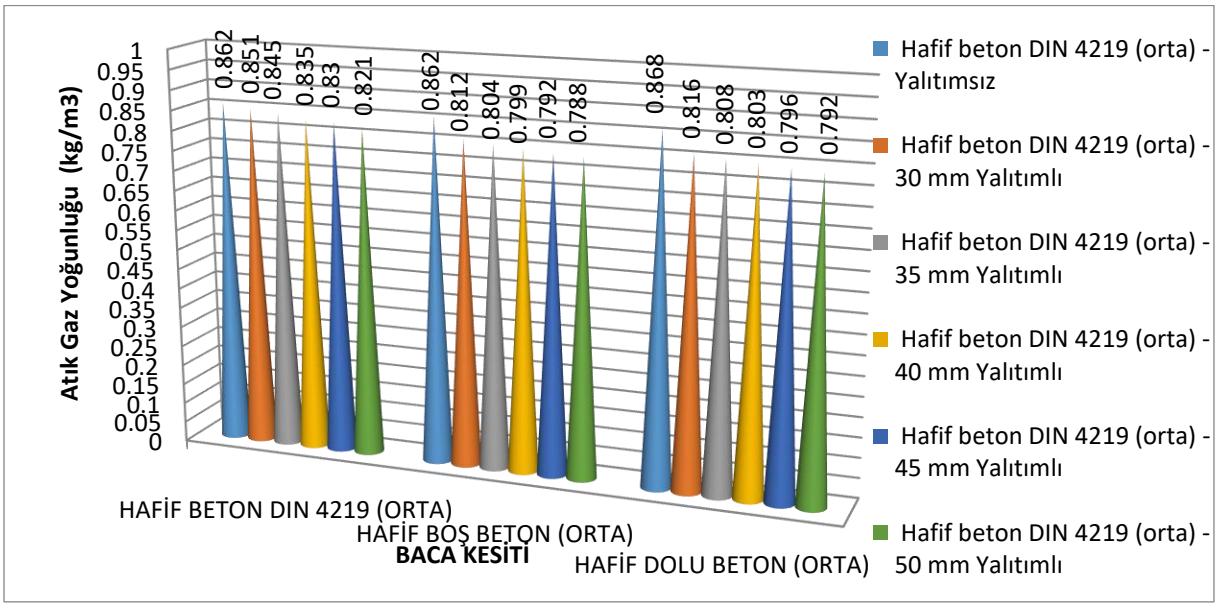


Şekil 2. Yalıtım Kalınlığının Akım Hızına Etkisi

Simülasyon sonuçlarına göre yalıtım kalınlığının artması baca içerisindeki akım hızının yükselmesine katkı sağlamaktadır. Bunun temel nedeni, yalıtım sayesinde baca gazı sıcaklığının daha iyi korunması ve buna bağlı olarak çekiş etkisinin artmasıdır.



Şekil 3. Yalıtım Kalınlığına Bağlı Atık Gaz Yoğunluğu Değişimi

Baca sistemlerinde yalıtım kalınlığının artmasıyla birlikte atık gaz yoğunluğunda azalma eğilimi gözlenmiştir. Bu durum, baca gazı sıcaklığının korunması sonucu gaz yoğunluğunun düşmesi ve çekiş performansının iyileşmesi ile ilişkilidir.

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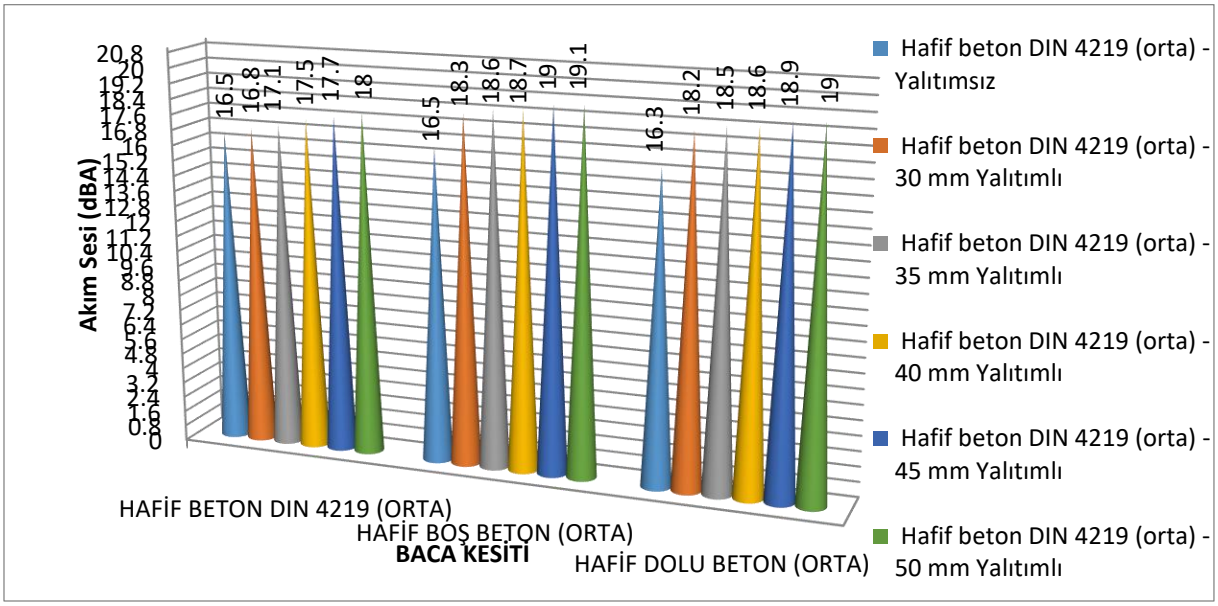
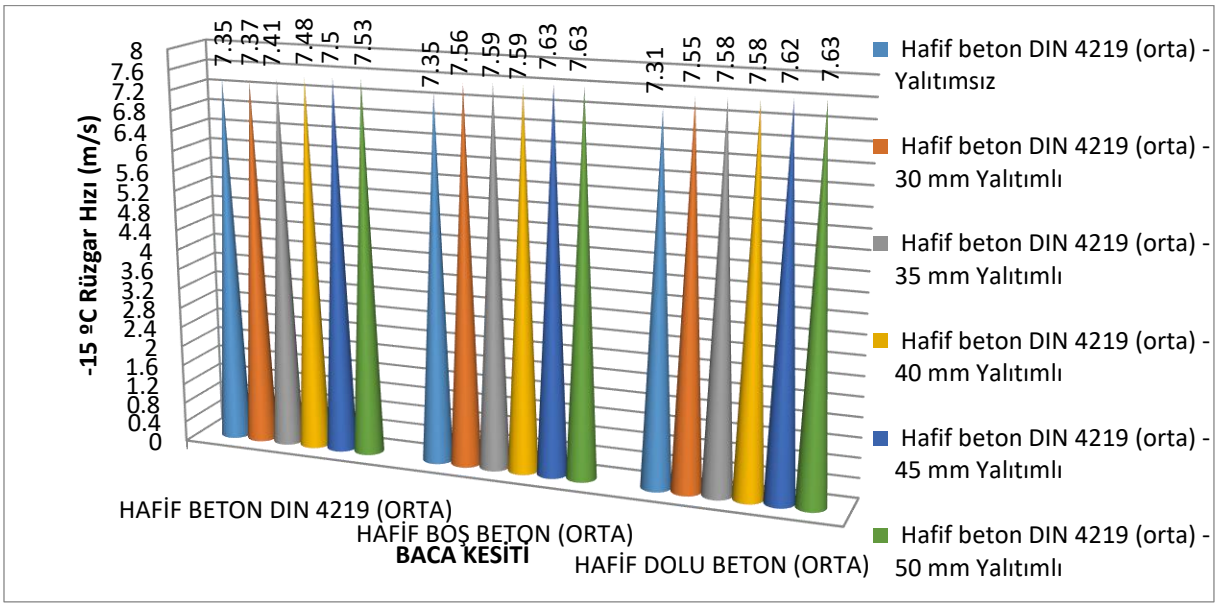


Şekil 4. Yalıtım Kalınlığının Akım Ses Seviyesine Etkisi

Baca içerisindeki akım hızının artmasına bağlı olarak akım sesi değerlerinde kademeli bir artış meydana gelmiştir. Bununla birlikte oluşan ses seviyeleri kabul edilebilir sınırlar içerisinde kalmaktadır.



Şekil 5. -15 °C Dış Ortam Sıcaklığında Rüzgar Hızının Yalıtım Kalınlığına Bağlı Değişimi

Düşük dış ortam sıcaklığı koşullarında yalıtım kalınlığının artması rüzgar hızında hafif bir artış oluşturmuştur. Bu durum baca gazı sıcaklığının korunması sayesinde oluşan daha güçlü çekiş etkisi ile açıklanabilir.

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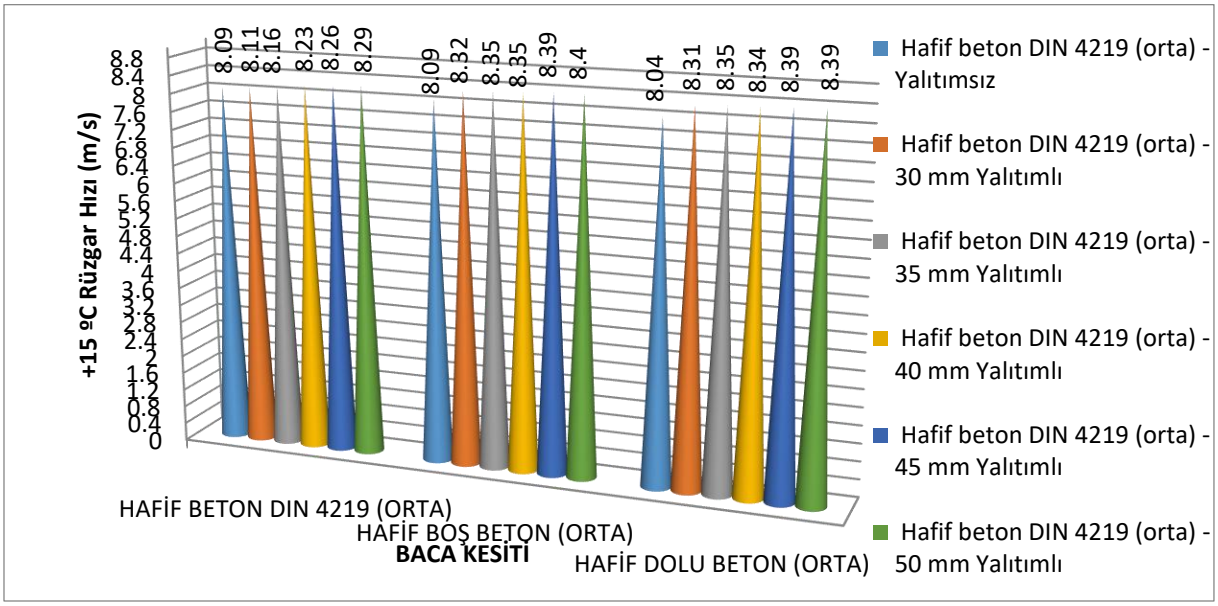
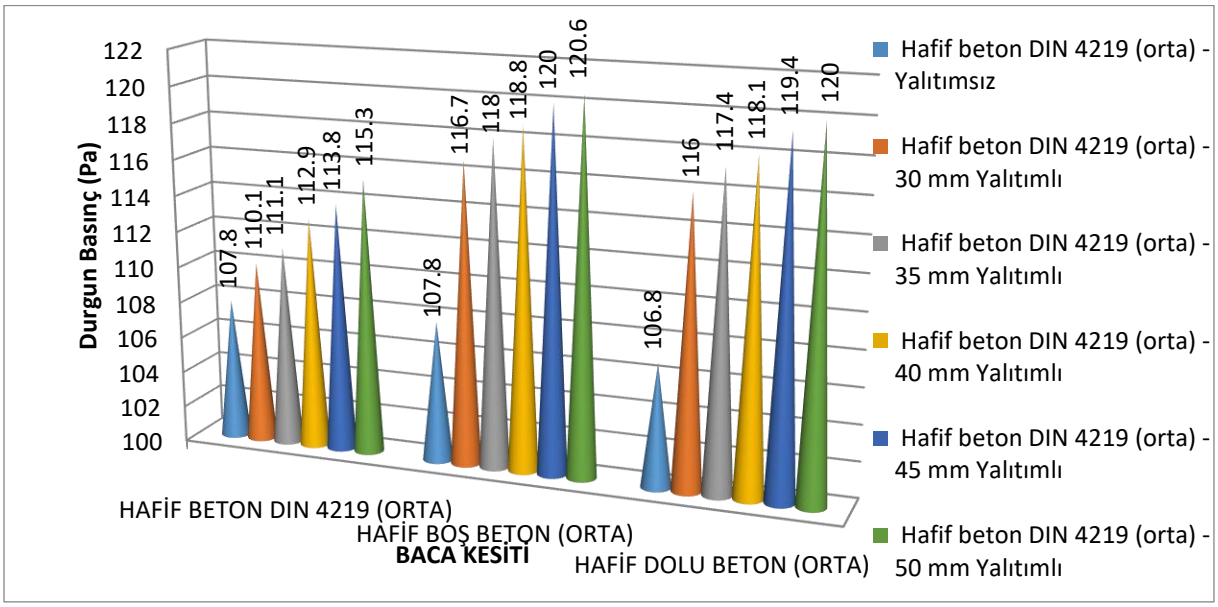


Şekil 6. +15 °C Dış Ortam Sıcaklığında Rüzgar Hızının Yalıtım Kalınlığına Bağlı Değişimi

Orta seviyedeki dış ortam sıcaklığında da benzer bir eğilim gözlenmiş ve yalıtım kalınlığının artmasıyla birlikte rüzgar hızında sınırlı bir artış meydana gelmiştir. Bu durum baca performansının çevresel koşullardan etkilendiğini göstermektedir.



Şekil 7. Yalıtım Kalınlığına Bağlı Durgun Basınç Değişimi

Simülasyon sonuçları yalıtım kalınlığının artmasıyla birlikte durgun basınç değerlerinde artış meydana geldiğini göstermektedir. Artan basınç değerleri baca çekiş performansının iyileştiğini ortaya koymaktadır.

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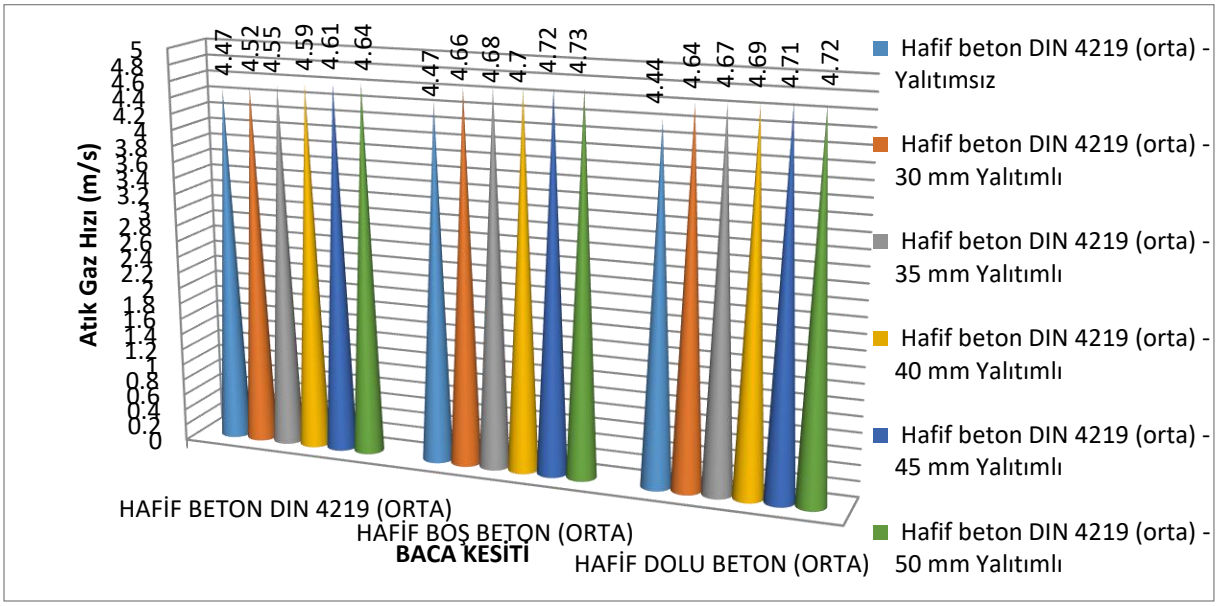
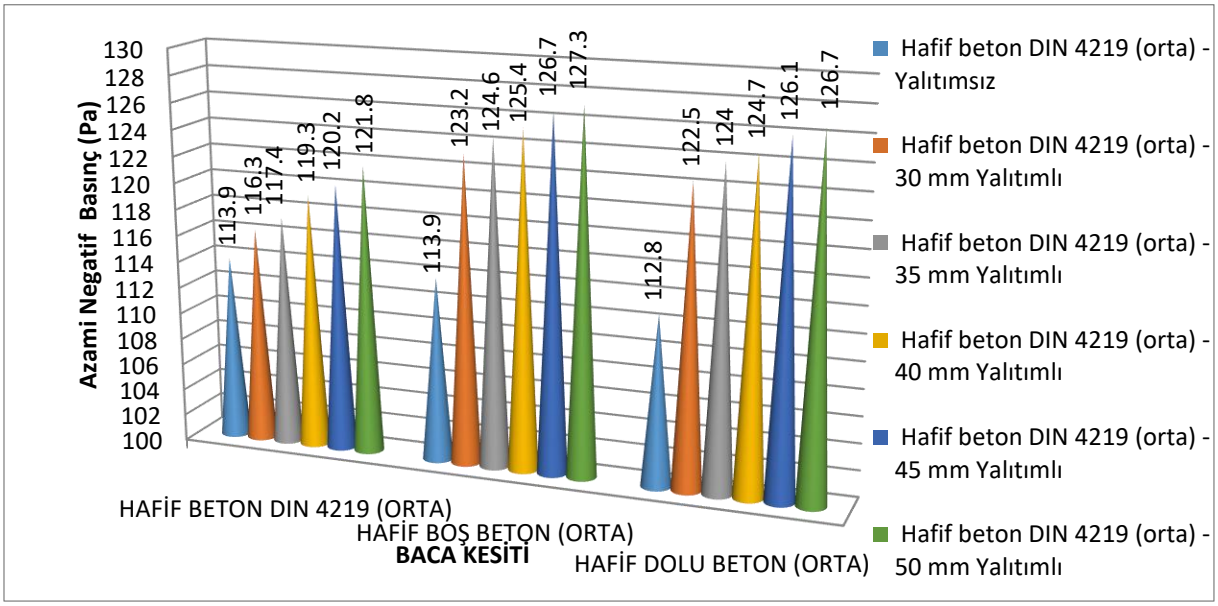


Şekil 8. Atık Gaz Hızının Yalıtım Kalınlığına Bağlı Değişimi

Yalıtım kalınlığının artırılmasıyla birlikte atık gaz hızının da kademeli olarak arttığı belirlenmiştir. Bu durum, baca içerisinde sıcak gaz akışının daha etkin şekilde gerçekleştiğini göstermektedir.



Şekil 9. Azami Negatif Basıncın Yalıtım Kalınlığına Bağlı Değişimi

Artan yalıtım kalınlığı ile birlikte azami negatif basınç değerlerinin de yükseldiği görülmektedir. Bu durum, baca çekiş kuvvetinin güçlendiğini ve sistem performansının arttığını göstermektedir.

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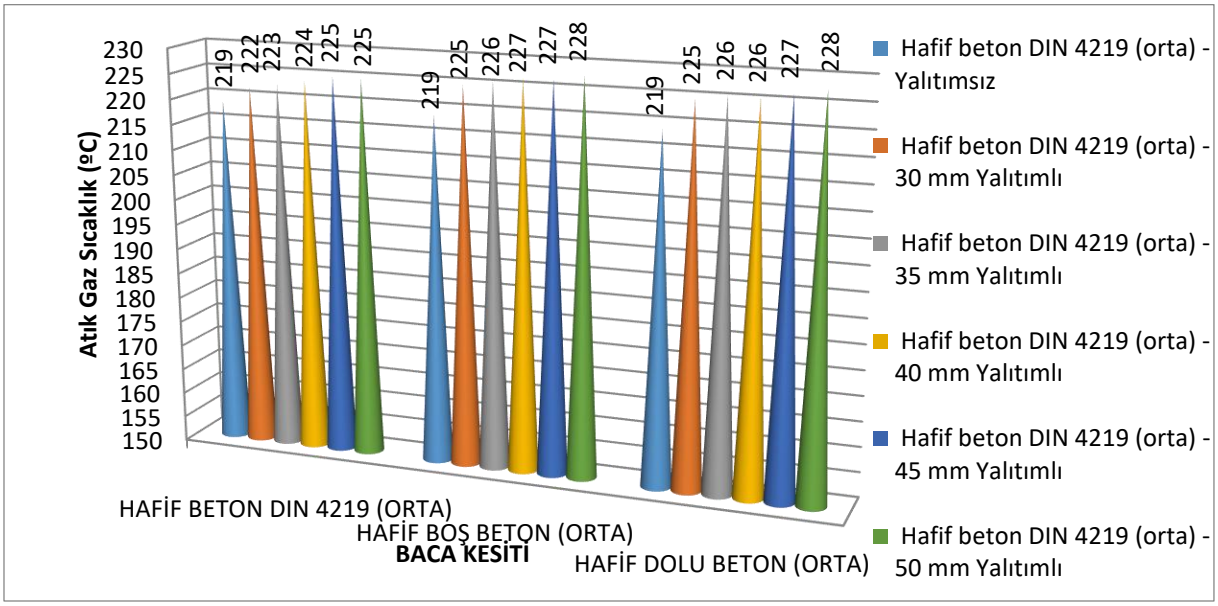
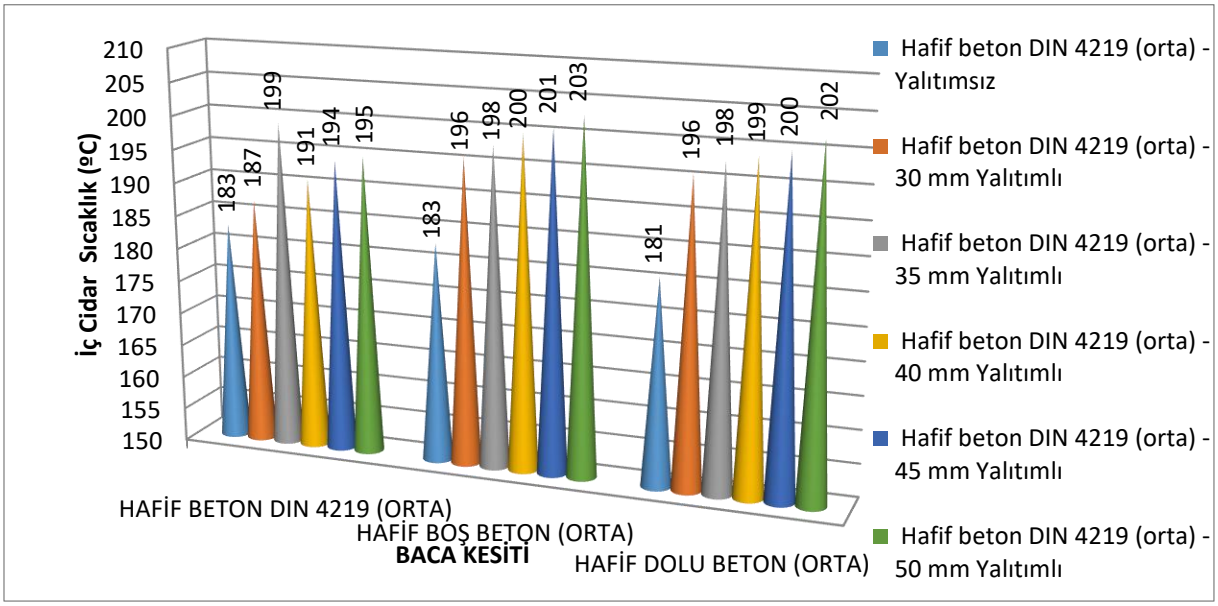


Şekil 10. Baca Gazı Sıcaklığının Yalıtım Kalınlığına Bağlı Değişimi

Yalıtım kalınlığının artması baca gazı sıcaklığının korunmasına katkı sağlamaktadır. Bu durum baca içerisinde ısı kayıplarının azalmasıyla ilişkilidir.



Şekil 11. İç Cidar Sıcaklığının Yalıtım Kalınlığına Bağlı Değişimi

Simülasyon sonuçları, yalıtım kalınlığının artmasıyla birlikte iç cidar sıcaklıklarının yükseldiğini göstermektedir. Bu durum, baca duvarlarında meydana gelen ısı kayıplarının azaldığını ortaya koymaktadır.

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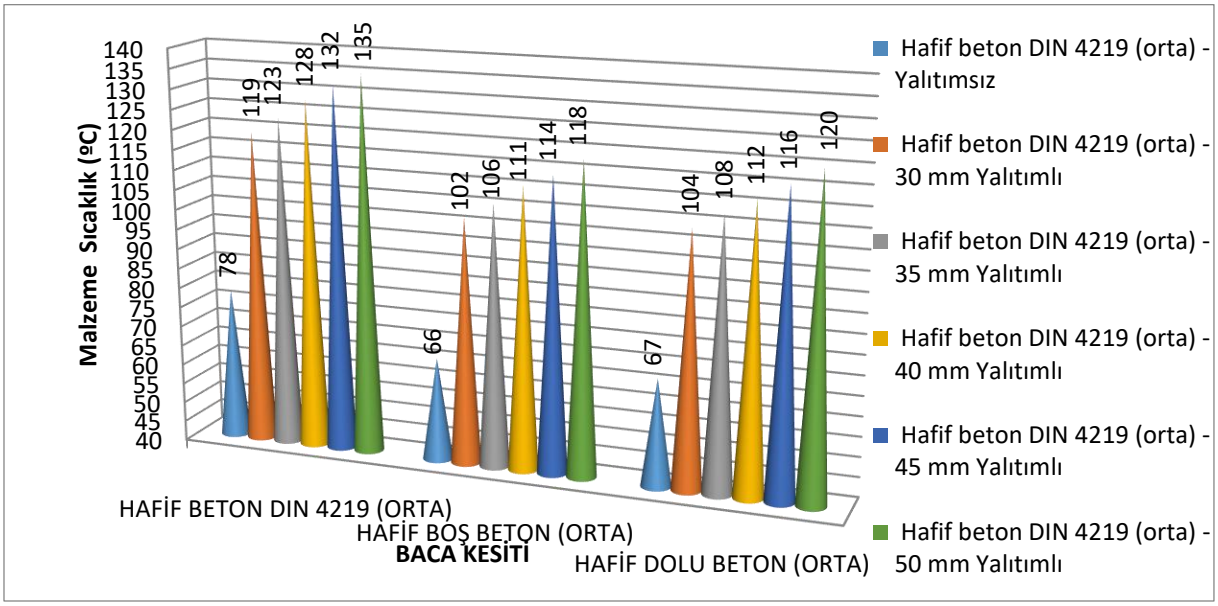
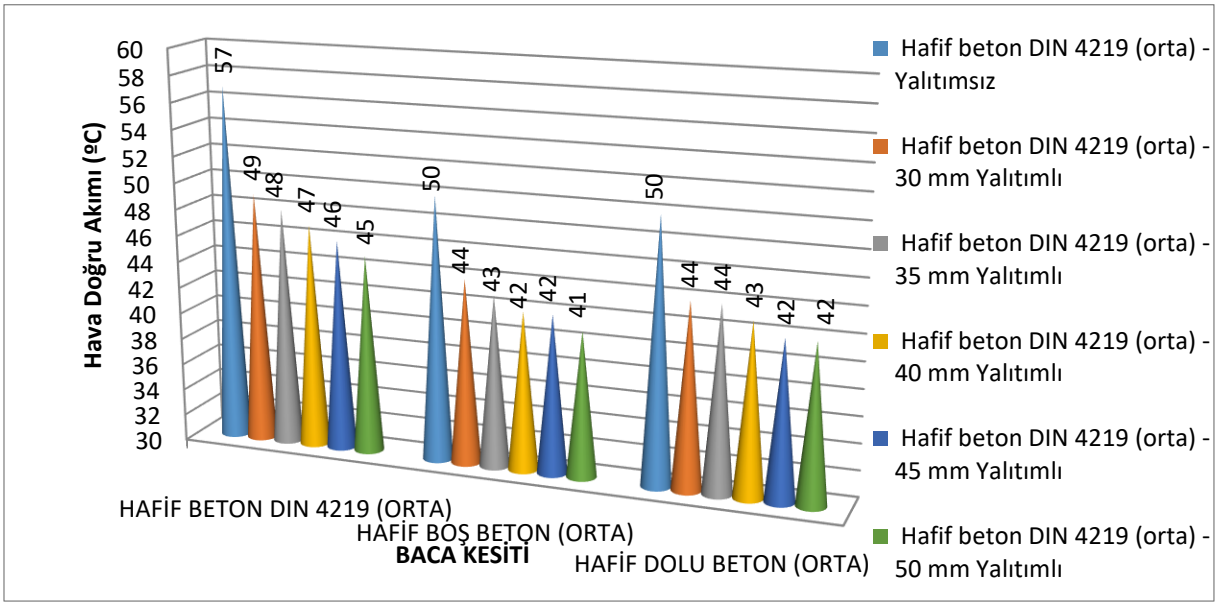


Şekil 12. Baca Malzemesi Sıcaklığının Yalıtım Kalınlığına Bağlı Değişimi

Yalıtım kalınlığının artması baca malzemesi içerisinde tutulan ısı miktarını artırmaktadır. Bu durum baca sisteminin termal davranışının yalıtım ile önemli ölçüde değiştiğini göstermektedir.



Şekil 13. Hava Doğru Akımı Sıcaklığının Yalıtım Kalınlığına Bağlı Değişimi

Yalıtım kalınlığı arttıkça hava doğru akımı sıcaklığının azaldığı görülmektedir. Bu durum, baca sisteminde dış ortama aktarılan ısı miktarının azaldığını göstermektedir.

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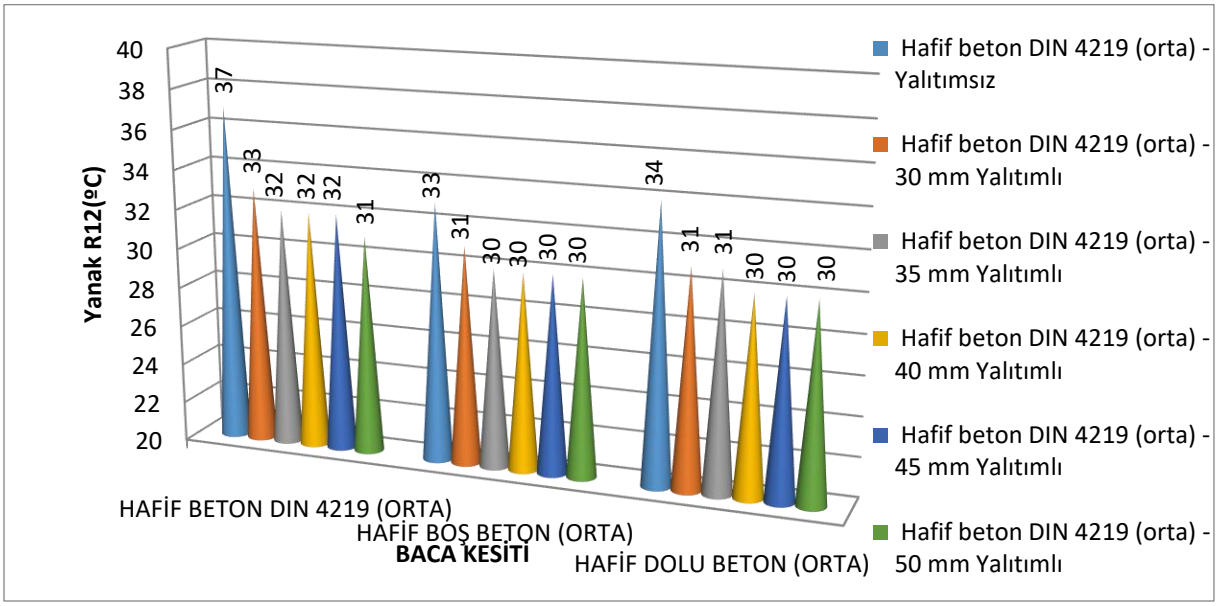

Şekil 14. Yanak (R12) Sıcaklığının Yalıtım Kalınlığına Bağlı Değişimi

Baca dış yüzeyine karşılık gelen yanak sıcaklığı değerlerinin yalıtım kalınlığının artmasıyla birlikte azaldığı belirlenmiştir. Bu durum, yalıtım uygulamasının dış yüzey ısı kayıplarını önemli ölçüde azalttığını göstermektedir.

3. Sonuç

Bu çalışmada Afyon ili iklim koşullarında çalışan 140.000 kcal/h kapasiteli katı yakıtlı bir kazan sistemine ait baca performansı, farklı baca malzemeleri ve yalıtım kalınlıkları için KesaAladin simülasyon programı kullanılarak incelenmiştir. Çalışmada hafif beton (orta), hafif boş beton (orta) ve hafif dolu beton (orta) baca malzemeleri için yalıtımsız durum ile birlikte 30 mm, 35 mm, 40 mm, 45 mm ve 50 mm taşyünü yalıtım kalınlıklarının baca performans parametreleri üzerindeki etkileri karşılaştırılmıştır.

Simülasyon sonuçları, tüm baca malzemelerinde yalıtım kalınlığının artmasıyla birlikte baca gazı sıcaklığının daha iyi korunabildiğini ve buna bağlı olarak çekiş performansının iyileştiğini göstermiştir. Yalıtımsız bacalarda baca gazı sıcaklığı yaklaşık 219 °C seviyesinde gerçekleşirken, 50 mm yalıtım uygulamasında bu değerin 225–228 °C seviyelerine yükseldiği belirlenmiştir. Benzer şekilde durgun basınç değerlerinin de yalıtım kalınlığının artmasıyla birlikte yaklaşık 107 Pa seviyelerinden 120 Pa seviyelerine kadar yükseldiği gözlenmiştir. Bu durum baca çekiş kuvvetinin arttığını ve yanma ürünlerinin daha etkin bir şekilde uzaklaştırıldığını göstermektedir.

Akım hızı ve atık gaz hızı değerleri de yalıtım kalınlığı ile birlikte artış göstermiştir. Özellikle hafif boş beton ve hafif dolu beton baca malzemelerinde akım hızlarının daha yüksek değerlere ulaştığı belirlenmiştir. Bununla birlikte dış yüzey sıcaklıklarının azalması, yalıtım uygulamasının baca duvarlarından gerçekleşen ısı kayıplarını önemli ölçüde azalttığını ortaya koymaktadır. Bu durum enerji verimliliği açısından önemli bir avantaj sağlamaktadır.

Baca malzemeleri karşılaştırıldığında, hafif boş beton (orta) baca malzemesinin diğer alternatiflere göre daha yüksek çekiş basıncı, daha düşük gaz yoğunluğu ve daha yüksek akım hızları sağlayarak sistem performansını olumlu yönde etkilediği görülmüştür. Ayrıca bu malzeme ile birlikte kullanılan 50 mm taşyünü yalıtım kalınlığı, baca gazı sıcaklığının korunması ve ısı kayıplarının azaltılması açısından en iyi performansı göstermiştir.

Elde edilen bulgular doğrultusunda Afyon ili iklim koşullarında katı yakıtlı kazan sistemleri için hafif boş beton baca malzemesi ve 50 mm taşyünü yalıtım kalınlığına sahip baca tasarımının en enerji verimli ve en uygun çözüm olduğu sonucuna ulaşılmıştır. Bu tasarımın uygulanmasıyla baca çekiş performansı iyileştirilmekte, ısı kayıpları azaltılmakta ve dolaylı olarak yakıt tüketimi ile emisyon seviyelerinin düşürülmesine katkı sağlanmaktadır.

Sonuç olarak, endüstriyel tesislerde baca sistemlerinin tasarımında uygun malzeme seçimi ve yeterli yalıtım kalınlığının belirlenmesi enerji verimliliği ve çevresel sürdürülebilirlik açısından büyük önem taşımaktadır.

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BALKAN 15th INTERNATIONAL CONFERENCE ON APPLED SCIENCES
March 20 – 22, 2026 – SKOPJE
ISBN NR: 978-625-5694-92-8

FARKLI AÇILARDA GALVANİZ BORULARLA TASARLANAN BACA MEKANİZMALARININ PERFORMANS ANALİZİ

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Özet
Bu çalışmada, Van ilinin iklim koşullarında faaliyet gösteren ve 150.000 kcal/h kapasiteli sıvı yakıtlı ısıtma kazanına sahip bir karton bardak üretim tesisi için baca sistemlerinin enerji verimliliği ve emisyon performansı simülasyon yöntemiyle araştırılmıştır. Araştırma kapsamında, galvanizli ateşe dayanıklı alüminyum kaplamalı çelik ve galvanizli çelik olmak üzere iki farklı baca malzemesi ele alınmıştır. Her malzeme için 30°, 45°, 60° ve 90° açı kombinasyonlarında dairesel ve oval kesitli çift cidarlı baca tasarımları oluşturulmuştur. Tasarlanan tüm baca sistemlerinde ısı yalıtım malzemesi olarak taşyünü kullanılmıştır. Farklı geometrik ve malzeme özelliklerine sahip senaryoların performans analizi KesaAladin simülasyon programı yardımıyla gerçekleştirilmiştir. Elde edilen bulgular, baca malzemesi ve formunun, sistemin çekiş karakteristiği, ısı kayıpları ve baca gazı emisyonları üzerinde belirleyici bir etkiye sahip olduğunu göstermektedir. Çalışma, Van ili için endüstriyel tesislerde uygun baca tasarımının enerji verimliliğini artırma ve çevresel etkileri azaltma potansiyelini ortaya koyarak, sektöre yönelik uygulanabilir bir örnek sunmayı amaçlamaktadır.
Anahtar kelimeler: Baca tasarımı, enerji verimliliği, emisyon azaltımı, KesaAladin simülasyonu, endüstriyel kazan sistemleri, Van iklim koşulları

1 Giriş

Endüstriyel tesislerde enerji tüketiminin önemli bir bölümü ısıtma ve proses amaçlı kullanılan kazan sistemlerinden elde edilmektedir. Soğuk iklim bölgelerinde faaliyet gösteren üretim tesislerinde, kazan sistemlerinin verimli çalışması hem işletme maliyetleri hem de çevresel etkiler açısından daha önemlidir [1]. Enerji verimliliğinin artırılması, yalnızca yakıt tüketiminin azaltılması anlamına gelmemektedir. Bu aynı zamanda baca gazı emisyonlarının düşürülmesi, karbon ayak izinin azaltılması ve sürdürülebilir üretim hedeflerine katkı sağlanması gibi birçok pozitif kazanıma sebep olmaktadır [2].

Baca sistemleri, kazan performansının ayrılmaz bir parçasıdır. Yanma ürünlerinin güvenli ve etkin biçimde atmosfere atılmasını sağlarken kazanın performansına direkt etki edebilecek bir bölümdür. Bacanın geometrik formu, kesit tipi, eğim açıları ve malzeme özellikleri; sistemin çekiş karakteristiğini, basınç kayıplarını ve ısı transfer mekanizmalarını doğrudan etkilemektedir [3]. Özellikle çift cidarlı ve yalıtımlı baca tasarımlarında ısı kayıplarının minimize edilmesi, baca gazı sıcaklığının korunması ve yoğuşma riskinin azaltılması için daha dikkatli tasarım yapılmasını gerekir [4]. Bu bağlamda, baca sistemlerinde kullanılan galvanizli çelik ve alüminyum kaplamalı çelik gibi malzemelerin termal iletkenlik, korozyon direnci ve dayanım özellikleri performans üzerinde oldukça önemlidir [5].

Literatürde kazan ve baca sistemlerinin enerji performansına yönelik birçok deneysel ve sayısal çalışma bulunmaktadır. Endüstriyel kazan sistemlerinde yanma verimi ve baca gazı kayıplarının analizine yönelik çalışmalar, sistem optimizasyonu için temel parametreleri göstermektedir [6]. Baca gazı sıcaklığı, fazla hava oranı ve çekiş basıncı gibi değişkenlerin enerji kayıpları ve emisyon oluşumu üzerindeki etkileri bu çalışmalarda araştırılan başlıca parametrelerdir [7]. Ayrıca, baca tasarımında akış rejimi ve basınç kayıplarının hesaplanmasına yönelik teorik ve deneysel araştırmalar, sistem performansının erken tasarım aşamalarında belirlenmesine yönelik kritik katkılar sağlar [8, 9].

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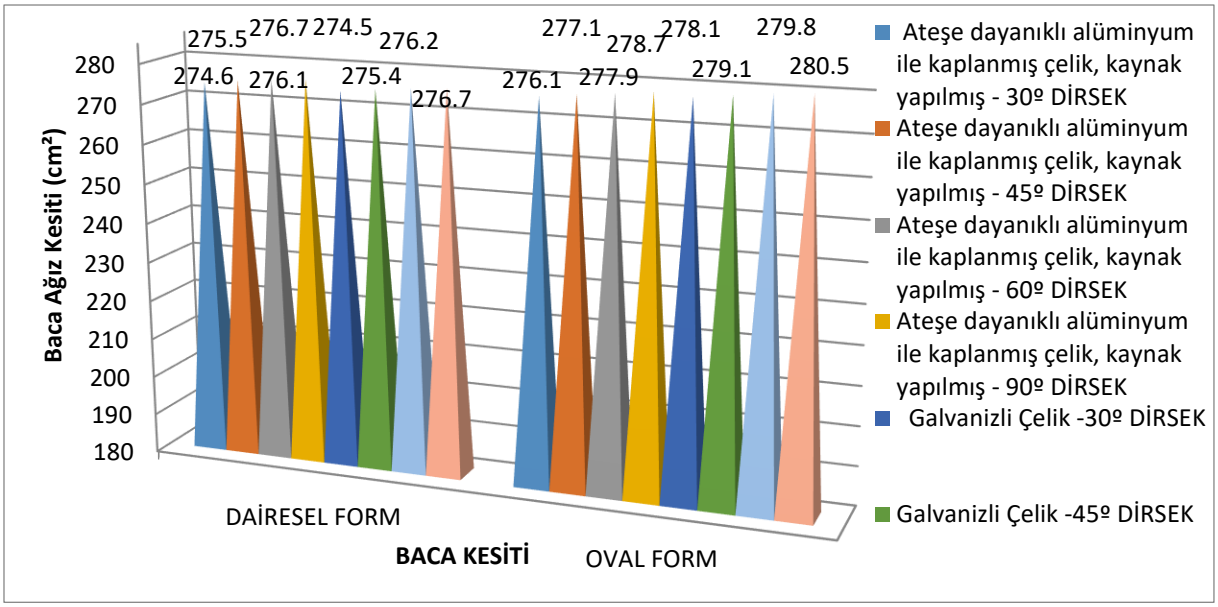
Son yıllarda bina ve endüstriyel enerji sistemlerinin analizinde simülasyon tabanlı yöntemler yaygın biçimde kullanılmaktadır. Dinamik ve kararlı durum simülasyon araçları sayesinde farklı malzeme, geometri ve işletme senaryoları karşılaştırmalı olarak değerlendirilebilmektedir. Bu sayede uygulama öncesinde optimum tasarım alternatifleri elde edilebilir [10-12]. Özellikle bölgesel iklim verilerinin dikkate alındığı simülasyon çalışmaları, yerel koşullara uygun enerji verimliliği stratejilerinin geliştirilmesinde oldukça kritiktir [13-16].
Van ili, uzun ve sert kış koşulları ile karakterize edilen karasal iklime sahip bir bölge olup, ısıtma sistemlerinin yüksek kapasite ve süreklilikle çalışmasını gerektirir. Bu nedenle, bölgede faaliyet gösteren endüstriyel tesislerde baca tasarımının enerji kayıpları ve emisyonlar üzerindeki etkisinin incelenmesi önemli bir araştırma alanı olarak araştırılmaktadır. Bu çalışmada, 150.000 kcal/h kapasiteli sıvı yakıtlı bir ısıtma kazanına sahip karton bardak üretim tesisinde farklı malzeme ve açı kombinasyonlarına sahip galvaniz baca tasarımları simülasyon yöntemiyle analiz edilmiştir. Çalışmanın amacı, baca malzemesi ve geometrisinin çekiş performansı, ısı kaybı ve baca gazı emisyonları üzerindeki etkilerini ortaya koyarak, Van iklim koşullarında endüstriyel tesisler için uygulanabilir ve enerji verimli baca tasarımına yönelik bilimsel bir değerlendirme sunmaktır.

2. Analiz sonuçları ve değerlendirmeler



Şekil 1. Farklı baca malzemesi ve dirsek açılarına göre dairesel ve oval baca tasarımlarının ağız kesiti değerlerinin karşılaştırılması

Grafik incelendiğinde oval kesitli baca tasarımlarında ağız kesiti değerlerinin dairesel formdan daha yüksek olduğu görülmektedir. Dirsek açısının artmasıyla birlikte ağız kesiti değerlerinde küçük artışlar meydana gelmiştir. Bu durum özellikle galvanizli çelik malzemede daha belirgin şekilde gözlemlenmiştir.

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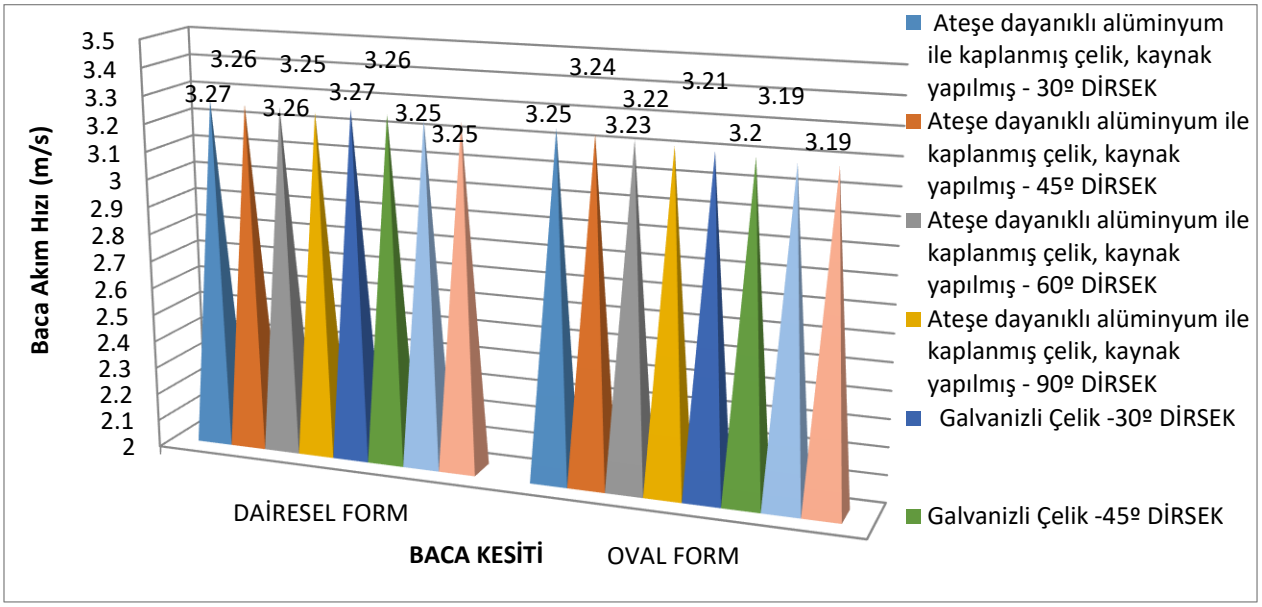
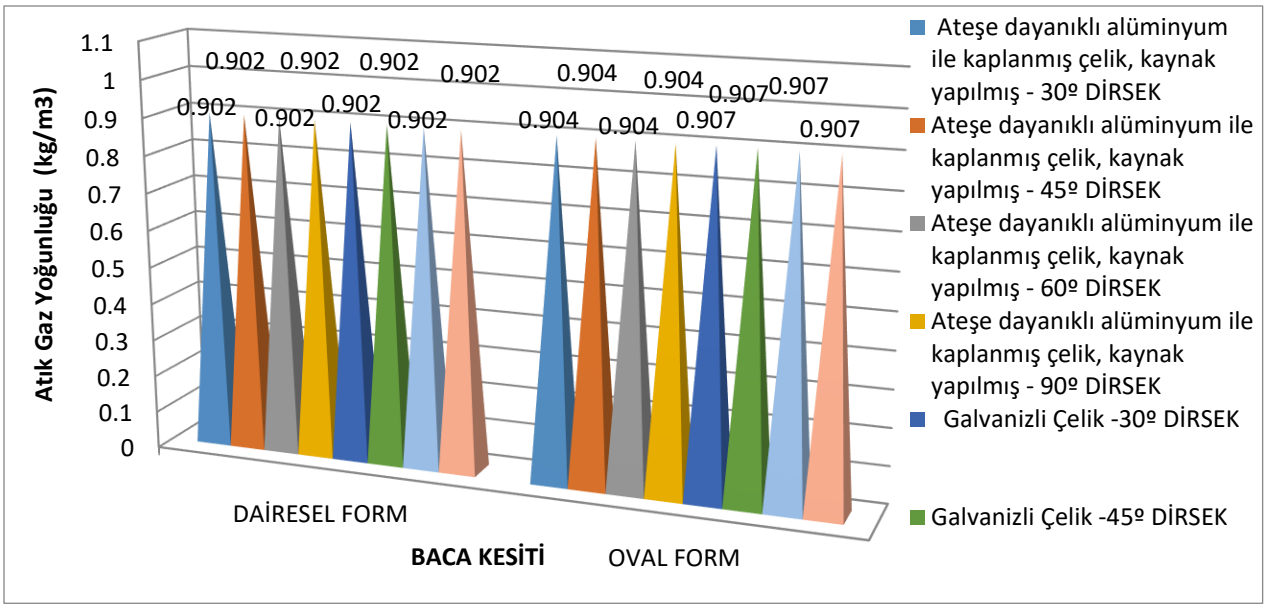


Şekil 2. Farklı baca geometrileri ve malzemeleri için akım hızı değerlerinin karşılaştırılması

Akım hızı değerleri tüm senaryolarda birbirine oldukça yakın sonuçlar vermiştir. Dairesel kesitli baca tasarımlarında akım hızının oval kesitli tasarımlara göre çok az daha yüksek olduğu görülmektedir. Dirsek açısının artmasıyla birlikte akım hızında küçük bir azalma eğilimi ortaya çıkmıştır.



Şekil 3. Farklı baca tasarımlarında atık gaz yoğunluğu değerlerinin karşılaştırılması

Atık gaz yoğunluğu değerleri tüm senaryolarda birbirine oldukça yakın sonuçlar göstermektedir. Oval kesitli baca tasarımlarında yoğunluk değerleri dairesel kesitlere göre çok az daha yüksek hesaplanmıştır. Malzeme türünün bu parametre üzerinde sınırlı bir etkisi olduğu görülmektedir.

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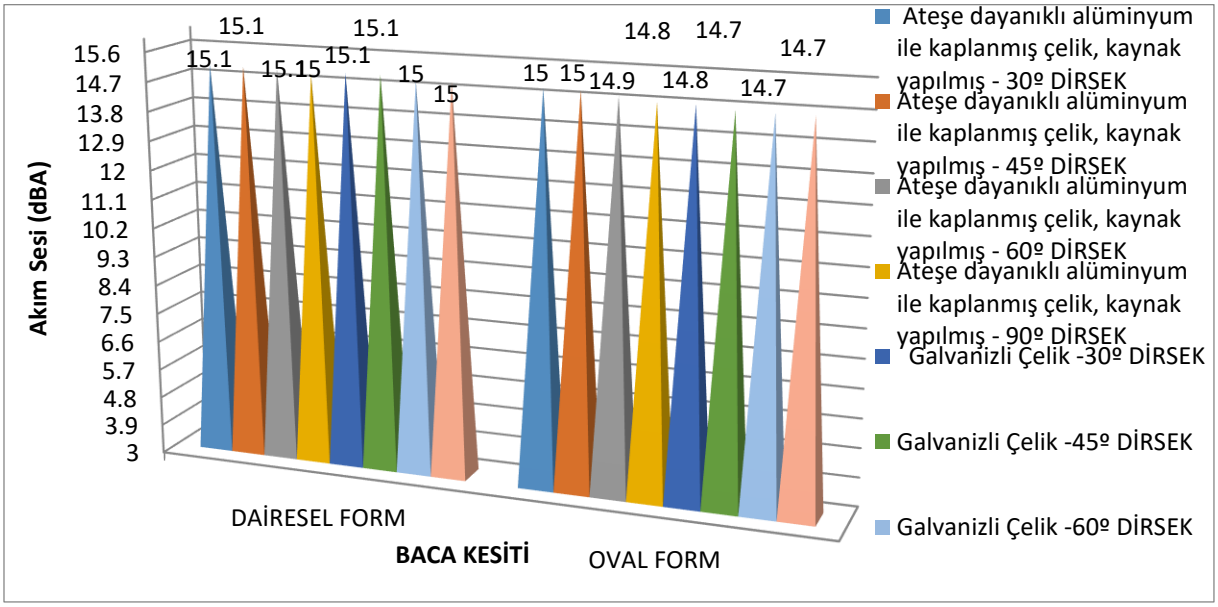
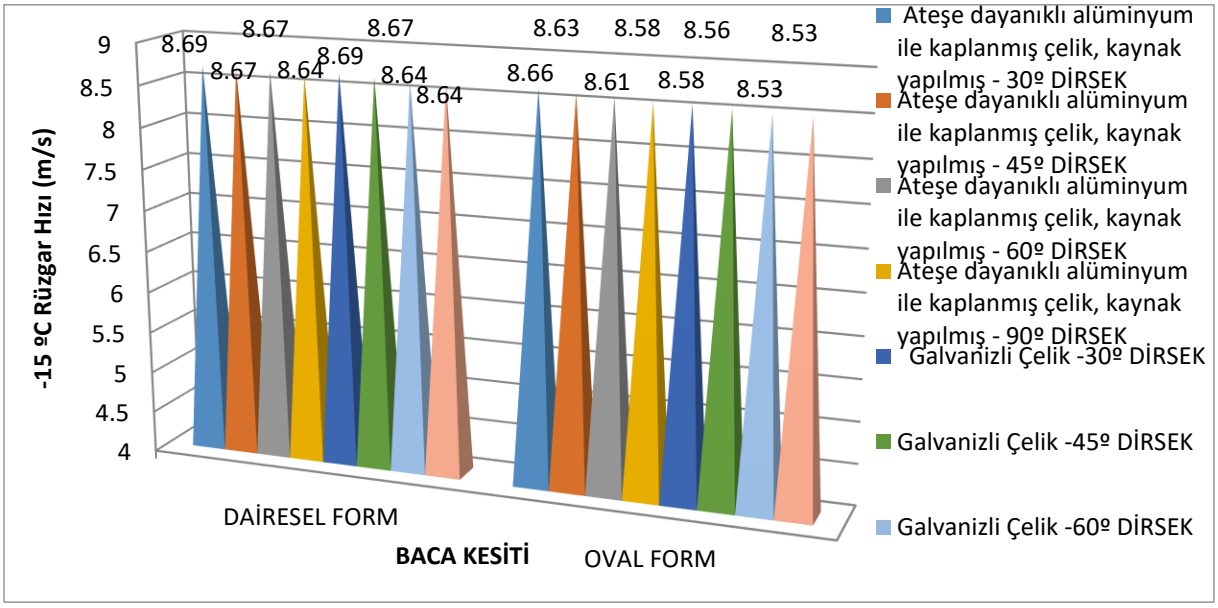


Şekil 4. Farklı baca malzemesi ve dirsek açılarına göre akım sesi seviyelerinin karşılaştırılması

Akım sesi değerleri incelendiğinde oval kesitli baca tasarımlarında ses seviyelerinin dairesel kesitli tasarımlara göre bir miktar daha düşük olduğu görülmektedir. Dirsek açısının artmasıyla birlikte akım sesinde küçük bir azalma eğilimi ortaya çıkmıştır. Bu durum oval geometrinin akış açısından daha stabil bir yapı oluşturduğunu göstermektedir.



Şekil 5. -15 °C dış ortam sıcaklığı koşullarında baca tasarımlarına göre rüzgar hızı değerlerinin karşılaştırılması

Grafik sonuçları düşük dış ortam sıcaklığında rüzgar hızının baca geometrisi ve dirsek açısına bağlı olarak küçük değişimler gösterdiğini ortaya koymaktadır. Oval kesitli bacalarda rüzgar hızının dairesel tasarımlara göre biraz daha düşük olduğu belirlenmiştir. Dirsek açısı arttıkça rüzgar hızında sınırlı bir azalma gözlenmiştir.

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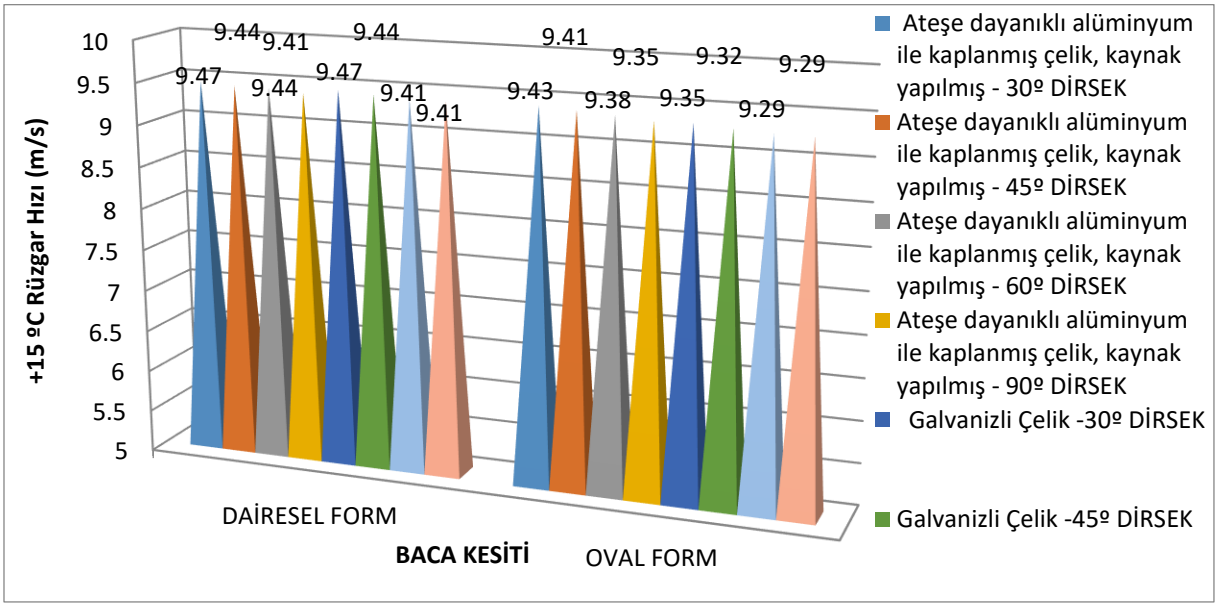
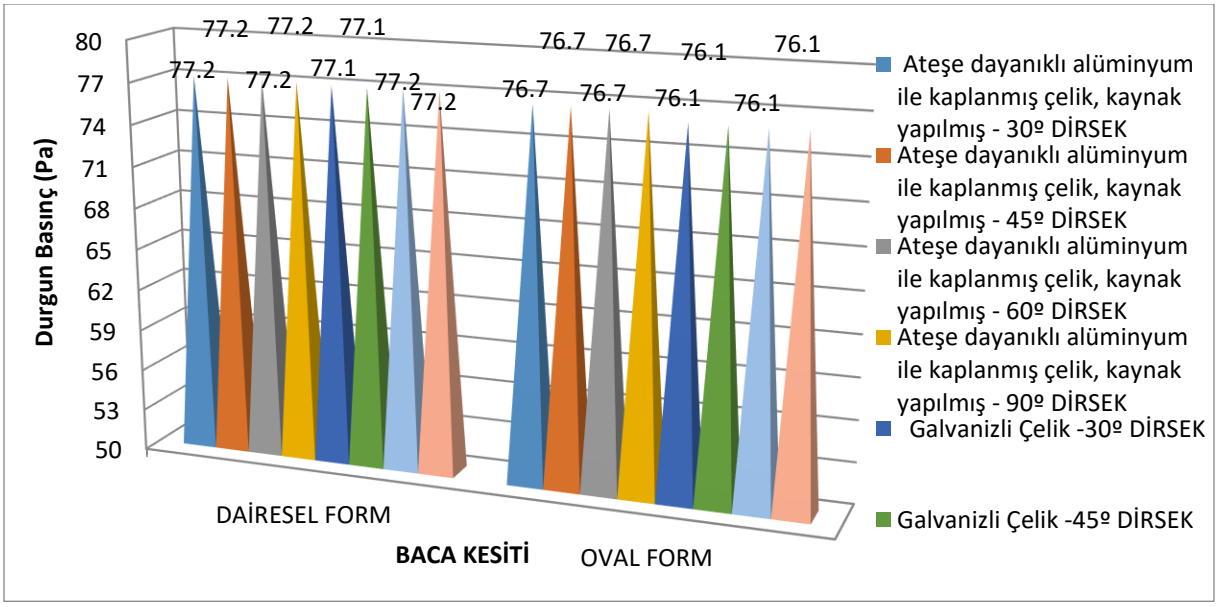


Şekil 6. +15 °C dış ortam sıcaklığı koşullarında baca tasarımlarına göre rüzgar hızı değerlerinin karşılaştırılması

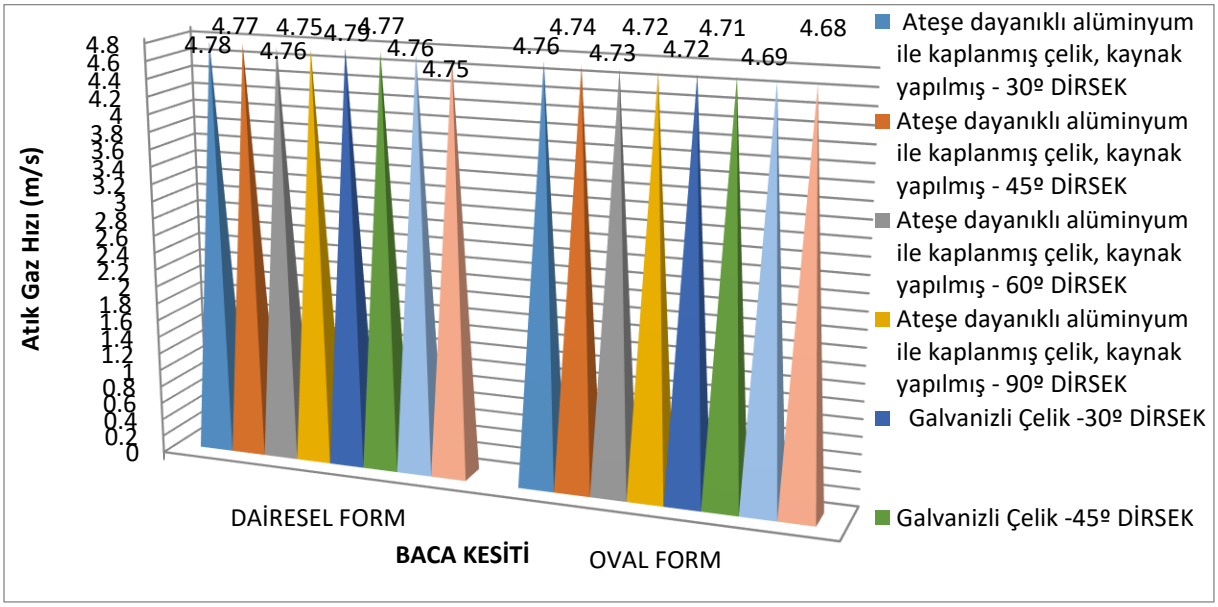
Pozitif sıcaklık koşullarında elde edilen rüzgar hızı değerleri -15 °C koşullarına göre daha yüksek hesaplanmıştır. Oval kesitli baca tasarımlarında rüzgar hızının daha düşük seviyelerde gerçekleştiği görülmektedir. Dirsek açısının artması rüzgar hızında küçük bir düşüş eğilimi oluşturmuştur.



Şekil 7. Farklı baca malzemesi ve geometrilerine göre durgun basınç değerlerinin karşılaştırılması

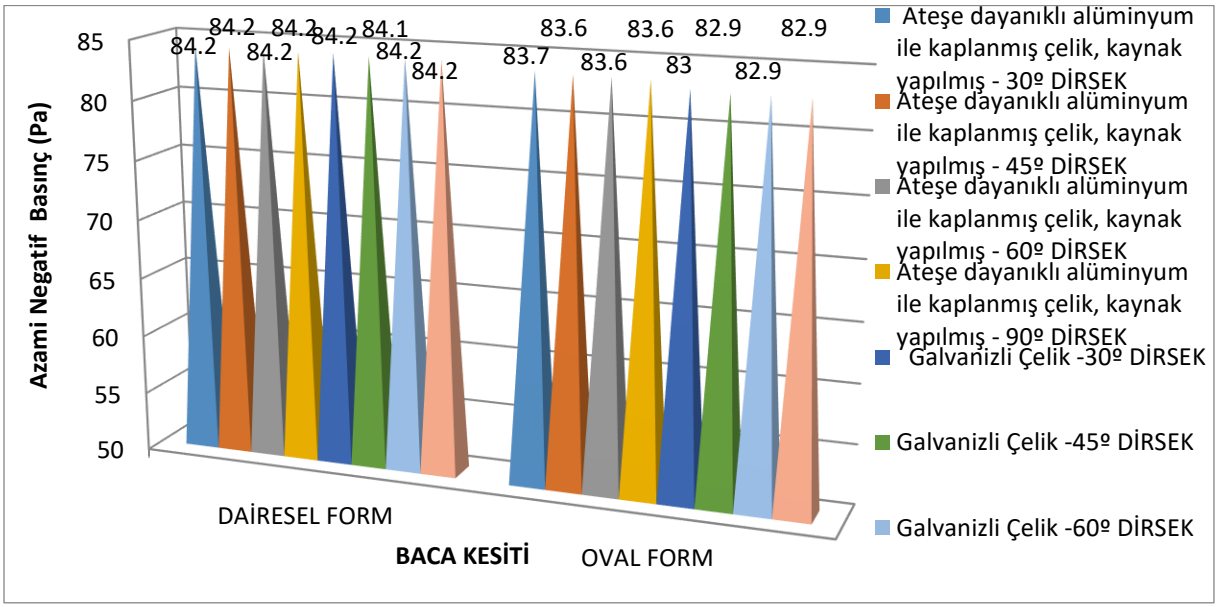
Durgun basınç değerleri dairesel kesitli baca tasarımlarında oval kesitlere göre biraz daha yüksek hesaplanmıştır. Malzeme türünün durgun basınç üzerinde sınırlı bir etkisi olduğu görülmektedir. Dirsek açısı değişiminin ise basınç değerlerinde önemli bir farklılık oluşturmadığı belirlenmiştir.

ISBN NR: 978-625-5694-92-8



Şekil 8. Farklı baca tasarımlarında atık gaz hızının karşılaştırılması

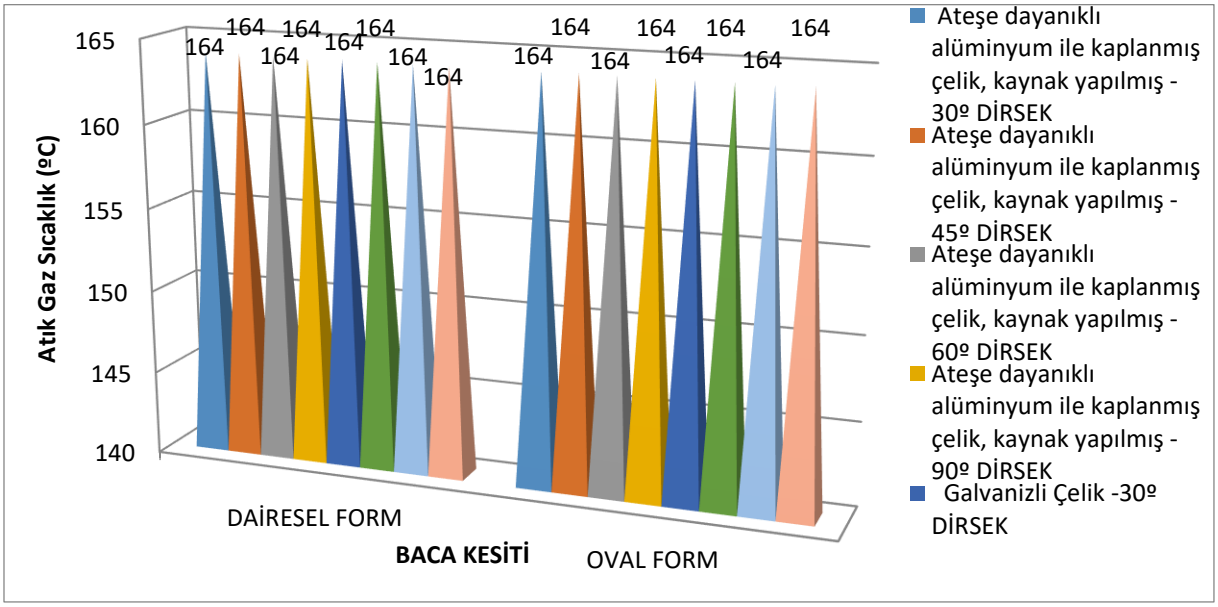
Atık gaz hızı değerleri tüm tasarım senaryolarında benzer sonuçlar göstermektedir. Dairesel kesitli bacalarda gaz hızının oval kesitli bacalara göre çok az daha yüksek olduğu belirlenmiştir. Dirsek açısının artması gaz hızında sınırlı bir azalmaya neden olmuştur.



Şekil 9. Farklı baca geometrileri ve malzemeleri için azami negatif basınç değerlerinin karşılaştırılması

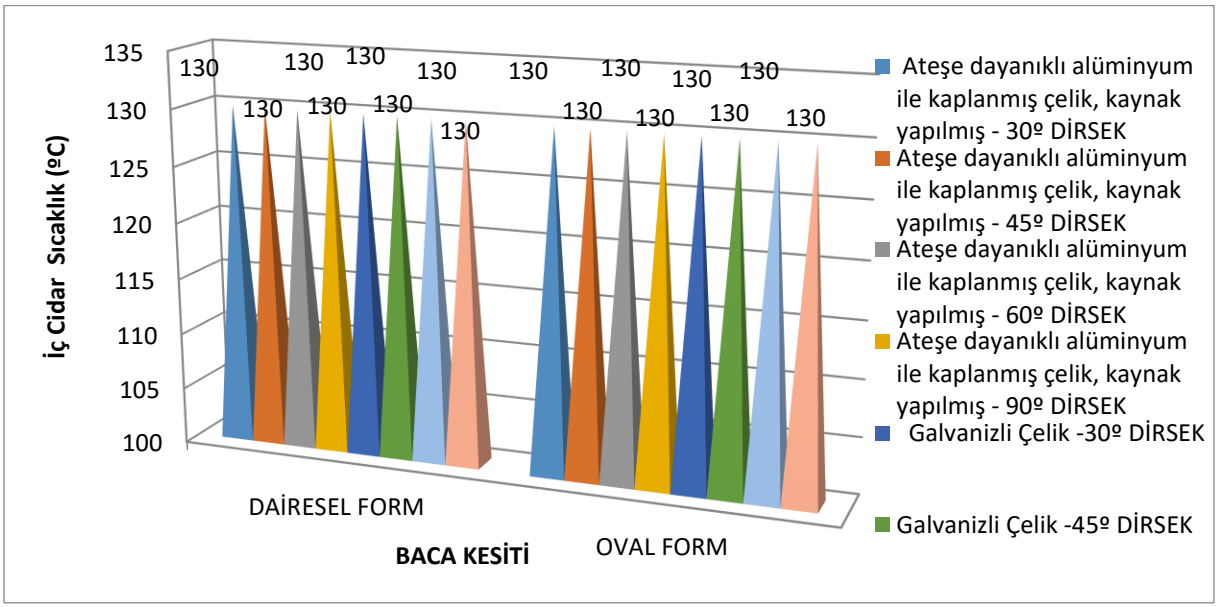
Azami negatif basınç değerleri baca sisteminin çekiş performansını yansıtan önemli bir parametredir. Grafik sonuçları dairesel kesitli baca tasarımlarının oval kesitlere göre biraz daha yüksek negatif basınç değerlerine sahip olduğunu göstermektedir. Bu durum dairesel bacalarda çekiş performansının daha güçlü olabileceğini göstermektedir.

ISBN NR: 978-625-5694-92-8



Şekil 10. Farklı baca tasarımlarında atık gaz sıcaklığı değerlerinin karşılaştırılması

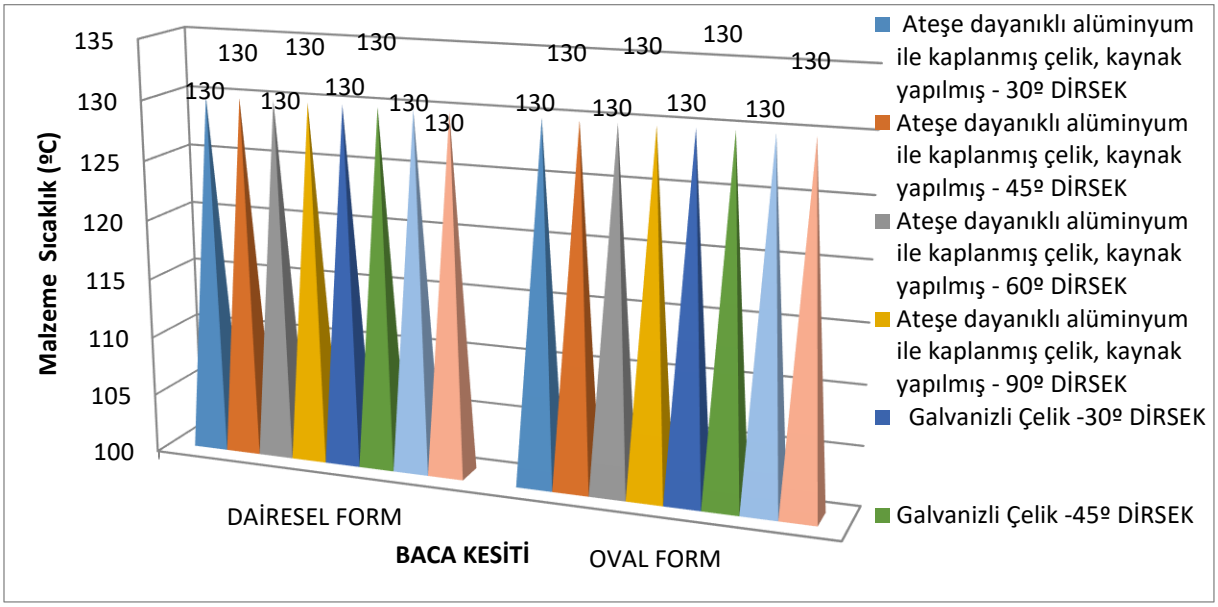
Simülasyon sonuçlarına göre tüm baca tasarımlarında atık gaz sıcaklığı aynı seviyede hesaplanmıştır. Bu durum baca geometrisi ve malzeme değişiminin atık gaz sıcaklığı üzerinde önemli bir etkisinin olmadığını göstermektedir.



Şekil 11. Farklı baca tasarımlarında iç cidar sıcaklığı değerlerinin karşılaştırılması

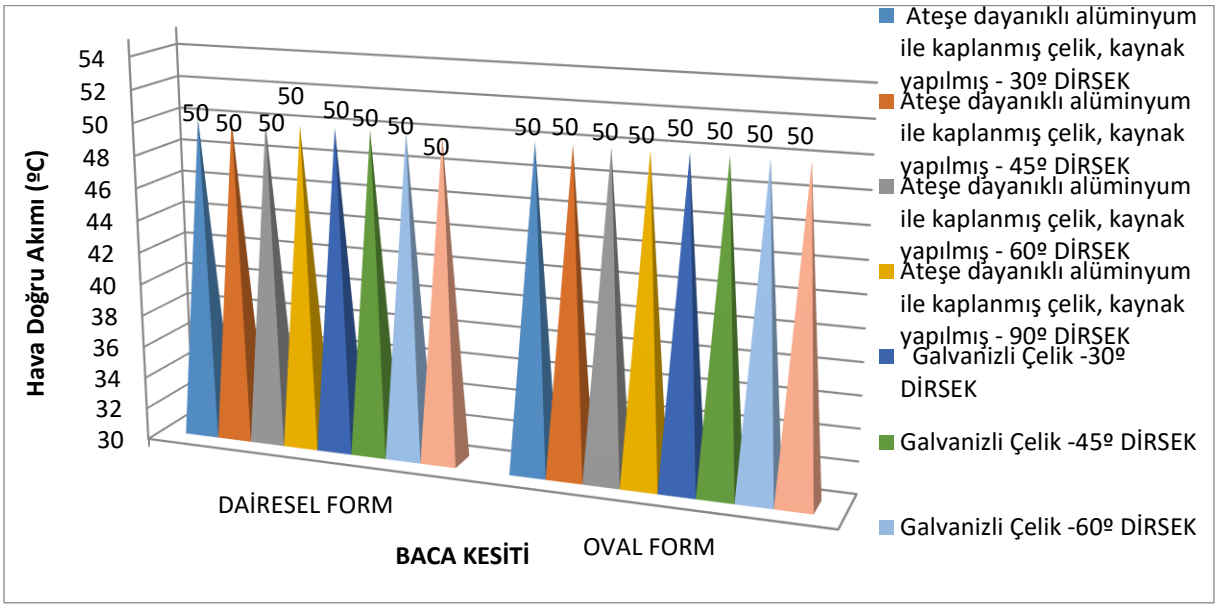
İç cidar sıcaklığı tüm senaryolarda aynı değerlerde gerçekleşmiştir. Bu durum kullanılan yalıtım malzemesinin ve baca tasarımının sıcaklık dağılımını dengeli bir şekilde koruduğunu göstermektedir.

ISBN NR: 978-625-5694-92-8



Şekil 12. Farklı baca malzemeleri için malzeme sıcaklığı değerlerinin karşılaştırılması

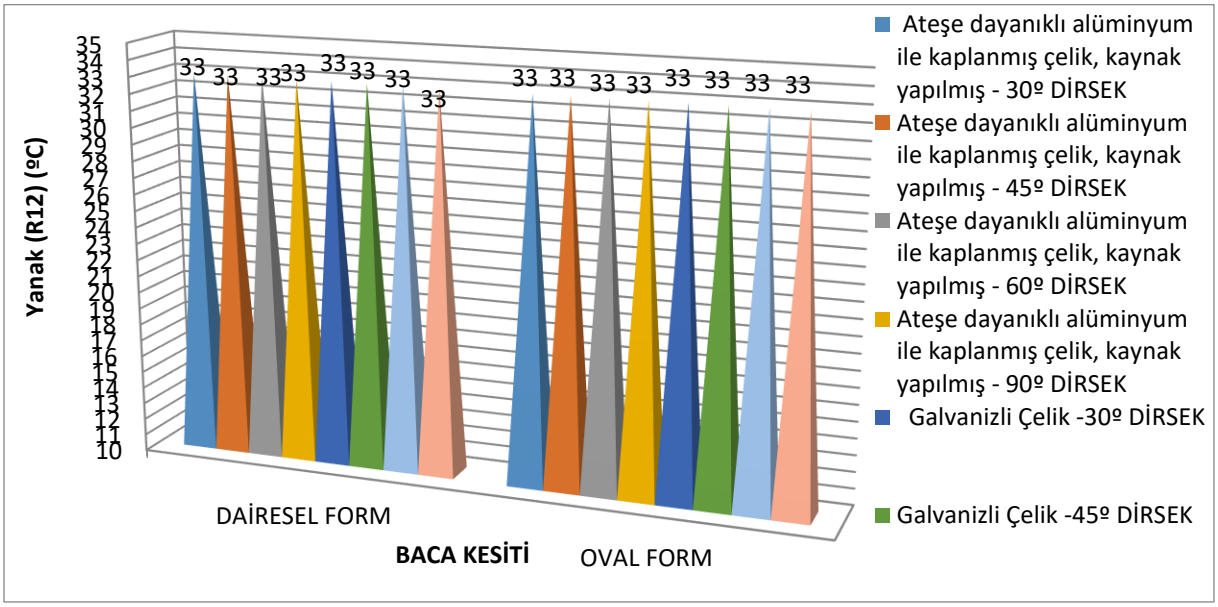
Grafik sonuçları tüm tasarımlarda malzeme sıcaklığının benzer seviyelerde olduğunu göstermektedir. Bu durum baca sistemlerinde kullanılan taşyünü yalıtımının sıcaklık stabilitesini sağladığını ortaya koymaktadır.



Şekil 13. Farklı baca tasarımlarında hava doğru akımı sıcaklığı değerlerinin karşılaştırılması

Hava doğru akımı sıcaklığı tüm senaryolarda aynı seviyede gerçekleşmiştir. Baca geometrisinin ve malzeme türünün bu parametre üzerinde önemli bir değişim oluşturmadığı görülmektedir.

ISBN NR: 978-625-5694-92-8



Şekil 14. Farklı baca tasarımlarında yanak (R12) sıcaklık değerlerinin karşılaştırılması

Yanak sıcaklığı değerleri tüm baca tasarımlarında aynı seviyede hesaplanmıştır. Bu durum baca sisteminde kullanılan yalıtım katmanlarının ısı transferini dengeli bir şekilde kontrol ettiğini göstermektedir.

3. Sonuç

Bu çalışmada, Van ili iklim koşullarında faaliyet gösteren ve 150.000 kcal/h kapasiteli sıvı yakıtlı bir ısıtma kazanına sahip karton bardak üretim tesisine ait baca sistemlerinin performansı simülasyon yöntemiyle analiz edilmiştir. Farklı malzeme türleri (ateşe dayanıklı alüminyum kaplı çelik ve galvanizli çelik), farklı dirsek açıları (30°, 45°, 60° ve 90°) ve farklı baca geometrileri (dairesel ve oval kesit) dikkate alınarak toplamda çeşitli senaryolar değerlendirilmiştir.

Baca geometrisinin akış performansı üzerinde önemli bir etkisi olduğu belirlenmiştir. Van ili iklim koşullarında en uygun ve enerji açısından en verimli baca tasarımının dairesel kesitli galvanizli çelik ve 30° dirsekli baca sistemi olduğu belirlenmiştir. Bu tasarımın düşük akım hızı, düşük atık gaz hızı ve düşük akım sesi değerleri sayesinde daha dengeli bir akış karakteristiği sağlayarak enerji kayıplarını azaltabileceği görülmüştür. Elde edilen sonuçlar, endüstriyel tesislerde uygun baca geometrisi ve malzeme seçiminin enerji verimliliği ve sistem performansı açısından önemli bir rol oynadığını ortaya koymaktadır.

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ISBN NR: 978-625-5694-92-8

A NATURAL SHIELD AGAINST AIR CONDITIONING LOAD: STRUCTURAL AND THERMAL PERFORMANCE OF PHASE-CHANGING MATERIAL COMPOSITES

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ABSTRACT

Energy exists in many forms, and thermal energy is the most researched area worldwide because storing this low-grade energy helps minimize losses and allows for longer storage periods. In this context, phase change materials (PCMs), a key component of thermal energy storage (TES) systems for passive cooling in building applications to balance indoor air temperature fluctuations and reduce building energy demand, have emerged in the literature as a promising technique.

PCMs have the ability to retain significant amounts of latent heat during melting and solidification processes, and to release this retained heat and reuse it repeatedly within a charge-recharge cycle. However, in addition to their advantageous properties, PCMs also have significant disadvantages when used directly in buildings. Among the biggest challenges are leakage and flammability that can occur during PCM phase transitions. The leakage problem reduces the mass and heat storage capacity of structural components such as concrete, plaster, and drywall over time, compromising the mechanical integrity of the material to which they are added. To completely eliminate leakage and flammability problems, the encapsulation of FDMs within natural and porous inorganic matrices is considered the most valid and reliable method in the literature. In this context, clay minerals such as kaolin, bentonite, sepiolite, and diatomite serve as a perfect protective scaffold for FDMs due to their nanometric pore networks and high specific surface areas. The incorporation of FDM into clay is achieved using immersion/direct mixing techniques where the FDM is heated and converted to a liquid phase under vacuum impregnation, where the air in the pores is evacuated by pressure difference and capillary adhesion is maximized, and the clay is directly added to the FDM. With these methods, the organic FDM, which penetrates deeply into the micropores of the clay, acquires a shape-stable form even when it passes into the liquid phase due to capillary tensions, without leaking out of the matrix. In addition, thanks to the microstructural properties of the clay, it provides physical thermal protection in case of fire, suppressing the risk of ignition of the FDM and giving the resulting composite superior flame-retardant properties. Consequently, clay-FDM composites, obtained by combining the thermal energy storage advantages of FDMs with the leak-proof,

ISBN NR: 978-625-5694-92-8

structural stability, and fire-resistant properties of clay minerals, create a groundbreaking passive cooling solution for the building industry. Integrating these innovative composite structures into the building envelope radically reduces electricity consumption and associated greenhouse gas emissions from air conditioning while maintaining indoor thermal comfort within the range most suitable for human health. These leak-proof and fire-safe materials reduce the operational costs of buildings, forming the basis of sustainable, energy-efficient, and environmentally friendly architectural designs in the fight against global warming.

Keywords: Phase change materials, thermal storage, clay minerals, passive cooling.

ISBN NR: 978-625-5694-92-8

İKLİMLENDİRME YÜKÜNE KARŞI DOĞAL KALKAN: FAZ DEĞİŞTİREN MALZEME KOMPOZİTLERİNİN YAPISAL VE ISIL PERFORMANSI

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ÖZET

Enerji birçok biçimde mevcuttur ve termal enerji, dünya çapında en çok araştırılan alandır; çünkü bu düşük dereceli enerjinin depolanması kayıpları en aza indirmeye yardımcı olur ve daha uzun süreler boyunca depolanabilir. Bu çerçevede bina uygulamalarında iç mekan hava sıcaklığı dalgalanmasını dengelemek ve bina enerji talebini azaltmak amacıyla pasif soğutma amacıyla termal enerji depolama (TES) sistemlerinin önemli aktörlerinden biri olan faz değişim malzemeleri (FDM'ler) için umut vadeden bir teknik olarak literatürde yerini almıştır.

FDM, erime ve katılaşma süreçleri sırasında önemli miktarda gizli ısıyı tutma ve bu tutulan ısıyı boşaltma ve şarj çevrim döngüsü içinde tekrarlarca kullanılabilme özelliğine sahiptir. Fakat FDM'lerin binalarda doğrudan kullanımında avantajlı özelliklerinin dışında önemli dezavantajları da vardır. Bu bağlamda en büyük zorluklar arasında FDM faz geçişi durumunda görülebilecek sızıntı ile yanıcılık söylenebilir. Sızıntı problemi beton, sıva, alçıpan gibi yapıda kullanılan bileşenlerin zamanla kütle ve ısı depolama kapasitesini düşürerek ilave edildiği malzemenin mekanik bütünlüğünün bozar. Sızıntı ve yanıcılık problemlerini tamamen ortadan kaldırmak amacıyla, FDM'lerin doğal ve gözenekli inorganik matrisler içerisine hapsedilmesi literatürde en geçerli ve güvenilir yöntem olarak kabul görmektedir. Bu bağlamda kaolin, bentonit, sepiyolit ve diyatomit gibi kil mineralleri, sahip oldukları nanometrik gözenek ağları ve yüksek spesifik yüzey alanları sayesinde FDM'ler için kusursuz bir koruyucu iskelet işlevi görür. FDM'nin kil içine dahil edilmesi, gözeneklerdeki havanın basınç farkı ile boşaltıldığı ve kılcal yapışmanın en üst düzeye çıkarıldığı vakum altında emdirme ile ısıtılıp sıvı faza dönüştürülen FDM içerisine kilin doğrudan eklendiği daldırma/doğrudan karıştırma teknikleri kullanılarak gerçekleştirilir. Bu yöntemlerle kilin mikro gözeneklerine derinlemesine nüfuz eden organik FDM, kılcal gerilimler sayesinde sıvı faza geçse dahi matris dışına sızmayarak şekil-kararlı bir form kazanır. Buna ilavaten kilin mikroyapısal özellikleri sayesinde bir yangın durumunda fiziksel bir ısıl koruma sağlayarak FDM'nin alev alma riskini bastırır ve elde edilen kompozite üstün bir alev geciktirici nitelik kazandırır. Netice itibarıyla, FDM'lerin termal enerji depolama üstünlükleri ile kil minerallerinin sızıntı önleyici, yapısal stabilite ve yanmazlık özelliklerinin birleştirilmesiyle elde edilen kil-FDM kompozitleri, yapı sektörü için çığır açan bir pasif soğutma çözümü yaratmaktadır. Bu yenilikçi kompozit yapıların bina kabuğuna entegre edilmesi, iç mekan termal konforunu insan sağlığına en uygun aralıklarda tutarken,

ISBN NR: 978-625-5694-92-8

iklimlendirme kaynaklı elektrik tüketimini ve buna bağlı sera gazı emisyonlarını radikal biçimde düşürmektedir. Sızıntı yapmayan ve yangın güvenliği sağlayan bu malzemeler, binaların operasyonel maliyetlerini azaltarak küresel ısınma ile mücadelede sürdürülebilir, enerji verimli ve çevre dostu mimari tasarımların temelini oluşturmaktadır.

Anahtar Kelimeler: Faz değiştiren malzemeler, termal depolama, kil mineralleri, pasif soğutma.

ISBN NR: 978-625-5694-92-8

MULTIDISCIPLINARY INTEGRATION AND STRATEGIC MANAGEMENT OF DIGITAL TWIN TECHNOLOGIES

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ABSTRACT

A Digital Twin (DT) is a virtual copy or model of any physical entity, and these technologies are interconnected through real-time data exchange. Conceptually, a Digital Twin (DT) mimics the state of its physical twin in real time, while the physical twin mimics its Digital Twin (DT). Applications of DT include real-time monitoring, design/planning, optimization, maintenance, and remote access, and these applications are expected to increase exponentially in the coming decades.

The emergence of Industry 4.0 has brought about more autonomous, intelligent, and highly interconnected complex industrial systems. These systems generate significant amounts of data useful for various applications such as performance improvement, predictive maintenance, and training. As the digital transformation (DT) market grows exponentially, investment in this technology is rapidly increasing across all sectors. However, to benefit from DT technology in any sector, it is important to understand the value it can provide to the existing business. Furthermore, understanding the different characteristics and types of Digital Twins (DTs) is crucial for selecting the right type of DT to complement the business and maximize profitability.

Digital Twins first found applications in the manufacturing sector. In these systems, they increase system reliability by identifying potential equipment, machinery, and electrical problems through maintenance based on failure prediction. Digital Twin technology has also become widespread in other fields. For example, in education, the availability of Digital Twin capabilities allows students or practitioners to experiment with logical representations that react and behave like physical objects. Similarly, human digital twin approaches developed in healthcare can enable the creation of personalized treatment plans and allow surgeons to practice complex surgeries under specific simulations without the need for actual on-site operations. For engineering students, they can learn how to operate fundamental systems without the risk of real impact. This paper presents many different application areas where the Digital Twin approach is relevant and successful.

Keywords: Digital Twin, digital transformation, technology.

BALKAN 15th INTERNATIONAL CONFERENCE ON APPLED SCIENCES
March 20 – 22, 2026 – SKOPJE
ISBN NR: 978-625-5694-92-8

DİJİTAL İKİZ TEKNOLOJİLERİNİN ÇOK DİSİPLİNLİ ENTEGRASYONU VE STRATEJİK YÖNETİMİ

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ÖZET

Dijital İkiz (DT), herhangi bir fiziksel varlığın sanal kopyası veya modeli anlamına gelmekte olup, gerçek zamanlı veri alışverişi yoluyla birbirine bağlı olan teknolojilerdir. Kavramsal olarak, bir Dijital İkiz (DT), fiziksel ikizinin durumunu gerçek zamanlı olarak taklit ederken; fiziksel ikizi de Dijital İkizini (DT) taklit eder. DT'nin uygulamaları arasında gerçek zamanlı izleme, tasarım/planlama, optimizasyon, bakım, uzaktan erişim gibi faktörler yer almakta olup bu uygulamaların önümüzdeki on yıllarda katlanarak artması beklenmektedir.

Endüstri 4.0'ın ortaya çıkışı, daha otonom, akıllı ve yüksek düzeyde birbirine bağlı karmaşık endüstriyel sistemler getirmiştir. Bu sistemler, performansı iyileştirme, öngörücü bakım, eğitim gibi çeşitli uygulamalar için yararlı olan önemli miktarda veri üretmektedir. Dijital dönüşüm (DT) pazarı katlanarak büyürken, bu teknolojiye olan yatırım her sektörde hızla artmaktadır. Ancak, herhangi bir sektörde DT teknolojisinden faydalanmak için, mevcut işletmeye sağlayabileceği değeri anlamak önemlidir. Ayrıca, işletmeyi tamamlayacak ve maksimum kar sağlayabilecek doğru DT türünü seçmek için DT'nin farklı özelliklerini ve türlerini anlamak da oldukça önemlidir.

Dijital İkiz, ilk uygulamalarını imalat sektöründe bulmuştur. Bu sistemlerde bulunan ekipman, makine ve elektriksel sorun teşkil edecek sorunları önceden arıza tahminine dayalı bakım kullanarak tespit ederek sistemin güvenilirliğini arttırmaktadır. Dijital ikiz teknolojisi diğer alanlarda da kullanımı yaygınlaşmıştır. Örneğin, eğitimde, Dijital İkiz yeteneklerinin kullanılabilirliği, öğrencilerin veya uygulayıcıların fiziksel nesneler gibi tepki veren ve davranan mantıksal temsiller üzerinde deneyler yapmalarına olanak sağlayabilir. Bununla birlikte sağlık alanında geliştirilen insan dijital ikizi yaklaşımları ise bireye özgü tedavi planlarının oluşturulmasına ve cerrahların sahada ameliyat yapmaya gerek kalmadan, belirli simülasyonlar altında zor ameliyatlar üzerinde pratik yapabilmesine imkan sağlayabilir. Mühendis adayları içinse gerçek bir etki riski olmadan temel sistemleri nasıl çalıştıracaklarını öğrenebilirler. Bu bildiri, Dijital İkiz yaklaşımının ilgili ve başarılı olduğu birçok farklı uygulama alanını sunmaktadır.

Anahtar Kelimeler: Dijital İkiz, dijital dönüşüm, teknoloji.

ISBN NR: 978-625-5694-92-8

CdS/METAL (Au,Ag,Cu) EKLEMLERİNİN ARAYÜZ ÖZELLİKLERİNİN İNCELENMESİ

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ÖZET

II–VI grubu yarıiletkenler ile metallerin bir araya getirilmesiyle oluşturulan Metal-Yarıiletken (MY) eklemler optoelektronik cihazlar, detektörler ve güneş pilleri gibi uygulamalar açısından büyük önem taşımaktadır.Bu çalışmada CdS ve metal bulk yapılarının minimum enerjili durumlarının belirlenmesi amacıyla k-nokta ağı, düzlem dalga enerji kesim değerleri ve örgü parametreleri için yakınsama testleri VASP (Vienna Ab initio Simulation Package) yazılımı kullanılarak gerçekleştirilmiştir. Örgü parametresi yakınsama testi sonuçları Birch–Murnaghan durum denklemi kullanılarak doğrulanmıştır. CdS ve metallerden (111) düzlemleri kesilerek bu yüzeylerin iş fonksiyonu hesaplamaları yapılmış ve makroskobik düzlem ortalama potansiyel grafikleri elde edilmiştir. CdS yarıiletkeninin hacimsel (bulk) band yapısı PBE ve HSE fonksiyonelleri kullanılarak incelenmiş ve elde edilen sonuçlar karşılaştırılmıştır. Ayrıca CdS (111) yüzeyinin band yapısının katman sayısına bağlı değişimi HSE06 fonksiyoneli kullanılarak analiz edilmiştir. CdS yarıiletkeni ile Cu, Ag ve Au metalleri ile oluşturulan MY yapı optimize edilmiş ve minimum enerjili arayüz mesafesi belirlenmiştir. Farklı arayüz mesafelerine sahip MY yapıların fiziksel modellemeye uygunluğu Buckingham potansiyeli ile incelenmiştir. Optimize edilen yapının arayüzünde gerçekleşen yük transferini ve oluşan bağ karakterini analiz etmek amacıyla Bader yük analizi gerçekleştirilmiştir.

Anahtar Kelimeler: Yoğunluk Fonksiyonel Teorisi, Metal-Yarıiletken Eklemler, PBE, HSE06, VASP

ISBN NR: 978-625-5694-92-8

INVESTIGATION OF THE INTERFACE PROPERTIES OF CdS/METAL (Au, Ag, Cu) JUNCTIONS

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ABSTRACT

Metal–Semiconductor (MS) junctions formed by combining II–VI group semiconductors with metals are of great importance for applications such as optoelectronic devices, detectors, and solar cells. In this study, convergence tests for the k-point mesh, plane-wave energy cutoff values, and lattice parameters were performed using the VASP (Vienna Ab initio Simulation Package) software in order to determine the minimum energy configurations of CdS and metal bulk structures. The lattice parameter convergence results were verified using the Birch–Murnaghan equation of state. The (111) surfaces of CdS and metals were cleaved, and work function calculations of these surfaces were carried out, from which macroscopic planar averaged potential graphs were obtained. The bulk band structure of the CdS semiconductor was investigated using the PBE and HSE functionals, and the obtained results were compared. In addition, the dependence of the band structure of the CdS (111) surface on the number of layers was analyzed using the HSE06 functional. The MS heterostructure formed by combining the CdS semiconductor with Cu, Ag, and Au metals was optimized, and the minimum energy interface distance was determined. The suitability of MS structures with different interface distances for physical modeling was examined using the Buckingham potential. In order to analyze the charge transfer occurring at the interface of the optimized structure and the resulting bonding characteristics, Bader charge analysis was performed.

Keywords: Density Functional Theory, Metal–Semiconductor Junctions, PBE, HSE06, VASP

ISBN NR: 978-625-5694-92-8

DEPOSITION OF LAYERED WO_3/Ag/WO_3 FILMS BY MAGNETRON SPUTTERING AS A CURRENT SPREADING LAYER

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ABSTRACT

Transparent electrodes have become a critical component in many optoelectronic devices due to their ability to provide both high optical transmittance and low electrical resistance. Among the most widely used materials for this purpose are indium tin oxide (ITO), Ni/Au-modified ITO structures (Ni/Au–Ni/ITO), and graphene-based hybrid electrodes. These electrodes are regarded as key parameters that directly affect the performance of light-emitting diodes (LEDs), laser diodes, solar cells, and various photonic devices. In particular, in GaN/InGaN-based blue micro-LED structures, transparent electrodes also serve as an effective current spreading layer because the p-GaN layer has low lateral conductivity. In this way, a more homogeneous current distribution across the active region is achieved, the light extraction efficiency is enhanced, and the overall device performance is significantly improved.

In this study, WO_3/Ag/WO_3 multilayer thin-film structures were fabricated using the magnetron sputtering technique, and their applicability as a current spreading layer suitable for the blue spectral region was investigated. The obtained WO_3/Ag/WO_3 layered structures were characterized by ultraviolet–visible (UV–Vis) spectroscopy, X-ray photoelectron spectroscopy (XPS), and sheet resistance measurements in order to determine their optical, chemical, and electrical properties.

In addition, by varying the deposition pressure, the electrical and optical properties of the thin films were optimized; thus, improvements in sheet resistance values were achieved, while the optical transmittance values determined by UV–Vis spectroscopy were also enhanced. The obtained results indicate that WO_3/Ag/WO_3 multilayer structures can be used as a potential current spreading layer for optoelectronic applications in the blue region, particularly in GaN/InGaN-based micro-LED structures.

ISBN NR: 978-625-5694-92-8

Keywords: WO_3/Ag/WO_3, current spreading layer, transparent electrode, magnetron sputtering

INTRODUCTION

Transparent conductive oxides (TCOs) are materials that provide a balance between optical transmittance and electrical conductivity and play a critical role in modern optoelectronic applications [1]. Such materials are required to simultaneously provide high optical transmittance and low electrical resistivity. In this context, multilayer structures consisting of a thin metal film sandwiched between two metal oxide layers (MO/metal/MO) have emerged in the literature as one of the most effective solutions due to their ability to offer appropriate electrical continuity and optical performance [2].

In recent years, dielectric–metal–dielectric (DMD) thin films, which can simultaneously offer transparency, conductivity, flexibility, and capacitive properties, have attracted considerable attention as promising alternatives for indium-free electronic systems. These structures have a wide range of applications, including electrochromic smart windows, organic solar cells, light-emitting diodes, and thin-film transistors. In particular, the ultrathin Ag layer (<20 nm) used in systems such as WO_3/Ag/WO_3 provides low resistivity and high optical transmittance, while dielectric layers such as WO_3, MoO_3, and NiO stand out as key components that determine the overall performance of the structure [3].

TCO thin films are used as transparent electrodes in many technologies such as flat-panel displays, solar cells, gas sensors, and smart windows, and they play an important role in carrier injection and extraction processes in optoelectronic devices [4]. Similarly, transparent conductive films (TCFs) offer versatile and cost-effective solutions owing to their high transmittance in the visible region (>80%) and low resistivity [5].

Although ITO is the most widely used transparent electrode material due to its high transmittance and low resistance, the limited availability of indium resources and the high cost of vacuum-based fabrication processes have increased the need for alternative materials [6]. In this context, alternative transparent electrode materials such as carbon nanotubes (particularly single-wall SWCNTs) [7] graphene-based structures [8], ITO/Ag hybrid systems [9] and Ag nanowire structures [10] are being extensively investigated in terms of both optical and electrical performance.

ISBN NR: 978-625-5694-92-8

GROWN OF THE WO_3/Ag/ WO_3

WO_3/Ag/WO_3 multilayer thin films were sequentially deposited by the magnetron sputtering method. For the first multilayer structure (WO_3/Ag/WO_3 at 3.2 mTorr), the bottom WO_3 layer, the middle Ag layer, and the top WO_3 layer were deposited one after another. During the deposition of the WO_3 layers, an Ar/O_2 gas mixture was used under a power of 100 W, and the Ar and O_2 flow rates for the bottom WO_3 layer were set to 40 and 5 sccm, respectively. This layer was deposited for 2.5 min at a working pressure of 3.0–3.2 mTorr, yielding an approximate thickness of 22 nm. The Ag film used as the intermediate metallic layer was deposited at 100 W under an Ar flow of 60 sccm without oxygen, at a pressure of 4 mTorr for 42 s, resulting in an approximate thickness of 20 nm. The resulting structure formed an approximately WO_3 (22 nm)/Ag (20 nm)/WO_3 (22 nm) multilayer thin-film architecture.

For the second multilayer structure, corresponding to the WO_3/Ag/WO_3 3.5 mTorr sample, the bottom and top WO_3 layers were again deposited at 100 W, with Ar and O_2 flow rates set to 40 and 8 sccm, respectively. The intermediate Ag film was deposited under the same conditions described above. Each WO_3 film was deposited for 5 min at a working pressure of 3.0–3.5 mTorr, resulting in an approximate thickness of 45 nm. Thus, the overall structure was formed as an approximately WO_3 (45 nm)/Ag (20 nm)/ WO_3 (45 nm) multilayer thin-film architecture, as shown in Figure 1.

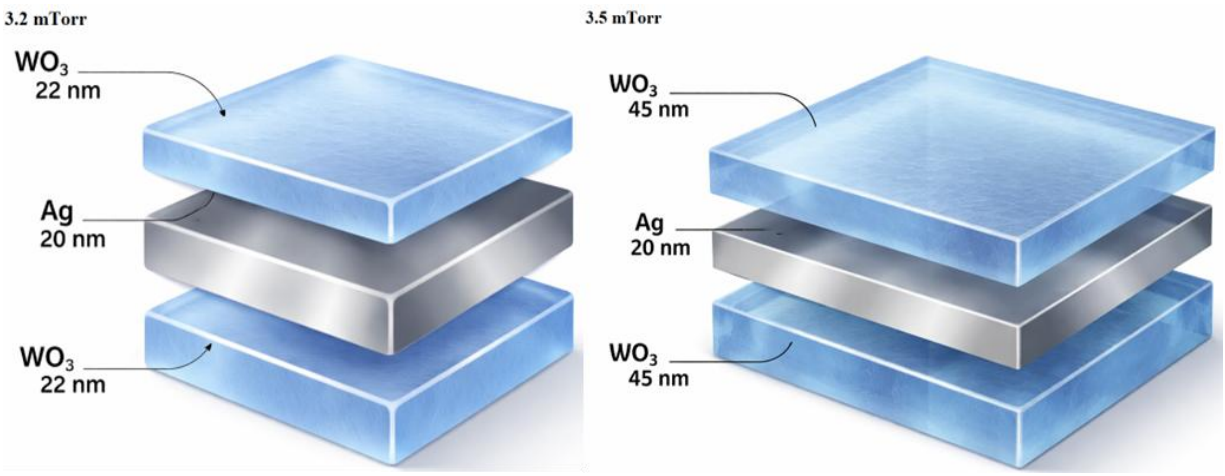

Figure 1. Illustration of the layered WO_3/Ag/WO_3 structures

ISBN NR: 978-625-5694-92-8

RESULTS AND DISCUSSION

Figure 1 shows the transmittance difference observed in the $WO_3/Ag/WO_3$ multilayer structures can be explained by the Fabry–Pérot interference effect associated with film thickness. While the total thickness of the sample obtained under the 3.2 mTorr condition was 64 nm, this value reached 110 nm for the sample prepared under the 3.5 mTorr condition. For normal incidence, the Fabry–Pérot resonance condition is expressed by the relation $\lambda = 2nd/m$; accordingly, an increase in the optical thickness of the dielectric layer causes the resonance wavelength to shift toward longer wavelengths [11, 12]. Therefore, a red shift is expected for the 3.5 mTorr sample with thicker WO_3 layers, whereas a blue shift is expected for the 3.2 mTorr sample with thinner WO_3 layers. Experimentally, the 3.2 mTorr sample exhibited 74% transmittance at 380 nm, while the 3.5 mTorr sample reached a transmittance of 89% at 440 nm [13, 14], which is consistent with this interpretation. The results show that the thicker WO_3 optical cavity formed with increasing deposition pressure shifts the resonance transmission peak toward the visible region and enhances the optical transmittance.

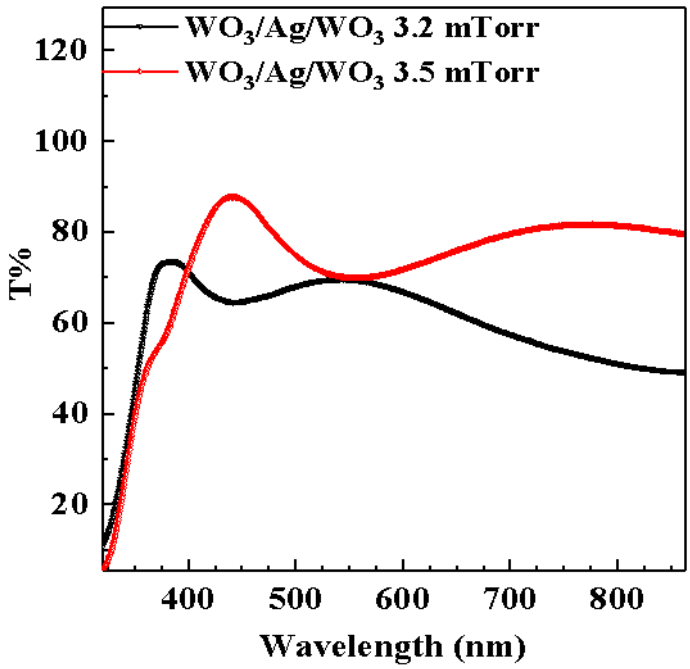

Figure 2. Transmittance spectrum of the layered $WO_3/Ag/WO_3$ structure

The sheet resistance results indicate that the film growth behavior, depending on the deposition pressure, has a pronounced effect on electrical conduction. Although the total thickness of the

ISBN NR: 978-625-5694-92-8

WO_3/Ag/WO_3 3.2 mTorr sample was in the range of 60–70 nm, the lower sheet resistance values of 70–85 Ω/sq suggest the formation of a more compact and electrically continuous conductive pathway under this condition. In contrast, although the total thickness of the WO_3/Ag/WO_3 3.5 mTorr sample increased to the range of 100–110 nm, the rise in sheet resistance to 150–175 Ω/sq indicates that the increased pressure and oxygen content adversely affected conductivity, particularly through reduced continuity in the intermediate Ag layer, enhanced scattering, or partial oxidation effects.

As shown in Figure 3, the survey XPS spectrum reveals no significant contribution from foreign elements other than the characteristic peaks of W, O, and Ag in the WO_3/Ag/WO_3 multilayer structure. This indicates that no remarkable impurity is present in the deposited films and that the overall chemical composition of the structure is consistent with the intended WO_3/Ag/WO_3 architecture. The C 1s and N 1s signals observed in the spectrum can be attributed to atmospheric carbon species adsorbed on the sample surface and environmental surface contamination, which are commonly encountered in XPS analyses; therefore, they should be regarded as contributions from surface adsorption rather than structural impurities.

Considering the atomic ratios, the WO_3/Ag/WO_3-3.2 mTorr sample was calculated to contain W: 16.62 at.%, O 1s: 47.56 at.%, Ag 3d: 0.20 at.%, C 1s: 32.54 at.%, and N 1s: 3.08 at.%; whereas for the WO_3/Ag/WO_3-3.5 mTorr sample, the values were determined as W: 13.58 at.%, O 1s: 51.20 at.%, Ag 3d: 0.23 at.%, C 1s: 32.36 at.%, and N 1s: 2.61 at.%. These results indicate that oxygen is dominant relative to tungsten in both samples, confirming the formation of a W–O-based oxide matrix. In particular, the combined evaluation of the W and O ratios supports that the films exhibit a chemical structure close to WO_3-based stoichiometry. The very low Ag signal can be explained by the fact that the intermediate Ag film is largely covered by the top WO_3 layer; therefore, this does not mean that Ag is absent from the structure, but rather that it is detected more weakly due to the surface-sensitive nature of XPS.

In addition, the higher oxygen percentage observed in the 3.5 mTorr sample is consistent with the increased oxygen supply during deposition. This increase may have caused tungsten to exist in a more oxygen-rich chemical environment; however, the obtained XPS data indicate that this did not disrupt the formation of the WO_3 phase and that the structure still retained its tungsten trioxide character. In other words, although a relatively higher oxygen content was observed under the 3.5 mTorr condition, this did not necessarily lead to a transition to a different tungsten oxide phase, and the film chemistry still predominantly resulted in WO_3 formation.

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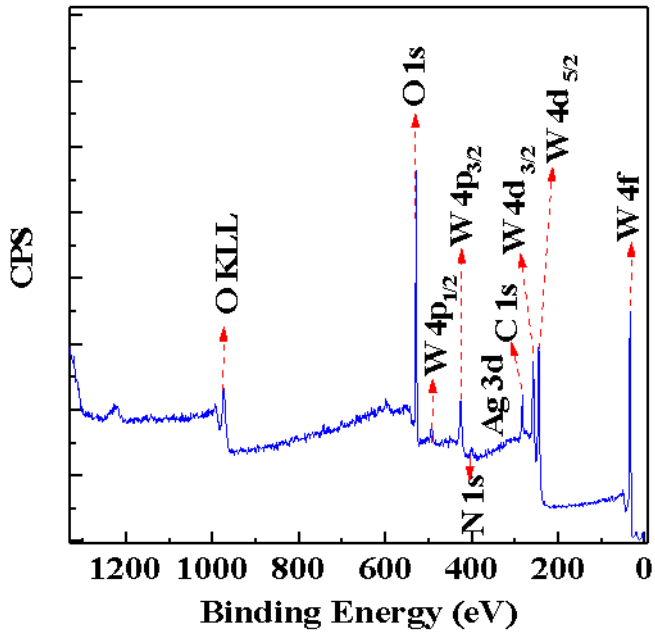

Figure 3. Survey spectrum of the WO_3/Ag/WO_3 structure

As shown in Figures 4(a) and 4(b), the high-resolution W 4f XPS spectra exhibit peaks located at approximately 35.5 eV and 37.5 eV, which can be assigned to the W $4f_{7/2}$ and W $4f_{5/2}$ components, respectively. These binding energies indicate that tungsten is present in the +6 oxidation state (W^{6+}) [15]. The observed peak positions are consistent with the characteristic W 4f doublet reported in the literature for WO_3, confirming that tungsten atoms are bonded to oxygen through W–O bonds. Therefore, the XPS results clearly demonstrate that the dominant phase in the sample is WO_3 and that tungsten exists in a highly oxidized chemical environment.

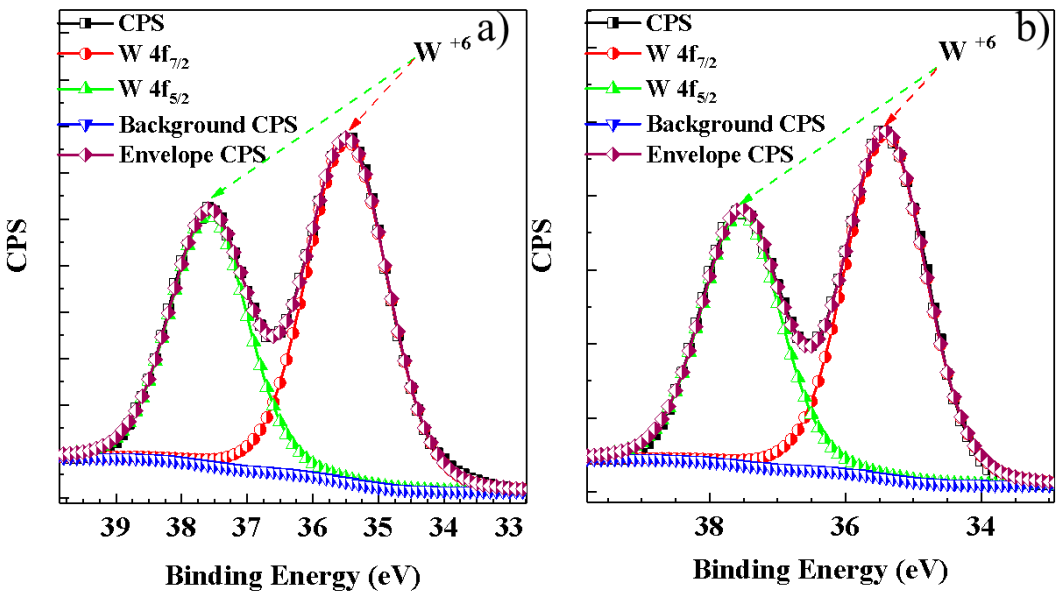

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Figure 4. W 4f spectrum of the $WO_3/Ag/WO_3$ structures: (a) 3.2 mTorr and (b) 3.5 mTorr

Finally, the high-resolution Ag 3d XPS spectra presented in Figure 5 indicate that the chemical state of silver varies depending on the deposition pressure and oxygen content. In the $WO_3/Ag/WO_3$ -3.2 mTorr sample, the Ag $3d_{5/2}$ peak observed at approximately 368.0 eV [16] is consistent with the binding energy characteristic of metallic silver (Ag^0). In contrast, in the $WO_3/Ag/WO_3$-3.5 mTorr sample, the Ag $3d_{5/2}$ peak shifts to approximately 367.7 eV [17], suggesting that silver underwent partial oxidation under the more oxygen-rich deposition environment, leading to the formation of an AgO_x-like chemical environment. These findings indicate that the higher oxygen flow used for the 3.5 mTorr sample could induce partial oxidation within the intermediate Ag layer or at the related interfaces, whereas in the 3.2 mTorr sample, Ag largely preserved its metallic character.

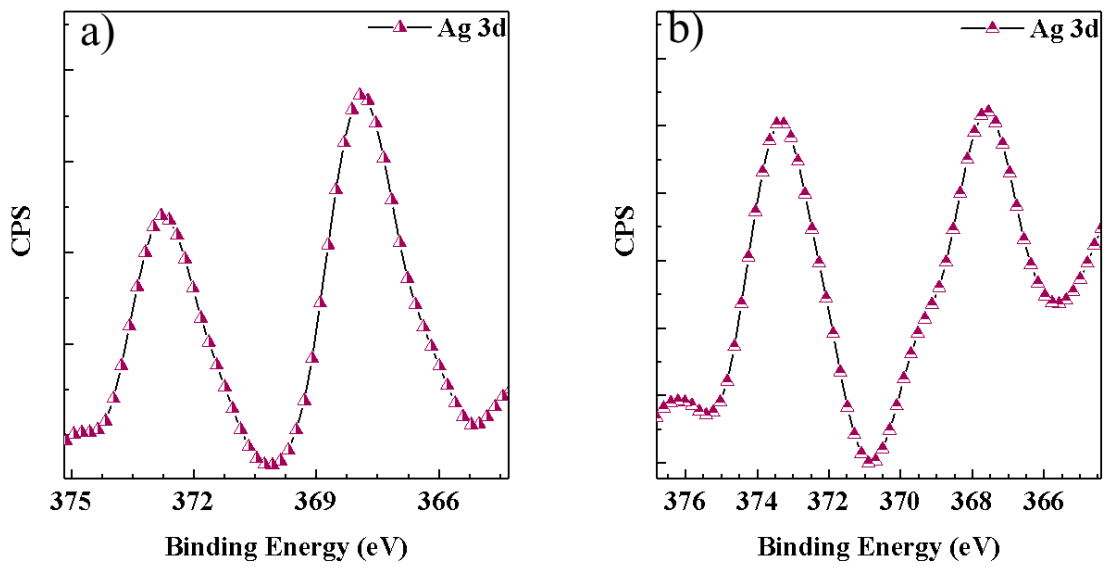

Figure 5. Ag 3d spectrum of the $WO_3/Ag/WO_3$ structures: (a) 3.2 mTorr and (b) 3.5 mTorr

As can be seen from the comparative data presented in Table 1, the obtained $WO_3/Ag/WO_3$ multilayer thin films are generally consistent with the transparent electrode performances reported in the literature. In particular, when the optical transmittance values obtained in the blue and UV regions are considered together with the sheet resistance results, these films demonstrate promising performance for transparent conductive electrode applications.

Moreover, the ability to control the optical phase transition and the associated transmittance behavior by varying the layer thicknesses in the $WO_3/Ag/WO_3$ layered structure indicates that this system offers a significant advantage not only in terms of its present performance but also

ISBN NR: 978-625-5694-92-8

in terms of its potential for further development. Therefore, the obtained multilayer $WO_3/Ag/WO_3$ structure can be regarded as a promising material system with tunable optical and electrical properties, open to further improvement, and suitable for future optoelectronic applications.

Table 1. Comparison of transmittance and sheet resistance values reported in the literature for transparent electrode applications

Sample	Wavelength	Transmittance	Sheet resistance	Ref.
Graphene transparent electrode (before annealing)	550 nm	82.1%	229 kΩ	[8]
Graphene transparent electrode (after annealing)	550 nm	84.7%	80 kΩ	[8]
ITO (300 nm)	380 nm	76.4%	18.7 Ω/sq	[9]
ITO/AgNW hybrid TCE	380 nm	69.5%	16.4 Ω/sq	[9]
AgNW	380 nm	72.2%	-	[9]
SWCNT thin film	550 nm	90%	65 Ω/sq	[18]
SWCNT spray-coated TCF	550 nm	78%	150 Ω/sq	[19]
CNT film (acid treated, very thin)	≈550 nm	≈98%	≈10 kΩ/sq	[20]
AgNW cross-aligned, plasma-welded TE		93.3%	13.4 Ω/sq	[21]
2-layer graphene	380 nm	~90%	290 Ω/sq	[22]
Graphene (few layer)	300–800 nm	≥80%	280–850 Ω/sq	[22]
Graphene (3 layer)	320–780 nm	≥81.9%	300–350 Ω/sq	[22]

CONCLUSIONS

The obtained findings demonstrate that the $WO_3/Ag/WO_3$ multilayer structure is a promising transparent conductive electrode candidate for future optoelectronic systems owing to its low resistance, high transmittance, and compatibility with flexible substrates.

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ISBN NR: 978-625-5694-92-8

MANGANEZ BAZLI OKSİT KOMPOZİTLERİN FOTOKATALİTİK GİDERİM PERFORMANSLARININ İNCELENMESİ

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ÖZET

Mekanik alaşımlama yöntemiyle farklı kütle katkılarına sahip MnO/Co_3O_4 (MCO) kompozitleri üretildi ve MnO ile Co_3O_4 arasındaki başarılı etkileşimi doğrulamak için çeşitli yöntemlerle karakterize edildi. XRD ve XPS analizleri, doğal güneş ışığı altında tetrasiklinin (TC) fotokatalitik olarak uzaklaştırılmasına katkıda bulunan gelişmiş Mn-Co entegrasyonunu ortaya koydu. Ek olarak, katalizör miktarı, pH, tutucu madde ve değişken su ortamlarının fotokatalitik performans üzerindeki etkileri belirlendi. Asidik koşullarda 20 mg MCO-5% katalizör ile %95'lik optimum TC uzaklaştırma sağlandı. Çalışma ayrıca, gerçek su matrislerinin, özellikle göl suyunun, bozunma sürecini hızlandırdığını gösterdi. Dahası, MCO-5% fotokatalizör, beş döngüden sonra %63 verimlilik sağlayarak iyi bir tekrar kullanılabilirlik sergiledi. Bu araştırma, su ortamlarında antibiyotik uzaklaştırma için mekanik alaşımlama yoluyla sentezlenen MCO hibrit sistemlerinin potansiyelini vurgulamaktadır.

Anahtar Kelimeler : Antibiyotik, Mekanik Öğütme, Fotokatalitik.

GİRİŞ

Antibiyotikler, canlı organizmalarda meydana gelen bakteriyel enfeksiyonların tedavisinde yaygın biçimde ve çoğu zaman yüksek dozlarda kullanılan ilaçlardır(Ding et al., 2024). Tetrasiklin (TC), etkili tedavi kapasitesi, geniş etki spektrumu ve ekonomik olarak kolay temin

ISBN NR: 978-625-5694-92-8

edilebilmesi nedeniyle sıklıkla tercih edilen antibiyotiklerden biridir(Kovalakova et al., 2020; Redouane-Salah, Boulahbal, Tuna, Balta, & Bilgin Simsek, 2024; Tuna, 2024; Wang et al., 2021). Ancak TC'nin suda yüksek oranda çözünebilmesi, çevresel ortamlarda birikmesine yol açabilmekte ve besin zinciri boyunca taşınarak toksik etkilere neden olabilmektedir. Bu madde, sulama suları aracılığıyla bitkilere geçebilmekte ya da doğrudan içme sularına karışarak insan ve hayvan sağlığını olumsuz etkileyebilmektedir. Bu nedenle, TC'nin ekosistemlerde oluşturabileceği riskler göz önüne alındığında, çevresel ortamlardan etkin bir şekilde uzaklaştırılması büyük önem taşımaktadır(Amangelsin, Semenova, Dadar, Aljofan, & Bjørklund, 2023).

Tetrasiklinin sucul ekosistemlerden giderilmesi amacıyla çeşitli alternatif arıtım yöntemleri kullanılmaktadır(Kanmaz, Buğdaycı, & Demircivi, 2024). Bu yöntemler arasında membran filtrasyonu, adsorpsiyon, flokülasyon ve fotokataliz gibi farklı fizikokimyasal teknikler yer almaktadır. Fotokataliz yöntemi, bir yarı iletken malzemenin ışık enerjisi ile etkileşime girerek kirletici maddelerin parçalanmasını sağlayan reaktif oksitleyici türler üretmesi esasına dayanmaktadır(Nguyen et al., 2021). Yarı iletkenler, iletken ve yalıtkan özellikler arasında davranış gösteren malzemeler olup, bant aralığı enerjisi, yüzey alanı, kristal yapısı ve parçacık boyutu gibi özelliklerin uygun şekilde düzenlenmesiyle fotokatalitik performansları önemli ölçüde geliştirilebilmektedir. Bu özellikler sayesinde, çevresel uygulamalarda kullanılmak üzere yüksek verimli fotokatalitik malzemelerin tasarlanması mümkün hale gelmektedir.

Yarı iletken temelli fotokatalitik sistemler, UV ışığı veya güneş ışığına yakın koşullar altında çalışabilmeleri, kirleticileri büyük ölçüde mineralize edebilmeleri, ilave kimyasal kullanımına ihtiyaç duymamaları ve düşük işletme maliyetleri gibi avantajları nedeniyle atık su arıtımında ön plana çıkmaktadır(Cai, Liu, Zou, & Cheng, 2018). Bu bağlamda Co_3O_4, geniş ışık spektrumunda aktif olması ve yüksek fotokatalitik etkinlik göstermesi nedeniyle çevresel uygulamalarda etkili bir katalizör olarak değerlendirilmektedir. Benzer şekilde MnO temelli yapılar da düşük maliyetli üretim olanakları, yüksek termal dayanımları ve hem görünür hem de UV ışık altında etkin fotokatalitik özellikleri sayesinde dikkat çekmektedir. Son yıllarda, farklı yarı iletken bileşenlerin üstün özelliklerini bir araya getiren hibrit fotokatalitik sistemlerin geliştirilmesi önem kazanmıştır. Bu yaklaşımla, yarı iletken metal oksitlerin bir arada kullanılması yoluyla daha yüksek performanslı ve gelişmiş özelliklere sahip yeni nesil fotokatalizörlerin tasarlanması mümkün olmaktadır. Fotokatalitik süreçlerde yüksek verim elde edilebilmesi, kullanılan malzemenin optik ve yapısal özelliklerinin doğru şekilde optimize

ISBN NR: 978-625-5694-92-8

edilmesine bağlıdır. Bu kapsamda, katalizörlerin yüzey alanının artırılması, yük taşıyıcıların yeniden birleşme hızının azaltılması ve ışık soğurma kapasitesinin geliştirilmesi gibi stratejiler büyük önem taşımaktadır. Nano boyutlu yapılar ve heteroyapılı kompozit malzemeler, bu gereksinimleri karşılayabilen etkili çözümler sunmaktadır. Özellikle farklı yarı iletkenlerin bir arada kullanılmasıyla oluşturulan kompozit fotokatalizörler, tek bileşenli sistemlere kıyasla daha yüksek aktivite ve kararlılık gösterebilmektedir. Günümüzde antibiyotik kalıntılarının giderimine yönelik çalışmalar, çevresel sürdürülebilirlik açısından giderek daha fazla önem kazanmaktadır. Fotokatalitik yöntemler, toksik kimyasal kullanımını en aza indirmesi ve güneş enerjisi gibi yenilenebilir enerji kaynaklarıyla uyumlu olması nedeniyle umut verici bir teknoloji olarak değerlendirilmektedir. Bu nedenle, TC gibi dirençli kirleticilerin etkili bir biçimde parçalanmasını sağlayacak yeni nesil fotokatalizörlerin geliştirilmesi, hem su kalitesinin korunması hem de halk sağlığının güvence altına alınması açısından kritik bir araştırma alanı olarak öne çıkmaktadır.

DENEYSEL ÇALIŞMALAR

Merck'ten alınan İzopropil alkol (IPA, %99,9), benzokinon (BQ, %99,0) ve NaOH (>%99,0) deneylerde kullanılmıştır. Tetrasiklin (>%98,0) Alfa-Aesar'dan satın alınmıştır. MnO (%99,9), Co3O4 (%99,9), HCl (dumanlı, %37) ve EDTA-2Na (%98,5) ise Sigma-Aldrich'ten temin edilmiştir.

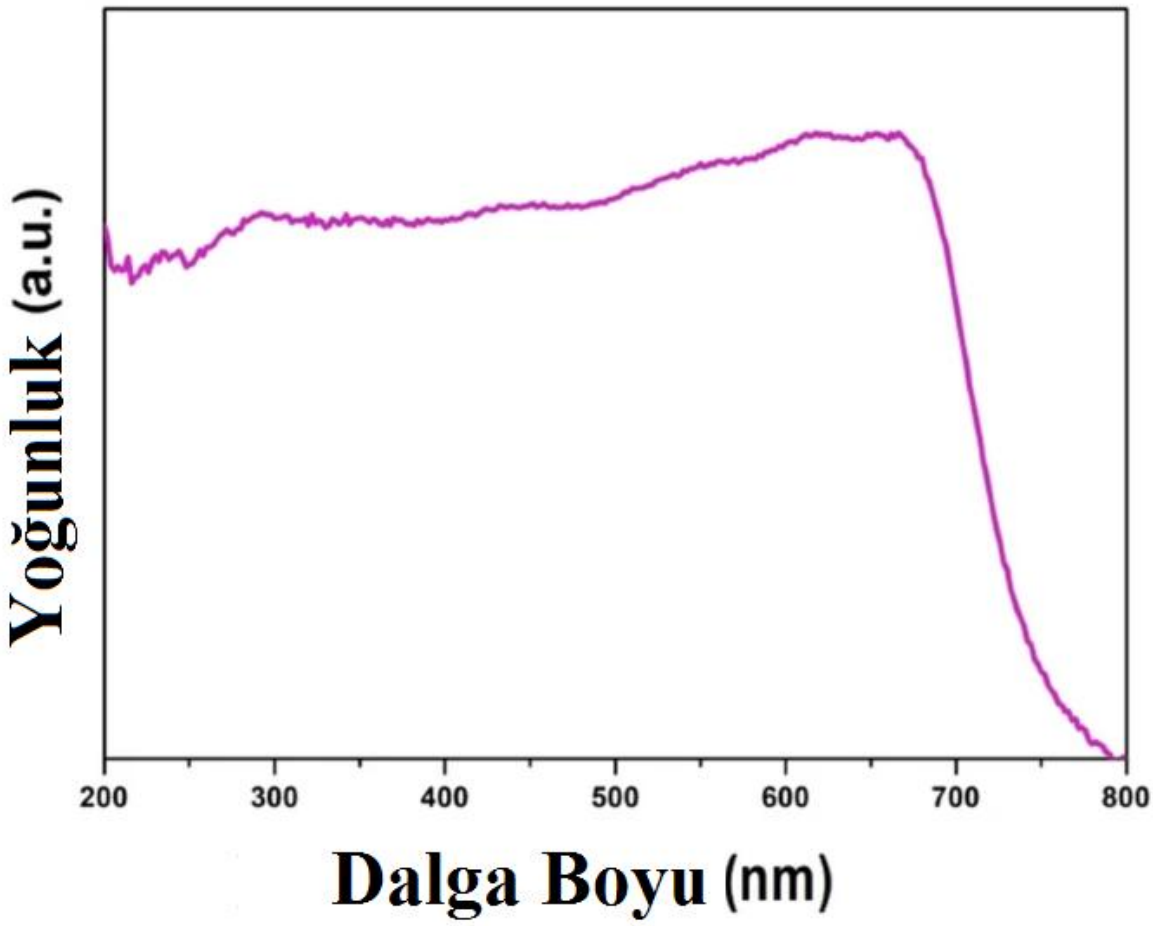
MCO katalizörlerinin üretimi için mekanik alaşımlama yöntemi kullanılmıştır. Paslanmaz çelik tanka farklı miktarlarda MnO ve Co_3O_4 tartılmıştır. 10 g Co_3O_4 için MnO tozlarının kütle dozajları 0,1, 0,5 ve 2,0 g dır. Sentez, Focucy™ F-P400 bilyalı değirmen makinesinde 500 rpm'de 5 saat süreyle gerçekleştirilmiştir. Daha sonra, fotokatalizör tozlarını paslanmaz çelik bilyelerden ayırmak için toz karışımı elendi. Sentezlenen fotokatalizörler MCO-1%, MCO-5% ve MCO-20% olarak etiketlenmiştir.

SONUÇLAR VE TARTIŞMA

MCO-5% fotokatalizörünün UV-Vis difüz yansıma spektrumu (UV-DRS) analiz edildi ve grafik Şekil (1)'de gösterildi. 200-800 nm aralığında kaydedilen spektrum, fotokatalizörün ışık emme kapasitesini ortaya koymaktadır. Bu sonuçlar, fotokatalizörün geniş bir dalga boyu aralığında görünür ışığı etkili bir şekilde emebildiğini göstermektedir. Bu nedenle, görünür ışığı verimli bir şekilde emebilir ve bu etkileşim nedeniyle ortamda TC'nin başarılı fotobozunmasını destekler. Bant aralığı, yarı iletkenin ışığı emmesi ve elektronları uyarması için gereken enerji

ISBN NR: 978-625-5694-92-8

miktarını temsil eder. Bant aralığının hesaplanmasında, emilim katsayısı (α), Kubelka-Munk fonksiyonu F(R) = (1 − R)2/2R kullanılarak difüz yansıma verilerinden türetilmiştir; burada R yansımadır ve Tauc grafiği, $[F(R)\cdot h\nu]^n$"nin foton enerjisine (hν) karşı çizilmesiyle oluşturulmuştur. Co_3O_4 ve MnO'nun doğrudan izin verilen geçişler sergilediği göz önüne alındığında, n değeri 1/2 olarak alınmıştır.



Şekil 1. UV-DRS spektrumu

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ISBN NR: 978-625-5694-92-8

KOBALT BAZLI OKSİT KOMPOZİTLERİN ADSORPSİYON PERFORMANSLARININ İNCELENMESİ

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ÖZET

Bu çalışmada, kobalt oksit (Co_3O_4) ve manganez oksit (MnO), bilyalı öğütme tekniği kullanılarak CoMnOx hibrit oksitlerinin sentezlenmesinde kullanılmış ve Kongo kırmızısı (CR) giderimi için değerlendirilmiştir. Hazırlanan adsorban numuneleri, yapısal, morfolojik ve kimyasal özelliklerini belirlemek için XRD, SEM-EDX, BET/N2, FT-IR ve XPS kullanılarak karakterize edilmiştir. Adsorpsiyon çalışmaları, adsorban dozajı, süre, pH, sıcaklık ve farklı su matrisleri parametrelerini optimize etmek için gerçekleştirilmiştir. Elde edilen sonuçlar, Langmuir modelini takip ederek CoMnOx2'nin 218,54 mg g^{-1} ile en yüksek adsorpsiyon kapasitesini gösterdiğini ortaya koymuştur. Kinetik çalışmalar, adsorpsiyonun 300 dakikada dengeye ulaştığını ve Elovich modeliyle desteklendiğini, yani kimyasal etkileşimlerin baskın olduğunu göstermiştir. Adsorpsiyon süreci ekzotermik ve düşük sıcaklıklarda kendiliğinden gerçekleşmiştir. Su ortamında anyon ve katyonların varlığına rağmen, etkili bir giderim göstermiştir. CoMnOx2, beş döngü boyunca istikrarlı performansını korudu ve farklı kirleticileri gidermede de iyi performans gösterdi..

Anahtar Kelimeler : Kongo Kırmızısı, Mekanik Öğütme, Kobalt oksit.

GİRİŞ

Su, insanlar, hayvanlar ve bitkiler başta olmak üzere tüm canlıların yaşamını sürdürebilmesi için vazgeçilmez bir kaynaktır. Su kaynaklarının kirlenmesine yol açan etkenlerin ortadan kaldırılması, ekosistemin devamlılığı açısından kritik bir öneme sahiptir(Green, Oxide, &

ISBN NR: 978-625-5694-92-8

Sheeba, 2023)(Jasim & Salman, 2024)(Bilgin Simsek & Tuna, 2023). Bu kirletici unsurlar arasında sentetik boyar maddeler önemli bir yer tutmaktadır. Söz konusu maddeler; tekstil, deri, gıda, kozmetik, boya, plastik, kağıt, matbaa, ilaç, petrol ve pestisit gibi çok sayıda endüstride yaygın biçimde kullanılmaktadır(Nandanwar, Saravanan, Bakshe, & Jugade, 2022). Farklı sektörlerde bu denli yoğun kullanılan kirleticilerin arıtılması, son yıllarda bilimsel araştırmaların temel konularından biri haline gelmiştir. Özellikle son çeyrek yüzyılda boyar maddeler ve ağır metaller, su kaynakları açısından ciddi bir çevre sorunu olarak öne çıkmıştır(Rani & Basu, 2012). Dapson ve ekibi tarafından yürütülen bir çalışmada, metal esaslı adsorbanlar kullanılarak metilen mavisinin sudan uzaklaştırılması başarıyla sağlanmıştır(Dapson, 2018). Boyar maddeler ve pigmentler, gıda, tekstil ve ilaç sektörlerinden kaynaklanan atık sularda en yaygın görülen kirleticiler arasında yer almaktadır. Bu bileşiklerin büyük bir kısmı kanserojen ve mutajenik özellikler gösterebilmekte, ayrıca biyolojik olarak parçalanmaları oldukça güç olduğundan çevre için kalıcı ve tehlikeli atıklar oluşturmaktadır. Su kirliliğine yol açan kirleticiler arasında, oldukça yüksek toksik etkiye sahip olan Kongo kırmızısı (CR) boyası da önemli bir yer tutmaktadır. Kimyasal olarak 1-naftalensülfonik asit, 3,3′-(4,4′-bifenilenbis(azo)) bis(4-amino-) disodyum tuzu şeklinde tanımlanan bu bileşik, sentetik olarak üretilen anyonik bir boyar maddedir. Kongo kırmızısı, özellikle polimer, tekstil ve boya endüstrilerinde yaygın biçimde kullanılmaktadır. Son 25 yıl içerisinde bu kirleticinin giderimine yönelik yaklaşık 7000 bilimsel çalışmanın yayımlanmış olması, konuya verilen önemin ve artan akademik ilginin açık bir göstergesidir. CR'nin sudan uzaklaştırılmasına yönelik araştırmalarda fotokatalitik oksidasyon, membran teknolojileri, adsorpsiyon ve katalitik bozunma gibi çeşitli yöntemler ele alınmıştır.

Boya gideriminde adsorpsiyon yöntemi, moleküler düzeyde ayırma yapabilme kapasitesi sayesinde oldukça etkili bir su arıtma tekniği olarak öne çıkmaktadır. Bu yöntem; kısa işlem süresi, pratik uygulanabilirliği ve düşük maliyet gereksinimi gibi avantajları nedeniyle yaygın olarak tercih edilmektedir(Jasim & Salman, 2024). Adsorpsiyon temelli çalışmalarda kil mineralleri, aktif karbon, biyokömür, metal-organik çerçeveler ve metal oksit kompozitleri gibi farklı yapılar adsorban malzeme olarak kullanılmış ve bu materyallerin Kongo kırmızısı giderimindeki performansları detaylı biçimde incelenmiştir(Tamil Thendral, Amutha, Ragunathan, & Saranya, 2024).

Kongo kırmızısının endüstriyel atık sulardan uzaklaştırılması, çevresel açıdan büyük önem taşımakta ve önemli operasyonel kazanımlar sağlamaktadır. Bu azo boyanın etkili bir şekilde

ISBN NR: 978-625-5694-92-8

adsorbe edilmesi ya da katalitik olarak parçalanması, toksik ve dirençli organik kirleticilerin su ekosistemlerine karışmasını büyük ölçüde engelleyerek insan sağlığı ve ekolojik denge üzerindeki riskleri azaltmaktadır. Özellikle tekstil ve boya üretim tesislerinde, gelişmiş adsorbanların ve oksidasyon katalizörlerinin kullanılması, atık suların sürekli ve etkin biçimde arıtılmasını mümkün kılmakta; kimyasal oksijen ihtiyacı (KOİ) ve renk yoğunluğu gibi parametrelerin düşürülmesine katkı sağlamaktadır. Bu durum, yasal deşarj standartlarına uyumu da kolaylaştırmaktadır. Bununla birlikte, kullanılan adsorban ya da katalizörlerin dayanıklılığı ve yeniden kullanılabilirliği, ekonomik sürdürülebilirlik açısından kritik bir öneme sahiptir; çünkü sık yenileme gereksinimi işletme maliyetlerini artırabilmektedir. Sonuç olarak, Kongo kırmızısı ile kirlenmiş atık suların arıtımında gerçek endüstriyel uygulamalar için; giderim verimliliği, işlem süresi ve malzeme tekrar kullanılabilirliği gibi parametrelerin optimize edilmesi, sürdürülebilir ve ölçeklenebilir çözümlerin geliştirilmesi açısından zorunludur(Xu et al., 2024).

DENEYSEL ÇALIŞMALAR

Kobalt-manganez oksit kompozitlerinin bilyalı öğütme sentezi, prensip olarak Kongo Kırmızısı giderme uygulamalarında endüstriyel ölçekte uygulanabilir. Uzun öğütme süreleri nedeniyle enerji tüketimi önemli bir husus olsa da, öğütme süresinin kısaltılması, enerji verimli öğütücülerin kullanılması ve yenilenebilir enerji kaynaklarının kullanılması gibi süreç optimizasyonu sürdürülebilirliği artırabilir. Dahası, kompozitin yüksek stabilitesi ve geri dönüştürülebilirliği, malzeme değişimini ve ikincil atıkları en aza indirerek, daha büyük ölçeklerde çevresel olarak sürdürülebilir atık su arıtımını destekler.

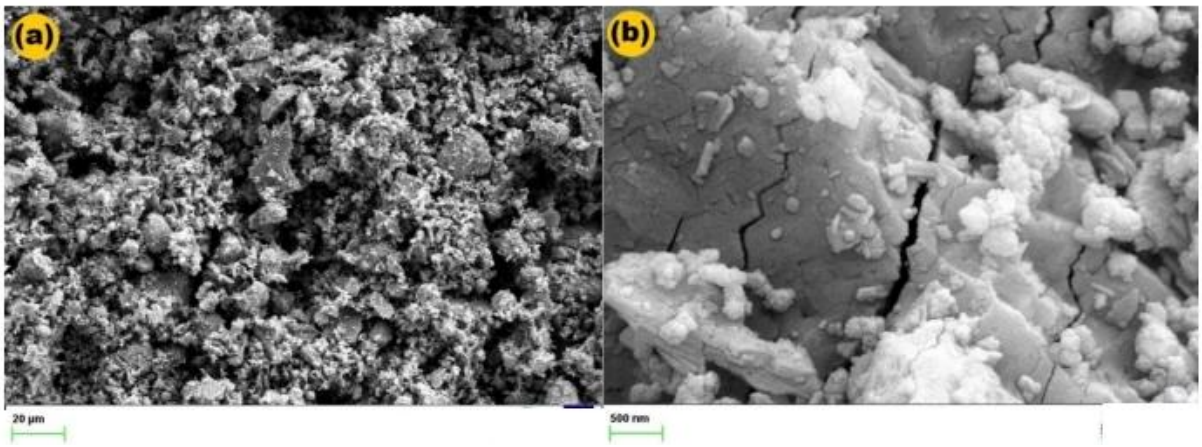
Öğütme süresinin ve bilye-toz oranının (BPR) değiştirilmesi, Co-Mn oksit ($CoMnO_x$) kompozitlerinin fiziksel özelliklerini önemli ölçüde etkiler. Öğütme süresinin artırılması, artan mekanik aktivasyon ve tekrarlanan parçacık kırılması nedeniyle genellikle daha ince parçacık boyutlarına ve daha yüksek yüzey alanlarına yol açar. Bununla birlikte, aşırı uzun öğütme, parçacık kümelenmesine neden olarak erişilebilir yüzey alanını azaltabilir ve gözenek yapısını değiştirebilir. Benzer şekilde, daha yüksek bir BPR genellikle çarpışma sıklığını ve darbe enerjisini artırarak daha verimli parçacık boyutu küçültülmesini ve kusur oluşumunu teşvik eder; bu da yüzey alanını artırabilir ve mezogözenekler oluşturabilir. Tersine, çok yüksek bir BPR, soğuk kaynaklanmaya ve yoğunlaşmaya neden olarak gözenekliliği azaltabilir. Bu nedenle, Kongo Kırmızısı gibi kirleticilerin verimli adsorpsiyonu için istenen yüzey alanına ve gözenek boyutu dağılımına sahip $CoMnO_x$ kompozitleri elde etmek için hem öğütme süresinin

ISBN NR: 978-625-5694-92-8

hem de BPR'nin dikkatli bir şekilde optimize edilmesi esastır. Bu çalışmada, değişen BPR oranlarıyla 1, 2, 4, 5 ve 8 saatlik ilk deneyler yapılmış ve çalışmalar en optimum adsorpsiyon yeteneğini gösteren 5 saatlik deneyle devam ettirilmiştir.

SONUÇLAR VE TARTIŞMA

Tozların mikroyapısını ve kimyasal bileşimini belirlemek için SEM analizleri yapıldı ve CoMnOx2 numunesinin 500 X ve 20 k X büyütme sonuçları sırasıyla Şekil 1 (a ve b)'de gösterilmiştir. Ayrıca, numunenin haritalama gösterilmiştir. SEM sonuçlarına göre, kobalt oksit fazlarının MnO matris yapısına bağlı ve birleşmiş olduğu görülmüştür ve EDX sonuçlarına göre, Mn, Co ve oksijen dışında başka bir yapı gözlemlenmemiştir. SEM mikrograflarının ölçeklendirilmesi dikkate alındığında, mekanik öğütme sonucu toz boyutunun 20 mikronun altında olduğu kolayca görülebilir. Bu, tozların adsorpsiyon kapasitesini artırmada önemli bir rol oynar. Haritalama sonuçları, kobalt bazlı yapıların belirli bölgelerde yoğunlaştığını ve homojen olarak dağılmış Mn bazlı yapı üzerinde konumlandığını ve oksijenin her yerde eşit olarak dağıldığını göstermektedir. Bu sonuçlar, optimize edilmiş öğütme parametrelerinin (5 saat öğütme süresi ve seçilen BPR) parçacık inceltmesi ve kümelenmenin önlenmesi arasında bir denge sağladığını ve bunun sonucunda yüzey alanının ve erişilebilir adsorpsiyon bölgelerinin iyileştiğini doğrulamaktadır.



Şekil 1. Numunelerin SEM Fotoğrafları

Bu çalışmada, sulu ortamdan zehirli Kongo kırmızısı boyasının adsorpsiyonu için bilyalı öğütme tekniğiyle sentezlenen CoMnOx hibrit oksitlerinin performansı araştırılmıştır. Tüm adsorbanların Langmuir tek tabakalı adsorpsiyon modeline uygun olduğu sonucuna varılmıştır.

1 g Co_3O_4 ile katkılanmış CoMnOx2 içeren CoMnOx2 en yüksek adsorpsiyon performansını göstermiş ve adsorpsiyon kapasitesi 218,54 mg g^{-1} olarak bulunmuştur.

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ISBN NR: 978-625-5694-92-8

Mycoplasma bovIs INFECTION IN CATTLE

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ABSTRACT

Mycoplasma bovis belongs to the *Mollicutes* class and causes mycoplasmosis in cattle. The disease is mostly seen in a chronic form. *M. bovis* affects numerous tissues and organs, but can also be isolated from healthy cattle. *M. bovis* is one of the most important mycoplasma pathogens in cattle. It is one of the primary factors in bovine respiratory disease complex and causes caseous necrotic pneumonia. It is the main cause of mastitis, arthritis, conjunctivitis and keratitis in cattle. Purulent otitis media, inflammation of the meninges, decubitus abscesses, inflammation of the endocardium and genital disorders have been associated with *M. bovis*. *M. bovis* is a primary or opportunistic pathogen in respiratory system disease in cattle. *M. bovis* has high disease incidence and mortality rates. Thus, it causes important economic losses. In this review context, the prevalence, risk factors, pathogenesis, clinical signs, diagnosis, treatment and control of *M. bovis* infection in cattle were comprehensively addressed. By extensively examining recent scientific sources, comprehensive knowledge was given on the most commonly used drugs and drug combinations in treatment.

Keywords: Cattle, *M. bovis*, infection, treatment

ISBN NR: 978-625-5694-92-8

SIĞIRLARDA *MYCOPLASMA BOVİS* ENFEKSİYONU

ÖZET

Mycoplasma bovis; *Mollicutes* sınıfına aittir ve sığırlarda mikoplazmozise neden olur. Hastalık çoğunlukla kronik şekilde görülür. *M. bovis* çok sayıda doku ve organı etkiler, ancak sağlıklı sığırlardan da izole edilebilmektedir. *M. bovis*, sığırlarda en önemli mikoplazma etkenlerindendir. Sığırların solunum sistemi hastalığı kompleksindeki temel etkenlerden birisidir ve kazeöz nekrotik pnömoniye neden olur. Sığırlarda meme yangısı, eklem yangısı, konjonktiva ve kornea yangısının temel nedenidir. İrinli orta kulak yangısı, beyin omurilik zarlarının yangısı, dekübit apseleri, endokardiyumun yangısı ve genital bozukluklar *M. bovis* ile ilişkilendirilmiştir. *M. bovis*; sığırların solunum sistemi hastalığında primer ya da fırsatçı bir patojendir. *M. bovis* yüksek hastalık oluşturma ve ölüm oranlarına sahiptir, dolayısıyla önemli ekonomik kayıplara neden olur. Bu makale kapsamında sığırlarda *M. bovis* enfeksiyonunun prevalansı, risk faktörleri, patogenezi, klinik bulguları, tanısı, sağaltımı ve kontrolü kapsamlı şekilde ele alındı. Son yıllara ait bilimsel kaynaklar geniş şekilde irdelenerek sağaltımda en çok kullanılan ilaçlar ve ilaç kombinasyonlarına yönelik olarak kapsamlı bilgiler verildi.

Anahtar kelimeler: Sığır, *M. bovis*, enfeksiyon, sağaltım

ISBN NR: 978-625-5694-92-8

Giriş

Sığırlarda *Mycoplasma* spp. enfeksiyonları meme yangısı (Fox ve ark., 2005), solunum hastalığı (Maunsell ve ark., 2011) ve çok sayıda eklemde yangıya (Wilson ve ark., 2007) neden olur. Ayrıca sığırlarda göz, kulak ya da beyni de etkileyebilir (Dudek ve ark., 2020).

Etiyoloji

Hücre duvarı olmayan *M. bovis*; *Mollicutes* sınıfına aittir ve sığırlarda mikoplazmozise neden olur. Hastalık çoğunlukla kronik şekilde görülür. *M. bovis* çok sayıda doku ve organı etkiler, ancak sağlıklı sığırlardan da izole edilebilmektedir (Bürki ve ark., 2015).

Bulaşma

Solunum hastalıkları en fazla soğuk mevsimlerde, sıcaklık dalgalanmalarının olduğu zamanlarda, ahır ortamında sürüdeki hayvanların yakın temasta olmasından kaynaklanır (Ridley ve Hateley, 2018; Nicholas, 2011).

Diğer stres faktörlerinden nakil, sığırların yaşadıkları ortamın fazla kalabalık olması, sürüye yeni hayvanların getirilmesi ve sütten kesme, yetersiz besleme ve çevre sıcaklığının düşük olması hastalığın gelişmesinde önemli rol oynar (Aebi ve ark., 2015; Perez-Casal, 2020).

Enfekte kolostrum ve süt, hava, uterus, semen yoluyla da bulaşmalar olabilir (Hermeyer ve ark., 2012; Haapala ve ark., 2018; Timonen ve ark., 2020).

Epidemiyoloji

M. bovis yüksek hastalık oluşturma ve ölüm oranlarına sahiptir, dolayısıyla önemli ekonomik kayıplara neden olur (Becker ve ark., 2015).

Litvanya'da 3 aylıktan küçük buzağılarda burun sıvabı örneklerinde *M. bovis*, %22.9 oranında, 17 aylık yaşta %11.4 oranında belirlenmiş, genç buzağılarda *M. bovis* ile birlikte *Pasteurella* spp. %5.7, 17 aylık olan sığırlarda *Mannheimia haemolytica* ile birlikte %2.9 oranında saptanmıştır (Gabinaitiene ve ark., 2011).

Mısır'da sığırların solunum sistemi hastalıklarında solunum yollarından alınan örneklerde *M. bovis* %61 ve *M. bovirhinis* %15 oranlarında tespit edilmiştir (Ammar ve ark., 2022).

Patogenez

ISBN NR: 978-625-5694-92-8

M. bovis mukozal yüzeylerde çoğalabilme ve kalabilme, dokulara invaze olabilme, hastalıklı yerlerde sürekli kalabilmelerini sağlayan özelliklere sahiptir. Yapışma, antijenik varyasyon, invazyon, immünmodülasyon, biyofilm oluşturma, toksik metabolitler oluşturmayla ilgili moleküllerin patogenezde önemli olma ihtimali vardır (Maunsell ve ark., 2011).

Klinik Bulgular

M. bovis ile doğal enfeksiyon ara sıra yoğun koagülatif nekrozlu bronkopnömoniye neden olabilir. Ancak deneysel enfeksiyonlar subklinik pnömoniye neden olmuştur (Garcia-Galan ve ark., 2021; Rodriguez ve ark., 1996).

Klinik bulgular özel değildir ve burun akıntısı ve öksürüğün varlığı ya da yokluğuyla birlikte yüksek ateş, solunum sayısında artış, solunum güçlüğü ve iştahta azalma görülür. Mikoplazma pnömonileri orta kulak yangısı, eklem yangısı ya da her 2 hastalıkla birlikte gelişebilir (Pfützner ve Sachse, 1996; Stipkovits ve ark., 2000; Caswell ve Archambault, 2007).

Ayrıca beyin omurilik zarlarında yangı, dekübit apseleri, endokardiyum yangısı ve genital bozukluklar meydana gelebilir (Maunsell ve ark., 2011).

Genç buzağılara ağızdan *M. bovis*'le enfekte kolostrum verilmesinden sonra etkenlerin tonsillalarda çoğaldığı ve orta kulak yangısı gelişmesine katkı sağladığı saptanmıştır (Maunsell ve ark., 2012). *M. bovis* infertilite ve yavru atmaya da neden olur (Ayling ve ark., 2014).

Abort olan fötüs ve yeni doğan buzağıda *M. bovis* nedeniyle interstisyel pnömoni ve irinli bronkopnömoni şekillendiği, buzağının akciğer ve plasentasında, fötüsün plasenta, beyin, akciğer ve karaciğerinde *M. bovis* saptanmıştır (Hermeyer ve ark., 2012).

Tanı

Sığırlarda enfeksiyonun klinik bulguları özel değildir. Tanı için duyarlı, doğru, hızlı test gereklidir. Kültür ortamında yavaş çoğalır. Gerçek zamanlı PCR analizleri, immünhistokimya ve in-situ hibridizasyon, matriks destekli lazer dezorpsiyon/iyonizasyon uçuş süresi kütle spektrometresi, moleküler tiplendirme ve serolojik analizler kullanılmaktadır (Dudek ve ark., 2020; Parker ve ark., 2018). Üçlü gerçek zamanlı PCR; sığırların solunum hastalığıyla ilgili mikoplazma türlerinin zamanında ve doğru saptanmasını sağlamaktadır (Cornelissen ve ark., 2017).

Sağaltım

Süt sığırı işletmelerinde *M. bovis* saçılımının önemli sürü sağlığı riski vardır ve enfeksiyondan etkilenen hayvanın sağaltımı bu patojenin sürekli saçılmasını durdurma ihtimali bulunmamaktadır. Dolayısıyla *M. bovis*'e bağlı pnömoni ya da diğer hastalıkların kanıtı olan sürü sığırlarının antimikrobiyal sağaltımına göre sürüden çıkarmak tercih edilebilir. Mikoplazmalara karşı etkili olma ihtimali olan antimikrobiyaller, sığırların solunum sistemi hastalığı kompleksinde tescilli olan birkaç ilacı örneğin makrolit (örneğin tilmikosin, gamitromisin, tildiprosin ve tulatromisin), fenikol (örneğin florfenikol), florokinolon (örneğin marbofloksasin, enrofloksasin ve danofloksasin) ya da tetrasiklin sınıfı ilaçları içermektedir (Wagner ve Depenbrock, 2025).

M. bovis'le ilgili sığırların solunum sistemi hastalığı için Amerika'da tulatromisin ve florfenikol, Kanada'da gamitromisin onaylı ilaçlardır. Enrofloksasin sadece *M. haemolytica*, *Pasteurella multocida* ve *Histophilus somni* enfeksiyonlarıyla ilgili sığırların solunum sistemi hastalığının sağaltımında onaylıdır (Maunsell ve ark., 2011).

Standardize edilmiş duyarlılık testi metotları ve yorumlama kriterleri herhangi bir endikasyon için *M. bovis* için oluşturulmamıştır (Apley ve ark., 2025).

Mikoplazma türleri için MIC düzeyleriyle dirençli ya da duyarlı olduğunu gösteren kesim noktaları belirlenmemiştir. Dolayısıyla, antimikrobiyal direncin kesin tanımı MIC verileri esasında mümkün değildir. Moleküler mutasyonlara dayalı olarak *Mycoplasma* türleri için kesim noktalarını belirlemek için çalışmalar gereklidir (Ayling ve ark., 2014).

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ISBN NR: 978-625-5694-92-8

BAZI MISIR GENOTİPLERİNİN SİVAS EKOLOJİK KOŞULLARINDA AGRO-MORFOLOJİK VE KALİTE ÖZELLİKLERİNİN ORTAYA KONULMASI

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ÖZET

Bazı mısır genotiplerinin agro-morfolojik ve kalite özelliklerinin ortaya konulması amacıyla Sivas ili ekolojik koşullarında 2025 yılında SBTÜ Tarımsal AR-GE merkezinde mısırın vejetasyon döneminde tesadüf blokları deneme deseninde üç tekrarlamalı olarak yürütülen araştırmada 16 adet mısır genotipi materyal olarak yer almıştır. Yürütülen çalışmada agronomik özellikler olan bitki boyu (cm), ilk koçan yüksekliği (cm), koçan boyu (cm), koçan çapı (cm), koçan ağırlığı (g), koçan sıra sayısı (adet), sırada tane sayısı (adet), koçanda tane sayısı (adet), koçanda tane ağırlığı (g), bin tane ağırlığı (g), dekara tane verimi (kg/da); kalite özellikleri olan hektolitre ağırlığı (kg/hl), protein oranı (%), sıvı yağ (km) ve nişasta oranı (%) özellikleri ele alınmıştır. Çalışma sonucunda mısır genotiplerinde dekara 600.01-1024.77 kg arasında tane verimi değeri tespit edilmiş olup dekara tane verimine en yüksek DKC 7240 genotipi sahip olurken en düşük verim ise DKC 6919 genotipinde saptanmıştır. Yine çalışmada mısır genotiplerine bağlı olarak bitki boyunda 181.66-249.47 cm, koçan boyunda 17.67-23.67 cm, koçanda tane sayısında 513.67-1002.67 adet, koçanda tane ağırlığında 63.20-129.55 g, bin tane ağırlığında 92.34-212.61 g, hektolitre ağırlığında 54.03-72.53 kg/hl ve protein oranında %11.10-15.43 aralığında değerler elde edilmiştir. Sonuç olarak; DKC 7240, Albayrak ve Kalumet genotip/çeşitlerinden elde edilen verim unsurlarına ait değerlerin diğer mısır genotip/çeşitlerine göre daha yüksek oldukları ortaya konulmuştur.

Anahtar Kelimeler: Mısır, Çeşit, Genotip, Verim, Agronomik özellikler, Kalite özellikleri

ISBN NR: 978-625-5694-92-8

FİTAZ UYGULAMASININ KETEN (*Linum usitatissimum* L.) TOHUMLARINDA ÇİMLENME VE KÖK GELİŞİMİ ÜZERİNE ETKİLERİ

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ÖZET

Keten (*Linum usitatissimum* L.), hem yağ hem de lif üretimi açısından önemli bir kültür bitkisidir. Tohumlarında yüksek miktarda omega-3 yağ asitleri, protein ve çeşitli biyoaktif bileşikler bulunması, gıda, yem, tekstil ve farklı endüstriyel alanlarda değerlendirilmesini sağlamaktadır. Bu nedenle keten bitkisinde çimlenme ve erken fide gelişimini etkileyen faktörlerin belirlenmesi tarımsal üretim açısından önem taşımaktadır. Fitaz enzimi, bitkisel dokularda bulunan fitik asidi parçalayarak bağlı fosforu serbest hâle getirir. Böylece bitkilerin kullanılabilir fosfor düzeyi artar ve besin elementlerinin bitki tarafından daha verimli kullanılmasına katkı sağlar. Bu çalışmada, keten bitkisine fitaz uygulamasının çimlenme ve kök gelişimi üzerine etkilerinin belirlenmesi amaçlanmıştır. Denemede dI-H_2O, Hoagland besin çözeltisi, fitaz+dI-H_2O ve fitaz+Hoagland olmak üzere dört farklı uygulama grubu oluşturulmuştur. Tohumlar petri kaplarında filtre kâğıdı üzerine ekilerek bitki büyütme kabininde kontrollü koşullar altında 8 gün süreyle çimlendirilmiştir. Çalışmada ticari bir fitaz ürünü olan Fitazim (Supersol) 10 mL olarak uygulanmıştır. Deneme sonunda, kök boyu, kök yaş ve kuru ağırlığı ile çimlenme hızı ve çimlenme yüzdesi belirlenmiştir. Elde edilen bulgular, fitaz uygulamasının özellikle dI-H_2O ortamında çimlenme ve kök gelişimi üzerinde olumlu etkiler gösterebildiğini ortaya koymuştur. Buna karşılık kök kuru ağırlığı bakımından uygulamalar arasında belirgin bir farklılık gözlenmemiştir. Elde edilen bulguların, keten bitkisinde çimlenme performansını artırmaya yönelik enzim temelli uygulamaların potansiyelinin ortaya konmasına ve erken dönem bitki gelişiminin iyileştirilmesine katkı sağlayabileceği düşünülmektedir.

Anahtar Kelimeler: Keten, *Linum usitatissimum*, fitaz, çimlenme, kök

1. GİRİŞ

Keten (*Linum usitatissimum* L.), Linaceae familyasına ait, yağlı tohumlara sahip dikotiledon bir bitki olup dünya genelinde yaygın olarak yetiştirilmektedir (Landoni vd., 2020; Talebi vd., 2021; Raole ve Raole, 2022). Hem yağ hem de lif üretiminde önemli bir ham madde olarak değerlendirilen keten, söz konusu endüstrilerin gelişimine katkı sağlamaktadır (Gomez-Campos vd., 2021). Tohumları, yüksek düzeyde α-linolenik asit (omega-3), lignan, protein, vitaminler ve mineraller içerir. Ayrıca fitosteroller ve flavonoidler gibi biyoaktif bileşikler açısından da zengindir. Bu nedenle keten hem besin hem de yem kaynağı olarak çeşitli besinsel ve terapötik faydalar sunduğundan fonksiyonel gıda olarak kabul edilmektedir (Dzuvor vd., 2018; Cui vd., 2022; Mueed vd., 2024; Wang vd., 2024). Dünya genelinde yıllık veya iki yıllık olarak yetiştirilen keten, içerdiği antioksidan bileşikler sayesinde biyomedikal ve ambalaj uygulamalarında da değerlidir (Kiryluk vd., 2020; Noreen vd., 2023). Ayrıca lif ve tohum küspesi gibi işleme yan ürünleri de fenoller gibi değerli bileşikler içerdiğinden keten bitkisi, atıksız ve verimli şekilde kullanılabilir (Usman vd., 2023). Dolayısıyla, tohumu yüksek oranda hasat edilen keten bitkisinin çimlenme potansiyelinin araştırılması sürdürülebilirlik için önemli bir konudur (Huang vd., 2021; Khare vd., 2021; Dong vd., 2021).

Bitkilerin kök gelişimi, çiçeklenme, tohum oluşumu ve enerji transferi olayları için hayati öneme sahip fosforun (P_i) bitki tohumlarındaki temel depo formu, fitik asittir (miyoinositol heksakisfosfat, IP6). Fitik asit, demir, çinko, magnezyum, bakır ve kalsiyum gibi temel minerallerin biyoyararlanımını engelleyen bir anti-besin faktörü olarak kabul edilmekte ve ayrıca sadece katyonların aynı zamanda proteinlerin de güçlü bir şelatlayıcısı olarak işlev görmektedir (Alves vd., 2016; Zhang vd., 2022). Karbohidratlarla kompleks oluşturması ve Ca bağlayarak α-amilaz aktivitesini düşürmesi, metabolik enerji verimliliğini azaltır (Liu vd., 2024). Bu olumsuz etkilerin azaltılmasında fitazlar (EC 3.1.3.8) önemli rol oynamaktadır. Çimlenme sırasında fitik asit, fide büyümesini desteklemek için P_i'yi yeniden mobilize etmek üzere fitazların etkisiyle parçalanır ve P_i'nin biyoyararlanımını artırır (Liu vd., 2022; Wang vd., 2023). Çimlenme sırasında depo maddelerin mobilizasyonu ile ilişkili enzimlerin (amilaz, fitaz, proteaz ve lipaz) aktivitelerinde artış gözlenmektedir (Guzmán-Ortiz vd., 2019). Bu süreçte fitaz, fitik asidi parçalayarak fosfor ve minerallerin serbestleşmesini sağlar ve embriyonun gelişimini destekler (Nkhata vd., 2018). Bununla birlikte, fitaz enzimi yalnızca bitki gelişimi açısından da kritik bir role sahip olmayıp beslenme açısından da önemlidir. Bitkiler, mantarlar ve bakteriler tarafından üretilen fitazlar, yüksek etkinlikleri ve dayanıklılıkları sayesinde fonksiyonel gıda ve yem uygulamalarında önem kazanmaktadır (Weng vd., 2024; Zaman vd., 2025). Ayrıca şeker ve fosfatın artan kullanılabilirliği, çimlenme ve fide oluşumunu olumlu yönde etkilemektedir (Chen vd., 2019; Dong vd., 2020).

Keten hem besin değeri yüksek tohumları hem de fonksiyonel özellikleri nedeniyle tarımda değerli bir bitki olarak kabul edilir. Çimlenme ve erken kök gelişimi, bitkinin besin alım kapasitesi ve verim potansiyelini doğrudan etkiler; dolayısıyla çimlenme çalışmaları, üretim stratejilerinin belirlenmesinde kritik öneme sahiptir. Bu bağlamda, keten tohumlarının farklı uygulama koşullarında çimlenme ve kök gelişimindeki tepkilerinin belirlenmesi ve bu amaçla

ISBN NR: 978-625-5694-92-8

dıştan uygulanacak kimyasalların erken dönem bitki gelişimine katkısının değerlendirilmesi açısından önem taşımaktadır. Bu çalışmanın amacı, keten bitkisine fitaz temelli ticari bir maddenin uygulamasının çimlenme ve kök gelişimi üzerindeki etkilerini incelemektir. Çalışmada, deiyonize su (dI-H_2O) ve Hoagland besin çözeltisinde yetiştirilen keten bitkilerine dıştan fitaz uygulamasının çimlenme oranı, kök uzunluğu, kök yaş ve kuru ağırlıklara etkileri değerlendirilmiştir.

Tohumlar, filtre kâğıdı serili petri kaplarına ekilmiş ve bitki büyütme kabininde kontrollü koşullar altında 8 gün boyunca çimlendirilmiştir. Ticari bir fitaz ürünü olan Fitazim (Supersol) ilgili uygulama grubuna 10 mL olarak uygulanmıştır. Deneme sonunda, kök uzunluğu, kök yaş ve kuru ağırlığı ile çimlenme hızı ve çimlenme yüzdesi belirlenerek uygulamaların etkileri değerlendirilmiştir.

2. MATERYAL VE YÖNTEM

2.1. Bitki Materyali ve Yetiştirme Koşulları

Çalışma, bitki büyütme kabininde, 24 °C sıcaklık ve %60–70 nem aralığında yürütülmüştür. Temin edilen tohumlar öncelikle %5'lik sodyum hipoklorit çözeltisi içerisinde 15 dakika süreyle steril edilmiş ve ardından saf su ile durulanmıştır. Her bir uygulama grubu için 20 tohum olacak şekilde tohumlar çift kat steril filtre kâğıdı içeren petri kaplarına yerleştirilmiştir. Uygulama grupları; deiyonize su (dI-H_2O), Hoagland besin çözeltisi, fitaz + dI-H_2O ve fitaz + Hoagland besin çözeltisi şeklinde oluşturulmuştur. Ticari bir ürünü olan Fitazim (Supersol) fitaz uygulamalarında kullanılmıştır. Tohumların çimlendirilmesi süresince tohumların nemi düzenli olarak kontrol edilmiş ve kurumaları engellenmiştir. Sekiz gün boyunca her gün tohumlar izlenmiş ve çimlenme verileri günlük kaydedilmiştir. Süre sonunda kök uzunlukları cetvelle ölçülmüştür. Daha sonra bitkilerin kök yaş ağırlıkları tartılmış ve 70 °C'de 72 saat etüvde kurutulduktan sonra kuru ağırlıkları kaydedilmiştir.

2.2. Çimlenme Oranı

Tohumların çimlenmesi her gün izlenmiş ve radikulanın 0,2 cm uzunluğa ulaşması çimlenme ölçütü olarak kabul edilmiştir. Çimlenme oranlarının (ÇO) değerlendirilmesinde 8. gün kaydedilen veriler esas alınmış, çimlenme yüzdesi ise aşağıda verilen formül kullanılarak hesaplanmıştır.

$$ÇO = (G/T) *100$$

G: Çimlenen tohum sayısını, T: Kullanılan toplam tohum sayısı

2.3. Çimlenme Hızı

Çimlenme hızının hesaplanmasında günlük olarak kaydedilen veriler esas alınmıştır. Bu doğrultuda hız, aşağıda verilen formül kullanılarak belirlenmiştir.

$$ÇH = N1/T1+N2/T2+\ldots\ldots\ldots+Nn/Tn$$

N: Çimlenen tohum sayısı, T: Çimlenmenin gerçekleştiği gün sayısı

2.4. İstatistiksel Analizler

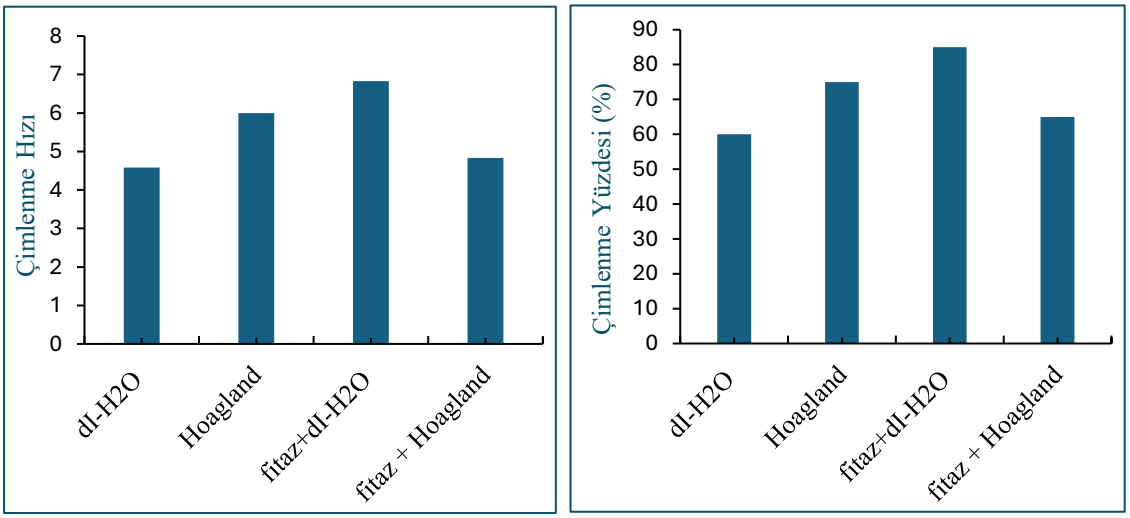
Deneme sonucunda elde edilen veriler, Tek Yönlü Varyans Analizi (One-way ANOVA) ile değerlendirilmiş ve ortalamalar arasındaki farklılıklar ise Duncan çoklu karşılaştırma testi ile

ISBN NR: 978-625-5694-92-8

belirlenmiştir. Uygulamalar arasındaki istatistiksel anlamlılık $p<0,05$ düzeyinde ifade edilmiştir.

3. SONUÇLAR VE DEĞERLENDİRME

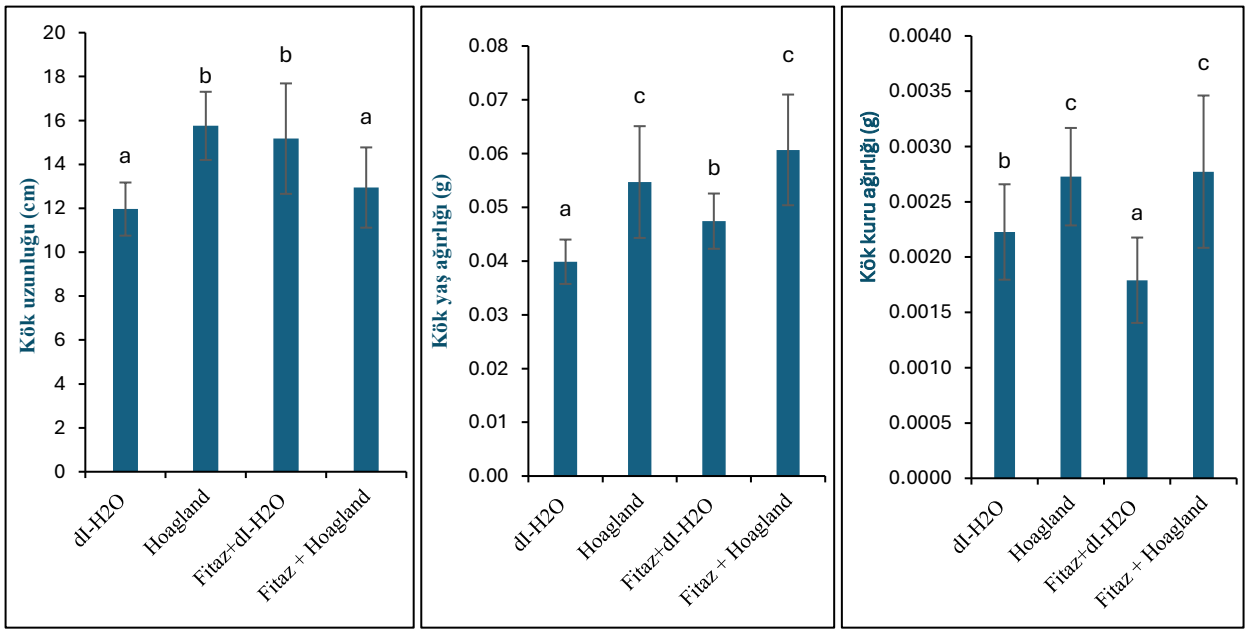
Bu çalışmada, keten tohumlarına saf su ve besin çözeltileri ile birlikte fitaz uygulanmış ve tohum çimlenmesi üzerine etkileri incelenmiştir. Erken dönem kök gelişimi ve çimlenme verilerinin belirlenmesinde dI-H_2O, Hoagland besin çözeltisi, fitaz + dI-H_2O ve fitaz + Hoagland besin çözeltisi olmak üzere dört farklı uygulama grubu oluşturulmuş ve tohumlar bu çözeltilerle muamele edilmiştir. Keten tohumlarının uygulanan çözeltiler altındaki çimlenme hızı ve çimlenme yüzdesi Şekil 1'de gösterilmiştir. Çimlenme hızları incelendiğinde, en yüksek çimlenme hızı fitaz + dI-H_2O uygulamasında (6,83) belirlenmiştir. Bunu sırasıyla Hoagland çözeltisi (6,00) ve fitaz + Hoagland (4,83) uygulamaları izlerken, en düşük değer dI-H_2O uygulamasında (4,58) elde edilmiştir. Bu bulgular, fitazın saf su ortamında çimlenme hızını artırıcı etkisinin daha belirgin olduğunu göstermektedir. Hoagland besin çözeltisi tek başına çimlenme hızını artırsa da fitaz ile birlikte kullanıldığında bu etkinin azaldığı görülmektedir. Bu durum, fitaz aktivitesinin dI-H_2O ortamında daha etkili gerçekleştiğini ve çimlenme hızını daha fazla artırdığını ortaya koymaktadır. Hoagland çözeltisindeki yüksek mineral iyonları ve uygun olmayan kimyasal koşulların fitaz aktivitesini kısmen baskılaması, bu uygulamada çimlenme hızının daha düşük olmasına neden olmuş olabilir. Çimlenme yüzdeleri incelendiğinde en yüksek değer %85 ile fitaz + dI-H_2O uygulamasında belirlenmiştir. Bu uygulamayı %75 ile sadece Hoagland besin çözeltisi ve %65 ile fitaz + Hoagland takip ederken, en düşük çimlenme oranı %60 ile dI-H_2O uygulamasında saptanmıştır. Bu sonuçlar, fitazın özellikle saf su ortamında çimlenmeyi belirgin şekilde artırdığını, ancak Hoagland besin çözeltisi ile birlikte kullanıldığında bu etkinin azaldığını göstermektedir. Ayrıca Hoagland çözeltisinin tek başına da çimlenme yüzdesini artırıcı bir etki yaptığı görülmektedir. Çalışmamızla benzer şekilde fitaz uygulamasının, fitik asidi parçalayarak besin ve fosfor kullanılabilirliğini arttırdığı ve böylece çimlenmeyi desteklediği rapor edilmiştir (Ngan vd., 2023).



Şekil 1. Su ve besin çözeltisi ortamlarında fitaz uygulamasının keten tohumlarında çimlenme hızı ve çimlenme yüzdesine etkisi

ISBN NR: 978-625-5694-92-8

Keten tohumlarının çimlendirilmesi üzerine fitaz uygulamasının etkisi ile kök gelişiminin belirlenmesi amacıyla kök uzunluğu ile kök yaş ve kuru ağırlıkları ölçülmüştür (Şekil 2). Kök yaş ağırlığı bakımından, dI-H_2O ile karşılaştırıldığında Fitaz + dI-H_2O uygulamasında %26,7 oranında artış meydana gelmiştir. Hoagland besin çözeltisi uygulaması kök gelişimini en fazla teşvik eden grup olmasına rağmen, fitaz ile birlikte uygulandığında bu değerde %18,35 oranında azalmıştır. Bu durum, fitazın saf su ortamında daha etkili olduğunu, ancak Hoagland çözeltisindeki iyonik bileşenler ve ortam koşullarının enzim aktivitesini sınırlayabileceğini göstermektedir. Nitekim, yapılan çalışmalarda fitazın fosfor etkinliğini artırarak kök büyümesini teşvik ettiği bildirilmiştir (Lazali vd., 2014; Li vd., 2021).



Şekil 2. Su ve besin çözeltisi ortamlarında fitaz uygulamasının keten tohumlarında kök uzunluğu, kök yaş ve kuru ağırlık verilerinde meydana gelen değişimler.

Kök yaş ağırlığı incelendiğinde, dI-H_2O ile Fitaz + dI-H_2O uygulamaları karşılaştırıldığında %17,5'lik bir artış kaydedilmiştir. Buna karşın, Hoagland ve Fitaz + Hoagland uygulamaları arasında istatistiksel olarak anlamlı bir fark bulunmamıştır (p<0,05). Kök uzunluğu açısından ise en yüksek değer Fitaz + Hoagland olup, bunu Hoagland uygulaması takip etmiştir. Bu bulgular, besin çözeltisinin kök gelişimini desteklediğini, ancak içerdiği bileşenler nedeniyle fitaz aktivitesinin sınırlanarak ilave bir etki oluşturmadığını göstermektedir. Kök kuru ağırlığı bakımından, dI-H_2O ile karşılaştırıldığında Fitaz + dI-H_2O uygulamasında, yaş ağırlığın aksine %18,2 oranında azalma gözlenmiştir. Hoagland ile Fitaz + Hoagland uygulamaları karşılaştırıldığında ise, yaş ağırlığa benzer şekilde istatistiksel olarak anlamlı bir fark oluşmamıştır (p<0,05). Kök kuru ağırlığındaki azalma, fitazın tohumdaki besinlerin daha hızlı kullanılmasını sağlaması ve kökün daha fazla su alması sonucunda kuru madde miktarının düşmesinden kaynaklanabilir.

4. GENEL DEĞERLENDİRME VE SONUÇLAR

Keten bitkisi, yüksek omega-3 içeriği, besleyici değeri ve kaliteli lif yapısı sayesinde gıda, tekstil ve sanayi alanlarında geniş kullanım potansiyeline sahip önemli bir tarım ürünüdür. Bu çalışmada, keten tohumları dI-H_2O, Hoagland besin çözeltisi, fitaz + dI-H_2O ve fitaz + Hoagland besin çözeltisi olmak üzere dört farklı uygulama ile sulanmış; çimlenme performansı ve kök gelişimi değerlendirilmiştir. Elde edilen bulgular, fitazın özellikle dI-H_2O ortamında çimlenme hızı ve çimlenme yüzdesini artırarak erken gelişimi olumlu etkilediğini göstermiştir. Buna karşılık, Hoagland çözeltisi tek başına çimlenmeyi desteklemesine rağmen fitaz ile birlikte kullanıldığında bu etkinin azaldığı belirlenmiştir. Bu durum, çözeltideki iyonik bileşenlerin fitaz aktivitesini sınırlayabileceğini düşündürmektedir. Kök gelişimi açısından, fitazın saf su ortamında kök yaş ağırlığını artırdığı, ancak Hoagland ile birlikte uygulandığında bu etkinin azaldığı saptanmıştır. Kök uzunluğunda ise besin çözeltisinin daha etkili olduğu, fitazın ek bir katkı sağlamadığı görülmüştür. Buna karşın, kök kuru ağırlığında azalma meydana gelmiş olup, bu durumun artan su alımı ve depo maddelerin daha hızlı kullanılmasıyla ilişkili olabileceği düşünülmektedir.

Sonuç olarak, fitaz uygulaması keten tohumlarında çimlenme ve erken gelişimi desteklemekte, ancak bu etkinin uygulama ortamına bağlı olarak değiştiği görülmektedir. Bu nedenle, farklı ortam koşulları ve dozların birlikte değerlendirilmesi, fitaz uygulamalarının optimize edilmesine katkı sağlayacaktır.

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ISBN NR: 978-625-5694-92-8

THE NUTRITIONAL POTENTIAL OF A FOOD LIES NOT ON THE LABEL, BUT IN ITS POST DIGESTIVE EFFECTS

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ABSTRACT

The nutritional value of foods is predominantly evaluated based on label information and pre-digestive chemical composition data. Information related to energy content, macro- and micronutrients, and certain bioactive compounds provides an important reference for both consumers and health professionals. However, this approach does not adequately account for the structural transformations occurring during gastrointestinal digestion or the resulting changes in the bioaccessibility and biological activity of bioactive compounds. During digestion, the food matrix undergoes extensive modification, which may lead to the release of new bioactive fractions or alterations in the activity of existing compounds. Recent studies increasingly indicate that the health-related effects of foods, particularly fermented and unprocessed (whole-food) products, can be more accurately and realistically assessed through bioaccessible fractions formed after digestion. This perspective is especially relevant for the scientific evaluation of functional foods and preventive nutrition strategies. The aim of this review is to discuss, considering current scientific literature, the differences between "label-based information" and "post-digestive bioactivity" in the assessment of the nutritional value and metabolic bioactivities of foods. In this context, findings obtained using *in vitro* gastrointestinal digestion models are systematically reviewed, with particular emphasis on antioxidant capacity, angiotensin-converting enzyme (ACE) inhibitory activity, antidiabetic effects, and cholesterol-lowering potential. The reviewed literature demonstrates that the digestive process may enhance the activity of certain bioactive compounds, including phenolics, peptides, and other low-molecular-weight fractions. Conversely, nutritional evaluations based solely on label information often fail to adequately reflect these biological effects. This discrepancy highlights the limitations of conventional nutritional assessment approaches that do not consider post-digestive outcomes. In conclusion, incorporating post-

digestive bioaccessible fractions into the evaluation of the health-related potential of foods provides a more realistic, holistic, and physiologically meaningful framework. Such an approach may contribute to improved interpretation of functional food claims and support evidence-based practices in the fields of nutrition and dietetics.

Keywords: Bioaccessibility, *in vitro* digestion, functional foods, fermented foods, nutritional properties

1. INTRODUCTION

Nutritional evaluation of foods has traditionally relied on compositional data presented on food labels, including energy content, macronutrients, micronutrients, and selected bioactive compounds (Maria et al., 2019). These label-based values play a central role in dietary planning, clinical nutrition, and public health recommendations, providing a standardized framework for comparing foods and guiding consumer choices. However, such evaluations are inherently static; they describe the chemical makeup of foods before consumption and do not account for the dynamic physiological processes that occur during digestion.

Digestion is not merely a passive release of nutrients, but a complex sequence of biochemical and structural transformations that profoundly influence the nutritional and functional expression of foods (Minekus et al., 2014). Digestion is a dynamic process involving enzymatic hydrolysis, physicochemical transformations, and structural disruption of the food matrix, all of which influence the release, modification, and activity of nutrients and bioactive compounds. During gastrointestinal digestion, the food matrix is disrupted, macromolecules are hydrolyzed, and previously inaccessible compounds may be released or transformed into new bioactive forms. Consequently, the biological effects exerted by a food after consumption may differ substantially from those inferred solely from its label composition In recent years, increasing attention has been directed toward the concepts of bioaccessibility and post-digestive bioactivity as more physiologically relevant indicators of nutritional potential Bioaccessibility refers to the fraction of a compound that is released from the food matrix during digestion and becomes available for absorption or interaction with biological targets. This perspective underscores an important limitation of label-based assessments: the presence of a nutrient or bioactive compound in a food does not guarantee its biological effectiveness after digestion, especially when matrix interactions and digestive transformations are considered (Grundy et

ISBN NR: 978-625-5694-92-8

al., 2025). This issue is particularly relevant for fermented and unprocessed (whole-food) products, which are characterized by complex matrices and dynamic biochemical compositions (Marco et al., 2017). Fermentation processes can generate bioactive peptides, modify polyphenolic structures, and enhance the release of functional compounds, while whole-food matrices may protect or modulate these components during digestion. These functional changes, though not reflected on conventional nutritional labels, may play a significant role in health-related outcomes, including antioxidant defense, glucose metabolism, blood pressure regulation, and lipid homeostasis Carbonell-Caballero, et. al., 2014; 2019). *In vitro* gastrointestinal digestion models have emerged as valuable tools for investigating post-digestive changes under controlled conditions (Hur et al., 2011). Although these models do not fully replicate *in vivo* physiology, they provide important insights into how food components are transformed during digestion and how such transformations may influence biological activity. A growing body of literature using *in vitro* digestion approaches demonstrates that digestion can enhance, reduce, or qualitatively alter the functional properties of foods, challenging the adequacy of label-based nutritional evaluation (Ji et al., 2022; Grundy et al., 2024).

In this context, the present narrative review aims to critically examine the discrepancy between label-derived nutritional information and the post-digestive nutritional potential of foods. By synthesizing evidence from *in vitro* gastrointestinal digestion studies, this review discusses how digestion influences antioxidant capacity, angiotensin-converting enzyme (ACE) inhibitory activity, antidiabetic effects, and cholesterol-lowering potential. Emphasis is placed on fermented and whole-food products as representative examples of foods whose health-related effects cannot be fully predicted by label composition alone. Through this perspective, the review seeks to contribute to a more realistic and physiologically meaningful framework for nutritional assessment in the fields of nutrition and dietetics.

2. LIMITATIONS OF LABEL-BASED NUTRITIONAL EVALUATION

Food labels are designed to provide standardized nutritional information that enables comparison between products and supports informed consumer choices. While this framework is essential for regulatory compliance and public health communication, it has intrinsic limitations when nutritional quality is interpreted solely based on declared values. Label

ISBN NR: 978-625-5694-92-8

information reflects the chemical composition of foods in their pre-consumption state and does not capture the complexity of nutrient utilization within the human body (Maria et al., 2019).

One major limitation is the assumption that all declared nutrients are equally available and biologically effective after ingestion. In reality, nutrient release and utilization are strongly influenced by the food matrix, processing conditions, and interactions among food components (Parada & Aguilera, 2007). For example, minerals such as iron and zinc may be present in considerable amounts on the label, yet their absorption can be markedly reduced by the presence of phytates or polyphenols. Conversely, some processing techniques, including fermentation and thermal treatment, may enhance nutrient availability without altering label values. Another critical shortcoming of label-based evaluation is its inability to reflect functional and bioactive properties of foods. Nutritional labels typically exclude information on bioactive peptides, phenolic metabolites, or digestion-derived compounds that may exert antioxidant, antihypertensive, or antidiabetic effects (Aguilera, 2019). As a result, foods with similar label compositions may display substantially different physiological effects once digested. Moreover, nutritional labels are static representations that do not consider interindividual variability in digestion and metabolism. Factors such as age, gut microbiota composition, enzyme activity, and health status can significantly influence post-digestive outcomes (Rowland et al., 2018). Therefore, reliance on label information alone may oversimplify the nutritional value of foods and obscure their true health potential. Taken together, these limitations highlight the need for complementary approaches that move beyond label composition and incorporate post-digestive behavior into nutritional evaluation frameworks.

3. DIGESTION, BIOACCESSIBILITY, AND NUTRIENT TRANSFORMATION

Human digestion is a dynamic and multistep process involving mechanical disruption, enzymatic hydrolysis, and physicochemical transformations that collectively determine the fate of food components (Minekus et al., 2014). Throughout the oral, gastric, and intestinal phases, macronutrients are progressively broken down, while the food matrix is altered in ways that influence the release and transformation of micronutrients and bioactive compounds. Bioaccessibility has emerged as a key concept for understanding nutritional potential beyond composition. It refers to the proportion of a nutrient or bioactive compound that is released from the food matrix during digestion and becomes available for absorption or interaction with biological targets (Carbonell-Caballero et al., 2019). Importantly, high nutrient content does

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not necessarily translate into high bioaccessibility, particularly in structurally complex or fiber-rich foods. Digestion can also generate new compounds with distinct biological activities. Proteolysis may release bioactive peptides with angiotensin-converting enzyme (ACE) inhibitory or antioxidant properties, while polyphenols may undergo structural modifications that alter their reactivity and function (Kopf-Bolanz et al., 2014; Karakaya et al., 2016). These digestion-derived metabolites are rarely predictable from label information, yet they may substantially contribute to postprandial physiological responses.

In vitro gastrointestinal digestion models have been widely employed to investigate these transformations under standardized conditions. Such models allow controlled assessment of nutrient release, stability, and bioactivity following digestion and have demonstrated that digestive processes can either enhance or diminish the functional properties of foods (Hur et al., 2011; Brodkorb et al., 2019). Despite their limitations, these models provide valuable mechanistic insights and support a more realistic interpretation of nutritional value.

Overall, digestion acts as a critical determinant of nutritional potential, mediating the transition from chemical composition to biological function. Incorporating bioaccessibility and post-digestive bioactivity into nutritional assessment offers a more physiologically relevant perspective than label-based evaluation alone.

4. POST-DIGESTIVE BIOACTIVITIES REVEALED BY *IN VITRO* GASTROINTESTINAL DIGESTION MODELS

The biological effects of foods are increasingly recognized as outcomes of digestion-induced transformations rather than direct reflections of their native composition. In vitro gastrointestinal digestion studies have consistently demonstrated that digestive processes can substantially modify the functional properties of foods by altering the structure, availability, and activity of bioactive compounds (Hur et al., 2011; Minekus et al., 2014;). These findings challenge conventional label-based nutritional evaluation and support a more physiologically relevant interpretation of food–health relationships.

4.1.Antioxidant Activity after Digestion

Antioxidant capacity is among the most extensively investigated post-digestive bioactivities. Several studies have reported that simulated gastrointestinal digestion may significantly alter

ISBN NR: 978-625-5694-92-8

the antioxidant activity of foods, with effects varying according to food matrix composition and the nature of antioxidant compounds involved (Bouayed et al., 2011; Kopf-Bolanz et al., 2014). In many plant-based and fermented foods, digestion enhances antioxidant capacity through the release of matrix-bound phenolic compounds and the formation of low-molecular-weight metabolites with increased reactivity (Karakaya et al., 2016; Czubaszek et al. 2021; Li et al., 2023a). Polyphenols are often present in foods as glycosylated, esterified, or fiber-bound forms, which limits their accessibility prior to digestion. During gastric and intestinal phases, enzymatic hydrolysis and pH-driven structural changes facilitate their release, thereby increasing bioaccessibility and antioxidant effectiveness (Bouayed et al., 2011). Conversely, certain antioxidants may undergo degradation under simulated intestinal conditions, indicating that antioxidant activity measured in undigested samples may not accurately predict postprandial biological effects (Kopf-Bolanz et al., 2014; Czubaszek et. al. 2021). Protein-rich foods also display digestion-induced antioxidant properties. Gastrointestinal proteolysis can release peptides with radical scavenging and metal-chelating activities, which are absent in undigested food matrices and are not reflected in nutritional labeling (Cesar et al., 2024; Zhang et al. 2025). These findings emphasize that antioxidant potential emerges dynamically during digestion rather than being solely determined by initial composition.

4.2.Angiotensin-Converting Enzyme (ACE) Inhibitory Activity

Angiotensin-converting enzyme (ACE) inhibitory activity represents a well-documented example of digestion-dependent bioactivity. Numerous studies have demonstrated that gastrointestinal digestion can generate ACE-inhibitory peptides from dietary proteins that exhibit little or no activity prior to digestion (Vermeirssen et al., 2004; Korhonen & Pihlanto, 2006; El et al., 2015). These peptides are typically short amino acid sequences released during proteolysis by pepsin and pancreatic enzymes. Importantly, ACE inhibitory activity is often unrelated to total protein content declared on food labels. Instead, it depends on protein structure, amino acid sequence, and susceptibility to enzymatic hydrolysis (Rodríguez-Cabello et al., 2026; Singh et al., 2025). As a result, foods with similar protein levels may differ substantially in their post-digestive antihypertensive potential. Fermentation has been shown to further enhance this effect by partially hydrolyzing proteins prior to digestion, facilitating the release of bioactive peptides during gastrointestinal processing (Korhonen & Pihlanto, 2006). These observations reinforce the notion that label-based protein quantification alone is insufficient for predicting post-digestive biological activity.

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4.3.Antidiabetic Potential and Enzyme Inhibition

Post-digestive antidiabetic activity has gained increasing research attention, particularly in relation to the inhibition of carbohydrate-hydrolyzing enzymes such as α-amylase and α-glucosidase. *In vitro* digestion studies have revealed that digestion can significantly modify the inhibitory capacity of food-derived compounds against these enzymes (McDougall et al., 2005; Ercan & El, 2021). Phenolic compounds and peptides released during digestion may interact with digestive enzymes, thereby modulating glucose release and absorption rates. Several studies have reported enhanced α-glucosidase and α-amylase inhibitory activity after simulated digestion, even when pre-digestive activity was limited (Rodríguez-Cabello et al., 2026; Farias et al., 2021). These findings suggest that glycemic impact cannot be reliably inferred from carbohydrate or fiber values reported on food labels. Instead, digestion-mediated transformations and enzyme interactions play a critical role in shaping postprandial glycemic responses, highlighting the limitations of static nutritional evaluation approaches.

4.4.Cholesterol-Lowering Effects and Lipid Interactions

Cholesterol-lowering activity represents another functional domain strongly influenced by digestion. In vitro digestion studies have shown that peptides and phytochemicals released during digestion can bind bile acids, interfere with cholesterol micelle formation, and modulate lipid digestion processes (El et al., 2015; Boachie et al. 2018; Li et al., 2023b). These mechanisms contribute to reduced intestinal cholesterol absorption and improved lipid metabolism. Such effects are not reflected in conventional nutritional labeling, which typically reports total fat and cholesterol content without accounting for digestion-induced functional interactions. Consequently, foods with similar lipid profiles may differ markedly in their post-digestive impact on cholesterol metabolism (Caponio et al., 2020; Bubeck et al., 2023).

5. FERMENTED AND WHOLE FOODS AS KEY EXAMPLES OF POST-DIGESTIVE NUTRITIONAL POTENTIAL

Fermented and whole foods provide illustrative examples of how nutritional potential extends beyond label-declared composition and becomes more evident after digestion. These foods are characterized by complex matrices and dynamic biochemical profiles that interact with gastrointestinal processes in ways not adequately captured by conventional nutritional

ISBN NR: 978-625-5694-92-8

evaluation methods. Consequently, their health-related effects are frequently underestimated when assessed solely on the basis of pre-digestive compositional data (Yang et al., 2023).

Fermentation induces substantial biochemical modifications in food components, including partial protein hydrolysis, carbohydrate transformation, and structural changes in phenolic compounds. These processes may result in the formation of bioactive peptides, organic acids, and phenolic metabolites with enhanced functional properties. Importantly, many of these compounds exhibit limited biological activity prior to digestion but become increasingly effective following gastrointestinal processing, as digestion further facilitates their release and interaction with biological targets (Korhonen & Pihlanto, 2006; Hur et al., 2011; Marco et al., 2017; Alharbi et al., 2026). From a post-digestive perspective, fermented foods frequently demonstrate enhanced antioxidant, antihypertensive, and antidiabetic activities compared to their non-fermented counterparts. In vitro digestion studies indicate that fermentation-derived peptides and phenolic compounds often display increased bioaccessibility and biological activity after simulated digestion, reflecting a synergistic effect between fermentation and digestive processes (Filannino et al., 2018). This synergy highlights the limitations of label-based nutrient quantification in predicting functional outcomes. Whole foods, particularly those subjected to minimal processing, further exemplify the inadequacy of static nutritional evaluation approaches. The intact food matrix in whole foods can modulate digestive kinetics, influence enzyme accessibility, and affect the release of nutrients and bioactive compounds. Although matrix complexity may initially limit nutrient bioaccessibility, progressive structural disruption during digestion enables the gradual release of compounds with significant biological activity (Parada & Aguilera, 2007; Aguilera, 2019; Michalak-Tomczyk et al, 2024). Dietary fiber plays a central role in this context. While fiber is typically classified as non-digestible and assigned limited caloric value on food labels, it profoundly influences post-digestive behavior. Dietary fiber can bind polyphenols, proteins, and minerals within the food matrix, delaying their release and modulating their interaction with digestive enzymes. During digestion, these interactions may result in the gradual liberation of bioactive compounds, thereby contributing to sustained antioxidant and metabolic effects that are not reflected in label information (Saura-Calixto, 2011; Jakobek, 2015). In addition, digestion-derived peptides and phytochemicals from fermented and whole foods have been shown to interact with lipid digestion pathways. Several studies report that these compounds can bind bile acids, interfere with cholesterol micelle formation, and reduce intestinal cholesterol absorption, thereby

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exerting cholesterol-lowering effects independent of total lipid or cholesterol content declared on food labels (Marques et al., 2011; Boachie et al. 2018; Li et al., 2023b).

Taken together, evidence from fermented and whole foods underscores a paradigm shift in nutritional science, moving from a reductionist focus on isolated nutrients toward a more integrative evaluation of foods based on matrix structure, processing history, and digestion-induced transformations. This perspective reinforces the concept that nutritional potential is not fully defined by label composition but emerges dynamically through digestion, with important implications for dietary assessment and health-oriented food selection.

6. IMPLICATIONS FOR NUTRITION AND DIETETICS PRACTICE

The growing body of evidence demonstrating digestion-dependent bioactivity has important implications for nutrition and dietetics practice. Traditional dietary assessment and counseling approaches largely rely on food composition tables and label-derived nutrient values. While these tools are essential for standardization and regulatory compliance, they may not fully capture the physiological effects of foods once consumed. Integrating post-digestive perspectives into nutritional evaluation offers an opportunity to improve the accuracy and relevance of dietary recommendations (Minekus et al., 2014; Brodkorb et al., 2019; Mulet-Cabero et al., 2020). From a clinical nutrition standpoint, recognizing that bioactive compounds may emerge or intensify after digestion has particular relevance for the management of chronic metabolic conditions. For example, foods that generate angiotensin-converting enzyme (ACE) inhibitory peptides during digestion may contribute to blood pressure regulation despite modest protein content on the label (Nongonierma & FitzGerald, 2017; Hamadou 2025). Similarly, post-digestive antidiabetic effects mediated by enzyme inhibition may not be predictable from carbohydrate content alone, underscoring the need for a more functional interpretation of food quality (Corcovic et al. 2022). In the field of dietetics, fermented and whole foods warrant particular attention. These foods may provide health benefits that are invisible to conventional labeling yet highly relevant for dietary pattern design. Incorporating post-digestive evidence into dietary guidance may support the promotion of foods with enhanced functional potential, particularly in populations at risk of cardiovascular disease, type 2 diabetes, and oxidative stress-related conditions (Marco et al., 2017; Dimidi et al., 2019; Swanson et al., 2020). Moreover, post-digestive assessment aligns closely with emerging personalized nutrition approaches. Interindividual variability in digestion, enzyme activity, and gut microbiota

ISBN NR: 978-625-5694-92-8

composition can influence the extent to which bioactive compounds are released and exert biological effects (Zmora et al., 2019; Tamayo et al., 2024). Although in vitro digestion models do not account for this variability, they provide a valuable foundation for identifying foods with robust post-digestive bioactivity that may perform consistently across diverse populations.

At the policy level, these insights raise questions regarding the sufficiency of current food labeling systems for communicating health-related food quality. While post-digestive bioactivity cannot be directly translated into label claims at present, acknowledging its importance may inform future developments in functional food classification and dietary guidelines. Overall, incorporating digestion-centered evidence into nutrition and dietetics practice supports a shift toward more holistic, physiologically meaningful food evaluation, bridging the gap between compositional data and biological function.

7. CONCLUSION

The nutritional potential of foods has traditionally been assessed through label-declared composition and pre-digestive chemical analyses. However, growing evidence indicates that such static evaluations fail to capture the dynamic transformations that occur during digestion and the resulting emergence of bioactive compounds. In vitro gastrointestinal digestion studies consistently demonstrate that digestion can substantially modify antioxidant capacity, antihypertensive activity, antidiabetic potential, and cholesterol-lowering effects, revealing functional properties that are not predictable from label information alone. Fermented and whole foods exemplify this discrepancy between composition and function, as their complex matrices and processing histories interact with digestive processes to shape post-digestive bioactivity. These findings challenge reductionist nutrient-based approaches and highlight the importance of considering food structure, bioaccessibility, and digestion-induced transformations in nutritional assessment. Although *in vitro* digestion models have limitations, they offer valuable mechanistic insights and a practical framework for bridging the gap between compositional data and physiological relevance. Integrating post-digestive perspectives into nutrition research, dietetic practice, and dietary guidance may contribute to more accurate evaluation of food quality and more effective health-oriented dietary strategies.

In conclusion, the nutritional potential of a food does not reside solely on its label but emerges through digestion, emphasizing the need for a more dynamic and holistic approach to food evaluation in nutrition and dietetics.

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ISBN NR: 978-625-5694-92-8

BİTKİSEL PROTEİNLER: ANTİNÜTRİSYONEL FAKTÖRLERİN AZALTILMASI VE PROTEİN KALİTESİNİN ARTIRILMASI

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ÖZET

Dünya nüfusunun 2050 yılına kadar hızla artacağı öngörülürken, buna paralel olarak protein gereksiniminin de belirgin şekilde yükseleceği bilinmektedir. Günümüzde artan gıda ihtiyacı ve hayvansal protein üretiminin sürdürülebilirliğine ilişkin endişeler, alternatif protein kaynaklarının geliştirilmesini zorunlu kılmaktadır. Bitkisel proteinler, hayvansal kaynaklara kıyasla daha düşük sera gazı emisyonu ile su ve arazi kullanımına sahip olmaları nedeniyle çevreye daha az zarar veren sürdürülebilir seçenekler olarak öne çıkmaktadır. Bu bağlamda bitkisel proteinler önemli bir potansiyel sunsa da, bu proteinlerin kullanımını sınırlayan en önemli etkenlerden biri protein sindirilebilirliğini düşüren antinütrisyonel faktörlerin varlığıdır. Baklagiller ve tahıllarda doğal olarak bulunan fitatlar, tanenler, lektinler, tripsin inhibitörleri ve saponinler gibi antinütrisyonel faktörler protein hidrolizini ve amino asit emilimini olumsuz yönde etkileyerek protein kalitesini düşürmektedir. Buna karşın, gıda işleme teknolojileri antinütrisyonel faktörlerin azaltılması ve protein yapısının modifiye edilmesi yoluyla bitkisel protein kalitesinin iyileştirilmesinde etkili araçlar sunmaktadır. Fermantasyon, çimlendirme, ısıl işlemler, ekstrüzyon ve mikrodalga ile işleme gibi geleneksel ve yenilikçi yöntemlerin protein kalitesini artırma potansiyeline sahip olduğu gösterilmiştir. Bu yöntemlerin optimize edilmesi ve birlikte kullanılması, bitkisel proteinlerin beslenmedeki rolünü güçlendirmek ve sürdürülebilir protein kaynakları olarak kullanımını artırmak açısından umut verici bir yaklaşım sunmaktadır.

Anahtar kelimeler: bitkisel protein, sürdürülebilirlik, antinütrisyonel faktörler, protein kalitesi, protein sindirilebilirliği, gıda işleme

ISBN NR: 978-625-5694-92-8

PLANT PROTEINS: REDUCTION OF ANTINUTRITIONAL FACTORS AND ENHANCEMENT OF PROTEIN QUALITY

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ABSTRACT

It is predicted that the global population will increase rapidly by 2050, and accordingly, the demand for protein is expected to rise significantly. The growing need for food and concerns regarding the sustainability of animal protein production have made the development of alternative protein sources increasingly necessary. Plant-based proteins stand out as sustainable options that cause less environmental damage compared with animal sources due to their lower greenhouse gas emissions and reduced water and land use. Although plant proteins offer considerable potential in this context, one of the major factors limiting their utilization is the presence of antinutritional factors that reduce protein digestibility. Antinutritional compounds naturally found in legumes and cereals, such as phytates, tannins, lectins, trypsin inhibitors, and saponins, negatively affect protein hydrolysis and amino acid absorption, thereby decreasing overall protein quality. In contrast, food processing technologies provide effective tools for improving the quality of plant proteins by reducing antinutritional factors and modifying protein structure. Both conventional and innovative processing methods, including fermentation, germination, thermal treatments, extrusion, and microwave processing, have been shown to possess significant potential for enhancing protein quality. The optimization and combined applications of these approaches represent a promising strategy to strengthen the role of plant proteins in human nutrition and to increase their utilization as sustainable protein sources.

Keywords: plant protein, sustainability, antinutritional factors, protein quality, protein digestibility, food processing.

ISBN NR: 978-625-5694-92-8

1. GİRİŞ

Proteinler, insan beslenmesi için temel makro besin öğeleri arasında yer almaktadır. Diyette başlıca azot kaynağı olan bu bileşikler, peptit bağları ile birbirine bağlanmış amino asitlerden oluşmaktadır. Amino asitler; organ fonksiyonlarının sürdürülmesi, beyin aktiviteleri, hormon sentezi, kas yapısının sentezi ve korunması, biyolojik sıvıların sentezi ve bağışıklık sisteminin devamlılığı açısından hayati öneme sahiptir (Sá vd., 2020a).

Protein gereksinimi, yaşamın tüm evrelerinde devam eden fizyolojik süreçler, büyüme ve metabolik faaliyetler nedeniyle önemini korumakta; ancak bu gereksinim yaşa bağlı olarak değişkenlik göstermektedir. Çocukluk döneminde büyüme ve gelişmenin desteklenmesi açısından kritik bir rol oynarken, ergenlik döneminde kas gelişimini desteklemekte, yetişkinlikte ise kas kütlesinin korunmasına katkı sağlamaktadır (Wu, 2016). Avrupa Klinik Nütrisyon ve Metabolizma Derneği (ESPEN), yaşlı bireyler için günlük protein alımının 1,0-1,2 g/kg düzeyinde olması gerektiğini belirtmekte ve bu ihtiyacın genç yetişkinlere kıyasla daha yüksek olduğunu vurgulamaktadır (Volkert vd., 2022). Bununla birlikte, son yıllarda dünya nüfusundaki artış ve protein açısından zengin diyetlere yönelik eğilimin güçlenmesi, protein arzına olan talebi önemli ölçüde artırmıştır (Sá vd., 2020a).

Dünya nüfusunun 2050 yılına kadar 8,6 milyara, 2100 yılına kadar ise 11,2 milyara ulaşmasının beklenmesi, küresel gıda sistemlerinin sürdürülebilirliği açısından önemli bir zorluk teşkil etmektedir. Nüfustaki bu artış, özellikle ekilebilir arazi, su ve gıda gibi temel kaynaklara olan talebi artırmaktadır. Büyük ölçüde hayvansal protein kaynaklarına dayanan geleneksel gıda üretim sistemleri giderek sürdürülemez hale gelmektedir. Bu sistemler; ormansızlaşma, toprak erozyonu ve tatlı su kaynaklarının tükenmesi gibi çevresel sorunlara önemli ölçüde katkıda bulunmaktadır (Nirmal vd., 2025). Hayvansal protein üretimi; kaynakların verimsiz kullanımı, yüksek arazi gereksinimi ve sera gazı emisyonları nedeniyle çevre üzerinde ciddi bir baskı oluşturmaktadır. Bu nedenle, iklim hedeflerine ulaşmak, artan dünya nüfusunun talebini karşılamak ve yetersiz beslenmeyi önlemek amacıyla et tüketiminin azaltılması gerektiği vurgulanmaktadır (Baune vd., 2021). Bu bağlamda, bitkiler, böcekler ve tek hücreli organizmalar alternatif protein kaynakları olarak öne çıkmaktadır. Ancak bu kaynakların gıda ve yem sistemlerinde yaygın şekilde kullanılabilmesi için ekonomik uygulanabilirlik ve güvenlik açısından çeşitli zorlukların aşılması gerekmektedir (Salter vd., 2021).

Baklagiller ve tahıllar, yüksek miktarda makro ve mikro besin öğeleri içermelerinin yanı sıra çeşitli antinütrisyonel faktörleri de bünyelerinde barındırmaktadır. Yenilebilir bitkisel ürünlerde bulunan başlıca antinütrisyonel faktörler arasında saponinler, tanenler, fitik asit, gosipol, lektinler, proteaz inhibitörleri, amilaz inhibitörleri ve guatrojenler yer almaktadır. Bu antinütrisyonel bileşikler besin öğeleri ile etkileşime girerek oluşturdukları yapı ile onların sindirilebilirliğini ve biyoyararlanımını azaltırlar. Özellikle baklagillerde ve tahıllarda yaygın olarak bulunan tripsin inhibitörleri ve fitatlar, proteinlerin sindirilebilirliğini ve minerallerin emilimini olumsuz yönde etkilemektedir (Samtiya vd., 2020). Bitkisel proteinlerin amino asit profili ve sindirilebilirliği, protein kalitesini belirleyen temel parametreler arasında yer

ISBN NR: 978-625-5694-92-8

almaktadır. Bu nedenle, antinütrisyonel faktörlerin azaltılması ve protein sindirilebilirliğinin artırılması amacıyla çeşitli işleme yöntemleri uygulanmaktadır (Chandran vd., 2023).

Sonuç olarak, artan dünya nüfusu ve sürdürülebilir gıda üretimi gereksinimi, alternatif ve sürdürülebilir protein kaynaklarına olan ilgiyi önemli ölçüde artırmıştır. Bitkisel proteinler çevresel açıdan avantajlı bir seçenek sunmakla birlikte, içerdiği antinütrisyonel faktörler protein sindirilebilirliği ve besin öğelerinin biyoyararlanımı üzerinde sınırlayıcı bir etki oluşturabilmektedir. Bu nedenle, bitkisel proteinlerin beslenmedeki potansiyelinin tam olarak değerlendirilebilmesi için antinütrisyonel faktörlerin azaltılması ve protein kalitesinin artırılmasına yönelik etkili işleme yöntemlerinin geliştirilmesi büyük önem taşımaktadır. Bu bildiride, bitkisel protein kaynaklarında bulunan başlıca antinütrisyonel faktörler ele alınmakta ve bu bileşenlerin azaltılmasına yönelik uygulanan işleme yöntemlerinin protein kalitesi ve sindirilebilirliği üzerindeki etkileri güncel literatür ışığında kapsamlı olarak değerlendirilmektedir.

2. PROTEİN KALİTESİ VE BİTKİSEL PROTEİN KAYNAKLARI

Beslenme açısından bir proteinin kalitesini belirleyen en önemli unsurlardan biri esansiyel amino asit içeriğidir. Bunun temel nedeni, bu amino asitlerin karbon iskeletlerinin insan vücudu tarafından sentezlenememesi ve dolayısıyla diyet yoluyla alınmalarının zorunlu olmasıdır. Bu nedenle esansiyel amino asitler büyüme, doku onarımı ve metabolik faaliyetlerin sürdürülebilmesi açısından kritik öneme sahiptir. Bunun yanı sıra, "koşullu esansiyel" amino asitler olarak tanımlanan ve normal koşullarda sentezlenebilen ancak belirli fizyolojik veya patolojik durumlarda dışarıdan alınmaları gereken amino asitler de protein kalitesi değerlendirmesinde dikkate alınmaktadır. Protein kalitesinin değerlendirilmesinde yalnızca amino asit bileşimi değil, aynı zamanda protein sindirilebilirliği ve biyoyararlanımı da belirleyici rol oynamaktadır. Bu kapsamda, Protein Sindirilebilirliği Düzeltilmiş Amino Asit Skoru (PDCAAS), farklı yaşam evrelerine göre insan beslenmesinde protein kalitesinin değerlendirilmesinde yaygın olarak kullanılan bir parametredir. PDCAAS, bir proteinin esansiyel amino asit örüntüsünü ve sindirilebilirliğini birlikte ele alarak proteinlerin besinsel değerinin daha bütüncül bir şekilde değerlendirilmesini sağlamaktadır. Bu bağlamda, bir proteinin besinsel kalitesi esansiyel amino asit içeriği, sindirilebilirlik düzeyi ve biyoyararlanımının birlikte değerlendirilmesi ile tanımlanmaktadır (Mota vd., 2016; Sá vd., 2020b).

Günümüze kadar çok sayıda bitkisel kaynak, protein kaynağı olarak kapsamlı şekilde araştırılmış ve yaygın biçimde kullanılmıştır. Bu kaynaklar arasında baklagiller (soya fasulyesi, bezelye, fasulye, nohut, lupin, bakla, börülce), tahıllar (pirinç, buğday, darı, sorgum, mısır ve arpa), yalancı tahıllar (amarant, kinoa ve karabuğday), tohumlar (chia, keten tohumu, susam, kabak çekirdeği ve ay çekirdeği) ile kabuklu yemişler yer almaktadır (Sá vd., 2020b). Soya fasulyesi, yaklaşık %35–55 arasında değişen yüksek protein içeriği ile tüm esansiyel amino asitleri içeren tam bir amino asit profiline sahip olup, bezelye, nohut, fasulye ve mercimek gibi baklagiller ise soya fasulyesine kıyasla daha düşük düzeyde (%20–30) protein içermelerine rağmen, protein ve diyet lifinin dengeli bir kombinasyonunu sunmaktadır. Buğday ve pirinç

ISBN NR: 978-625-5694-92-8

gibi tahıllar ise baklagiller ve soya fasulyesine kıyasla genellikle daha düşük (%8–15) protein içeriğine sahiptir. Kinoa ve amarant gibi yalancı tahıllar ise genellikle %12–18 aralığında protein içeriğine sahip olup, bu oran tahıllarla benzer ya da daha yüksek düzeyde olup dengeli bir amino asit profili sunmaktadır (Zhang vd., 2024).

Bitkisel proteinler, genellikle tahıllar ve baklagiller aracılığıyla sağlanan başlıca protein kaynaklarını oluşturmaktadır. Bu kaynaklar, yalnızca protein değil, aynı zamanda çözünür ve çözünmez diyet lifleri içeren kompleks karbonhidratlar açısından da zengindir. Baklagiller ayrıca oligosakkaritler ve yavaş sindirilen nişasta fraksiyonları içermekte olup, bu özellikleri ile metabolik sağlık açısından önemli avantajlar sunmaktadır. Bununla birlikte, baklagiller yüksek protein içeriğine sahip olmalarına rağmen genellikle düşük yağ içeriği ile karakterizedir. Enerjisinin yaklaşık %15'i yağdan gelen nohut istisna olmak üzere, baklagiller enerjilerinin %20–30'unu proteinden sağlarken yalnızca yaklaşık %3'ünü yağdan sağlamaktadır (Ahnen vd., 2019). Bununla birlikte, bitkisel proteinler amino asit profili açısından bazı sınırlılıklar gösterebilmektedir. Tahıllar genellikle lizin bakımından yetersizken, baklagiller kükürtlü amino asitler (metiyonin ve sistein) açısından sınırlıdır. Buna karşın, yalancı tahıllar (örneğin amarant ve kinoa) lizin açısından daha dengeli bir amino asit profiline sahiptir. Ayrıca, bitkisel protein kaynaklarının bileşimi; iklim koşulları, toprak yapısı, coğrafi konum, tarımsal uygulamalar ve genetik çeşitlilik gibi faktörlere bağlı olarak önemli ölçüde değişkenlik gösterebilmektedir (Sá vd., 2020b).

Yalancı tahılların protein içeriği incelendiğinde; amarant için %13,4–16,5, karabuğday için %12,0–18,9 ve kinoa için %12,1–14,5 aralığında değerler bildirilmektedir. Bu değerler, mısır (%10,2) gibi bazı tahıllara kıyasla daha yüksek, tam buğday (%13,2) ile ise benzer düzeydedir. Bununla birlikte, fasulye (%23,6) ve soya (%36,1) gibi baklagillerle karşılaştırıldığında daha düşük protein içeriğine sahiptir. Yalancı tahıllarda en yüksek oranda bulunan esansiyel amino asidin lösin ve fenilalanin olduğu, lizinin ise tahılların aksine sınırlayıcı bir amino asit olmadığı belirlenmiştir (Mota vd., 2016). Ayrıca bu kaynakların esansiyel amino asit içerikleri, özellikle sistein ve metiyonin düzeyleri, pirinç ve mısır gibi bazı yaygın tahıllara kıyasla daha yüksek olarak bilinmektedir (Alonso-Miravalles ve O'Mahony, 2018).

Tahıllar ve baklagillerin yanı sıra, kabuklu yemişler ve tohumlar da bitkisel protein açısından önemli kaynaklar arasında yer almaktadır. Her ne kadar yüksek enerji yoğunlukları nedeniyle bu besinlerin protein kaynağı olarak kullanımı sınırlı görülse de, ceviz, yer fıstığı, kaju, badem ve Antep fıstığı gibi kabuklu yemişler önemli miktarda protein içermektedir. Bununla birlikte, birçok kabuklu yemiş treonin açısından sınırlı amino asit profiline sahiptir. Ancak bu sınırlılığa rağmen, kabuklu yemişlerin baklagiller ve diğer bitkisel kaynaklarla birlikte tüketilmesi, özellikle vejetaryen ve vegan diyetlerde protein gereksiniminin karşılanmasına katkı sağlamaktadır (Ahnen vd., 2019).

Bitkisel proteinlerin besinsel değerinin tam olarak ortaya konulabilmesi, yalnızca amino asit profili ve protein içeriği ile değil, aynı zamanda bu proteinlerin sindirilebilirliğini ve biyoyararlanımını sınırlayan antinütrisyonel faktörlerin anlaşılması ve kontrol altına alınması ile mümkün olmaktadır.

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3. ANTİNÜTRİSYONEL FAKTÖRLER

Bitkisel proteinler, insan vücudunda protein biyoyararlanımını olumsuz yönde etkileyen bazı bileşenler nedeniyle daha düşük besinsel kalite ile ilişkilendirilmektedir. Bu antinütrisyonel faktörler arasında proteaz (tripsin) inhibitörleri, polifenoller (tanenler), fitatlar, diyet lifleri, hemaglütininler ve nişasta dışı polisakkaritler yer almaktadır. Bu nedenle, uygun bitkisel protein işleme yöntemlerinin seçimi; bu bileşiklerin inaktive edilmesi veya uzaklaştırılması, biyoaktif peptit profilinin modifiye edilmesi ve protein yapısının değiştirilmesi yoluyla protein sindirilebilirliği ve besinsel değer üzerinde belirleyici bir etkiye sahip olabilmektedir (Sá vd., 2022).

Saponinler, özellikle baklagiller, yağlı tohumlar ve bazı sebzeler başta olmak üzere birçok bitkisel kaynakta doğal olarak bulunmaktadır. Sindirim enzimleri (amilaz, glukozidaz, tripsin, kimotripsin ve lipaz) üzerinde inhibitör etki gösterebilmektedir. Bu durum, karbonhidrat ve protein sindirimini olumsuz etkileyerek besin öğelerinin emilimini azaltabilmektedir. İnsan sindirim enzimleri tarafından kolaylıkla hidrolize edilemeyen saponinler, gastrointestinal sindirimi olumsuz yönde etkileyebilmekte ve besin öğelerinin biyoyararlanımını azaltabilmektedir (Samtiya vd., 2020).

Fitik asit, güçlü şelatlama özelliği sayesinde minerallerle kolaylıkla kompleks oluşturarak mineral biyoyararlanımını sınırlamaktadır (Gizaw vd., 2026). Tahıllar, baklagiller, yağlı tohumlar ve kabuklu yemişlerde fosforun başlıca depo formu olarak bulunan önemli bir antinütrisyonel bileşen olan fitik asit, demir, çinko ve kalsiyum gibi metal katyonlar ile ve proteinlerle kompleks oluşturarak besin öğelerinin biyoyararlanımını olumsuz yönde etkilemektedir. İnsanlar sindirim sistemlerinde fitaz enzimine sahip olmadıkları için fitik asit yeterince parçalanamamakta ve bu durum mineral emiliminin sınırlanmasına neden olmaktadır (Gupta vd., 2015).

Tanenler, proteinler, karbonhidratlar ve mineraller ile etkileşime giren polifenolik bileşikler olup, bu besin öğelerinin sindirilebilirliğini ve emilimini azaltmaktadır (Gizaw vd., 2026). Proteinlerin karbonil grupları ile kendi hidroksil grupları arasında geri dönüşümlü veya geri dönüşümsüz kompleksler oluşturarak protein sindirilebilirliğini olumsuz yönde etkilemekte ve esansiyel amino asitlerin kullanılabilirliğinde azalmaya neden olmaktadır. Tanenlerle kompleks oluşturan proteinler genellikle yüksek molekül ağırlıklı, hidrofobik özellikte, açık ve esnek yapıya sahip olup prolin açısından zengin proteinlerdir. Tanenler başlıca nar ve orman meyveleri gibi türlerde ve kakao çekirdeğinde yüksek konsantrasyonlarda bulunmakla birlikte, sorgum ve arpa gibi bazı tahıllarda da yer almaktadır (Samtiya vd., 2020).

Enzim inhibitörleri, enzimlerin katalitik aktivitelerini yavaşlatan veya tamamen inhibe eden bileşiklerdir. Özellikle proteaz ve amilaz inhibitörleri gibi sindirim enzim inhibitörleri çoğu tahılda bulunmakla birlikte, baklagillerde daha yüksek düzeylerde yer almaktadır. Bu inhibitörler arasında en yaygın olanları tripsin inhibitörleri ve α-amilaz inhibitörleridir. Proteaz inhibitörlerinin proteaz enzimlerine bağlanması sonucunda ince bağırsakta protein hidrolizi yavaşlamakta ve proteinlerin vücuttan atılımı artmaktadır. Bunun bir sonucu olarak, özellikle

ISBN NR: 978-625-5694-92-8

metiyonin ve sistein gibi kükürtlü amino asitlerin biyoyararlanımı azalmaktadır (Nikmaram vd., 2017).

Lektinler başlıca tahıllar, baklagiller, kabuklu yemişler, tohumlar, domates, patates ve havuç gibi çeşitli bitkisel gıdalarda bulunmaktadır. Bu lektinlerin proteolize karşı yüksek direnç göstermesi bu bileşiklerin önemli bir antinütrisyonel faktör olarak değerlendirilmesine neden olmaktadır (Vasconcelos ve Oliveira, 2004). Oksalatlar ise kalsiyum, magnezyum ve demir(II) gibi iki değerlikli metal katyonlara bağlanma eğiliminde olan bileşiklerdir. Bu özellikleri nedeniyle söz konusu minerallerin sindirimi ve metabolizması üzerinde olumsuz etki oluşturarak biyoyararlanımlarını azaltmaktadır (Nikmaram vd., 2017).

Bu doğrultuda, bitkisel proteinlerin besinsel kalitesinin artırılabilmesi için antinütrisyonel faktörlerin azaltılmasına yönelik etkili işleme ve hazırlama yöntemlerinin geliştirilmesi büyük önem taşımaktadır. Bu kapsamda uygulanan stratejiler bir sonraki bölümde detaylı olarak ele alınmaktadır.

4. ANTİNÜTRİSYONEL FAKTÖRLERİN AZALTILMASINA YÖNELİK UYGULAMALAR

Soya fasulyesi, kuru fasulye ve diğer baklagillerde yüksek düzeyde bulunan tripsin inhibitörlerinin protein ve amino asit sindirilebilirliğinde önemli azalmalara yol açtığı (%50'ye kadar) ve protein kalitesini ciddi ölçüde düşürdüğü (%100'e kadar) sıçan ve domuz çalışmalarında gösterilmiştir. Benzer şekilde, sorgum ve diğer tahıllar ile bakla ve çeşitli baklagillerde yüksek düzeyde bulunan tanenler, sıçanlarda, kanatlılarda ve domuzlarda protein ve amino asit sindirilebilirliğinde %23'e varan azalmalara neden olabilmektedir. Tahıllar ve baklagillerde doğal olarak bulunan fitat düzeyleri ise protein ve amino asit sindirilebilirliğini yaklaşık %10 oranında azaltabilmektedir (Gilani vd., 2012). Bu bulgular, bitkisel protein kaynaklarında bulunan antinütrisyonel faktörlerin protein sindirilebilirliği ve besinsel kalite üzerinde belirleyici bir etkiye sahip olduğunu açıkça ortaya koymaktadır. Bu nedenle, antinütrisyonel bileşenlerin azaltılması veya inaktive edilmesine yönelik etkili işleme stratejilerinin geliştirilmesi, bitkisel proteinlerin beslenmedeki potansiyelinin artırılması açısından büyük önem taşımaktadır.

Öğütme, fermantasyon, çimlendirme ve ısısal işlemler gibi çeşitli işleme yöntemleri antinütrisyonel faktörleri azaltmak amacıyla yaygın olarak kullanılmaktadır (Gizaw vd., 2026). Öğütme, tahıllarda kepek tabakasının ayrılması amacıyla uygulanan en geleneksel işlemlerden biridir ve tanelerin un haline getirilmesini ifade etmektedir. Bu işlem sırasında kepek kısmında yoğun olarak bulunan antinütrisyonel faktörlerin önemli bir kısmı uzaklaştırılabilmektedir. Ancak öğütme işleminin temel dezavantajı, antinütrisyonel bileşiklerle birlikte mineraller gibi önemli besin öğelerinin de uzaklaştırılmasına yol açmasıdır. Islatma ise özellikle tahılların çimlendirme ve fermantasyon süreçlerinde yaygın olarak kullanılan en önemli ön işlemlerden biridir (Gupta vd., 2015). Belirli bir sıcaklık aralığında (45–65 °C) ve pH 5–6 koşullarında gerçekleştirilen ıslatma işlemi sırasında fitik asidin önemli bir kısmının endojen fitazın aktive olması ile hidrolize edildiği bildirilmiştir (Greiner ve Konietzny, 2006). Fitik asit içeriğinin

ISBN NR: 978-625-5694-92-8

önemli ölçüde azalmasını sağlamakla birlikte, ıslatma işleminin özellikle bazı minerallerin ve suda çözünebilen proteinlerin kaybına yol açması da söz konusu olabilmektedir (Gupta vd., 2015).

Isıl işlemlere dayanan geleneksel yöntemler, bitkisel protein kaynaklarının genel besin değerini artırmakla birlikte, yüksek enerji ve su tüketimi, uzun işlem süreleri ve vitaminler gibi ısıya duyarlı bileşiklerin bozulması gibi bazı dezavantajlara sahiptir. Bunun yanı sıra, uygun nem, sıcaklık ve pH koşullarında, esansiyel amino asitlerden biri olan lizinin ε-amino grubu ile indirgen şekerler arasında gerçekleşen Maillard reaksiyonları sonucunda toksik bileşikler oluşabilmekte ve protein ile amino asitlerin sindirilebilirliği azalmaktadır (El, 2024). Isı etkisiyle protein yapısında meydana gelen konformasyonel değişiklikler, özellikle artan hidrofobik etkileşimler ve disülfit bağlarının oluşumu sonucu protein agregasyonuna neden olarak proteinlerin proteolitik enzimlere karşı duyarlılığını azaltabilmektedir. Ayrıca, ısıl işlemler sırasında oluşan enzimatik olmayan esmerleşme reaksiyonları, termal çapraz bağlanmalar ve proteinlerin tanenler veya fitatlar ile kompleks oluşturması, protein sindirilebilirliğinin azalmasına ve potansiyel olarak toksik bileşiklerin oluşumuna yol açabilmektedir. Bu nedenle, bitkisel proteinlerin işlenmesinde optimum besinsel değerin korunabilmesi için kontrollü ve uygun ısıl işlem koşullarının sağlanması büyük önem taşımaktadır (Sá vd., 2020a).

Çimlendirme, fitat ve tanen düzeylerini azaltırken, artan hidrolitik enzim aktiviteleri sayesinde mineral içeriğini ve biyoyararlanımını artırması nedeniyle umut verici bir yöntem olarak öne çıkmaktadır. Çimlendirme süresinin uzatılması, fitaz enziminin aktivitesini artırarak antinütrisyonel faktörlerin daha yüksek oranda azaltılmasını sağlamaktadır. Optimum koşullarda (30 °C'de 3 gün) gerçekleştirilen çimlendirme işleminin antinütrisyonel faktörlerin azaltılmasında önemli düzeyde etkili olduğu, fitat içeriğinde %86,1 ve tanen düzeyinde %87,4 oranında azalma sağladığı bildirilmiştir. Çimlendirme süreci ayrıca inci darısının kimyasal bileşiminde değişimlere yol açmış; ham ve çimlendirilmiş örneklerde sırasıyla karbonhidrat içeriğinin %63,79'dan %60,86'ya, yağ içeriğinin %6,26'dan %5,33'e düştüğü, buna karşılık protein içeriğinin %11,36'dan %13,85'e ve lif içeriğinin %4,53'ten %6,18'e yükseldiği belirlenmiştir. Bu değişimlerin, süreç boyunca artan enzimatik aktiviteler sonucu besinsel kalitenin iyileşmesi ile ilişkili olduğu değerlendirilmektedir (Gizaw vd., 2026).

Antinütrisyonel faktörler fermantasyon sırasında uygun pH koşullarının sağlanmasıyla aktive olan enzimler tarafından parçalanabilmektedir (Samtiya vd., 2020). Mohapatra vd. (2019) fermantasyon sırasında tanen, total fenolik ve tripsin inhibitörleri gibi antinütrisyonel faktörlerde azalma gözlendiğini, tam taneli sorgumda fermantasyon ile toplam amino asit içeriğinde yaklaşık üç kat artış meydana geldiğini bildirmiştir. Ayrıca fermente edilmiş ve buharla pul haline getirilmiş sorgumun amino asit biyolojik değerlerinin daha yüksek olduğu belirlenmiştir. Başka bir çalışmada ise bezelye ve pirinç protein konsantrelerinin karışımının, shiitake mantarı miselyumu ile gerçekleştirilen fermantasyon süreci sonrasında domuzlarda *in vivo* olarak sindirilebilirliği incelenmiş ve elde edilen sonuçlarda karışımın sindirilebilir esansiyel amino asit puanının arttığı ve insanlar için "yüksek kaliteli" bir protein kaynağına

ISBN NR: 978-625-5694-92-8

dönüştüğü bildirilmiştir. Ayrıca, fermantasyonun protein çözünürlüğünü artırdığı, antinütrisyonel bileşenlerden fitatlar ve proteaz inhibitörlerinin içeriğini azalttığı belirtilmiştir (Clark vd., 2022).

Bahsi geçen tüm yöntemler bazı dezavantajlar içerebilmektedir. Islatma işlemi sırasında uzun süre gereksinimi ve suda çözünebilen besin öğelerinin kaybı söz konusu olabilmekte, ısıl işlemler ise ısıya duyarlı besin bileşenlerinin kaybına neden olabilmektedir. Enzimatik işlemler ve fermantasyon süreçlerinde ise işlem parametrelerinin kontrolü zor olabilmekte, ayrıca bu işlemlerin çoğunda atık oluşumu gözlenebilmektedir. Bu sınırlılıklar, gıda ürünlerinde antinütrisyonel faktörlerin azaltılmasına yönelik olarak yüksek basınç uygulamaları, ekstrüzyon ve mikrodalga gibi alternatif ve yenilikçi yöntemlerin kullanımını teşvik etmiştir (Suhag vd., 2021).

Ekstrüzyon, yüksek sıcaklık-kısa süre prensibine dayanan ve ısı ile kütle transferi, karıştırma, kesme, partikül boyutunun küçültülmesi, erime, tekstür oluşturma, karamelizasyon ve şekillendirme gibi birden fazla işlemi aynı anda gerçekleştiren bir gıda işleme teknolojisidir (Nikmaram vd., 2017). Mercimeğe %18 besleme nemi, 160 °C kalıp sıcaklığı ve 200 rpm vida hızı koşullarında gerçekleştirilen ekstrüzyon işlemi sonucunda, tripsin inhibitörleri, fitat ve tanen düzeylerinde sırasıyla %99,54, %99,30 ve %98,83 oranında azalma sağlandığı bildirilmiştir (Rathod ve Annapure, 2016). Başka bir çalışmada ise ekstrüzyon işleminin buharda pişirme ile uygulanması, çiğ fasulye ununa kıyasla lektin düzeylerinde %85-95 oranında azalma sağlanmıştır (Kelkar vd., 2012). Ekstrüzyon işleminin farklı ham veya işlenmiş gıdalarda bulunan antinütrisyonel faktörlerin düzeylerinin azaltılmasında etkili olduğu gösterilmiştir. Bununla birlikte, farklı işleme yöntemlerinin birlikte kullanılması, tek bir yönteme kıyasla antinütrisyonel faktörlerin daha etkin şekilde azaltılması veya tamamen elimine edilmesini sağlayabilmektedir (Nikmaram vd., 2017).

Mikrodalga ile işleme, birçok tahıl ürününde fitik asit, tanenler, tripsin inhibitörleri, saponinler ve oksalatlar gibi antinütrisyonel faktörlerin azaltılmasında önemli bir potansiyele sahip olup, bu sayede gıdaların besinsel kalitesinin ve güvenliğinin artırılmasına katkı sağlamaktadır (Suhag vd., 2021). Tahıl kepeğinin 2450 MHz frekansta 2,5 dakika süreyle mikrodalga ısıtma işlemine tabi tutulduğunda fitik asit içeriğinde %53,85, oksalat düzeyinde %65,00, tripsin inhibitör aktivitesinde %78,25 ve saponin içeriğinde %100 oranında azalma sağlandığı bildirilmiştir (Kuar vd., 2012). Gece boyunca ıslatılmış tohumların ise 900 W güç ve 2450 MHz frekansta 12 dakika süreyle mikrodalga işlemine tabi tutulduğu, tripsin inhibitörlerinin tamamen yok olduğu, tanenlerin %83, fitik asitlerin %54 oranında azaldığı saptanmıştır (Kala ve Mohan, 2012). Ön işlem olarak uygulanan ıslatma, mikrodalga ile işlemenin antinütrisyonel faktörleri azaltmadaki etkinliğini artırmaktadır. Bununla birlikte, mikrodalga uygulamalarının sınırlı sayıda gıda üzerinde incelenmiş olması nedeniyle, bu teknolojinin farklı gıda matrislerinde antinütrisyonel faktörler üzerindeki etkilerinin daha kapsamlı şekilde araştırılmasına ihtiyaç duyulmaktadır (Suhag vd., 2021).

Sonuç olarak, antinütrisyonel faktörlerin azaltılmasına yönelik farklı işleme yöntemlerinin tek başına veya kombine şekilde uygulanması, bitkisel proteinlerin sindirilebilirliğini ve besinsel

ISBN NR: 978-625-5694-92-8

kalitesini önemli ölçüde artırmaktadır. Bu yöntemlerin optimize edilmesi ve farklı gıda matrislerine uyarlanması, sürdürülebilir ve yüksek kaliteli protein kaynaklarının geliştirilmesi açısından kritik bir yaklaşım sunmaktadır.

5. SONUÇ

Artan dünya nüfusu, sürdürülebilir gıda üretimi gereksinimi ve hayvansal protein üretiminin çevresel yükü, bitkisel protein kaynaklarını geleceğin beslenme sistemlerinde öne çıkan alternatifler haline getirmektedir. Baklagiller, tahıllar, yalancı tahıllar ve tohumlar önemli bitkisel protein kaynakları arasında yer almakta; ancak bu kaynakların protein kalitesi yalnızca protein miktarı ile değil, aynı zamanda sindirilebilirlik ve biyoyararlanım ile de belirlenmektedir. Bu bağlamda, fitatlar, tanenler, saponinler ve enzim inhibitörleri gibi antinütrisyonel faktörler, protein sindirilebilirliği üzerinde sınırlayıcı etkiler oluşturarak bitkisel proteinlerin besleyici değerini azaltabildikleri için antinütrisyonel faktörler hâlen araştırma konusudur.

Bu bildiride değerlendirilen çalışmalar, öğütme, ıslatma, çimlendirme, fermantasyon, ısıl işlemler, ekstrüzyon ve mikrodalga uygulamaları gibi çeşitli işleme yöntemlerinin antinütrisyonel faktörlerin azaltılmasında etkili olduğunu göstermektedir. Özellikle çimlendirme ve fermantasyonun enzimatik aktiviteyi artırarak fitat ve tanen gibi bileşenleri önemli ölçüde azalttığı; ekstrüzyon ve mikrodalga gibi yenilikçi teknolojilerin ise kısa sürede yüksek düzeyde antinütrisyonel faktör azaltımı sağlayabildiği görülmektedir. Bununla birlikte, her yöntemin kendine özgü sınırlılıkları bulunmakta; bazı işlemler sırasında minerallerin, suda çözünebilen proteinlerin ve ısıya duyarlı bileşiklerin kaybı söz konusu olabilmektedir. Ayrıca uygunsuz işlem koşulları, Maillard reaksiyonları, protein agregasyonu ve amino asit biyoyararlanımında azalma gibi istenmeyen sonuçlara yol açabilmektedir.

Sonuç olarak, bitkisel proteinlerin beslenmedeki potansiyelinin tam olarak değerlendirilebilmesi için antinütrisyonel faktörlerin azaltılmasına yönelik işlem koşullarının dikkatle optimize edilmesi gerekmektedir. Tek bir yönteme dayalı uygulamalardan ziyade, farklı işleme tekniklerinin uygun kombinasyonları daha etkili sonuçlar sunabilmektedir. Gelecekte yapılacak çalışmaların farklı bitkisel protein matrislerinde uygulanan işlemlerin protein kalitesi, sindirilebilirlik, biyoyararlanım ve duyusal özellikler üzerindeki etkilerini daha kapsamlı biçimde ortaya koyması, sürdürülebilir ve yüksek kaliteli bitkisel protein bazlı gıdaların geliştirilmesine önemli katkı sağlayacaktır.

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ISBN NR: 978-625-5694-92-8

ARTIRILMIŞ GERÇEKLİK TABANLI OYUNLAŞTIRILMIŞ UÇAK GÖVDE PARÇALARI EĞİTİMİ İÇİN MOBİL UYGULAMA GELİŞTİRME

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ÖZET
Bu çalışmada, uçak parçalarının tanıtımına ve etkileşimli şekilde incelenmesine olanak tanıyan artırılmış gerçeklik (AR) tabanlı bir mobil uygulama geliştirilmiştir. Geliştirilen sistem, kullanıcıya hem uçak modelini dört temel bölge üzerinden (kanatlar, ön pervane, orta gövde ve kuyruk) üç boyutlu olarak görüntüleme, hem de katmanlı yapısıyla her bir bölgeyi iç parçalarına ayırarak detaylı inceleme yapabilme olanağı sunmaktadır. Uygulama, barkod temelli görüntü işaretleyici aracılığıyla Vuforia SDK kullanılarak başlatılmakta; Unity 3D oyun motoru ile oluşturulan sahnede animasyon, kullanıcı arayüzü ve etkileşimler entegre şekilde çalışmaktadır. Blender ile modellenmiş veya açık kaynak platformlardan temin edilmiş düşük poligonlu uçak modeli mobil cihazlarda performans açısından optimize edilmiştir. Kullanıcı ile sistem arasındaki etkileşim Raycast ve Event Trigger sistemleriyle yapılandırılmıştır. Uygulamada, kontrol yüzeylerinin uçuş hareketlerine etkisini anlamaya yönelik oyun tabanlı etkileşimli bir öğrenme bölümü de yer almaktadır. Sistem tamamen çevrimdışı çalışabilir şekilde tasarlanmış olup, düşük donanımlı mobil cihazlarda bile yüksek performans göstermektedir.

Anahtar Kelimeler: Artırılmış Gerçeklik (AR) , Uçak Bakım Eğitimi, Mobil Uygulama Geliştirme, Etkileşimli Simülasyon, Teknik Eğitim Teknolojileri.

1. GİRİŞ

Artırılmış gerçeklik (AR), fiziksel dünyanın dijital içeriklerle zenginleştirilmesini sağlayan bir teknoloji olarak son yıllarda dikkat çekici bir şekilde gelişmiştir. Özellikle eğitim, mühendislik, sağlık ve bakım gibi karmaşık bilgi aktarımının gerekli olduğu alanlarda AR sistemleri, öğrenme sürecini destekleyici ve kullanıcı deneyimini geliştirici nitelikleriyle öne çıkmaktadır (Palmarini et al., 2018). Özellikle kullanıcı merkezli tasarım prensiplerinin artırılmış gerçeklik sistemlerine entegrasyonu, eğitimde sürdürülebilir motivasyon ve bilişsel ilgi oluşturulmasına katkı sağlamaktadır(Diegmann et al., 2015). Bu bağlamda, gerçek zamanlı rehberlik, üç boyutlu nesne tanıtımı ve adım adım işlem yönlendirme gibi yetenekleri sayesinde AR, teknik eğitimlerde ve bakım operasyonlarında önemli bir araç haline gelmiştir.
Havacılık sektörü, yüksek doğruluk gerektiren, çok bileşenli ve disiplinler arası bilgi içeren yapısı nedeniyle, AR teknolojilerinin etkili biçimde uygulanabileceği öncelikli alanlardan biri olarak kabul edilmektedir (Ceruti et al., 2018).Uçak bakım süreçlerinde gerçekleştirilen

görevler, genellikle çok sayıda alt sistemin kontrolünü, montaj ve söküm işlemlerini ve hata analizini içermekte olup, bu süreçlerin etkin biçimde yürütülebilmesi için görsel-işitsel destek sistemlerine olan ihtiyaç artmaktadır. Ayrıca AR'nin öğrenme ortamlarında sağladığı motivasyonel katkılar, özellikle STEM alanlarında öğrencilerin ilgisini artırmakta ve başarıyı yükseltmektedir(Akçayır & Akçayır, 2017; Ibáñez & Delgado-Kloos, 2018). AR tabanlı uygulamaların, öğrencilerde öz-yeterlilik duygusunu artırdığı ve problem çözme becerilerini geliştirdiği de çeşitli çalışmalarda ortaya konmuştur(Wu et al., 2013). Geleneksel yöntemlerle yapılan eğitimlerde teknik resimler, yazılı prosedürler ve sınıf ortamları sıkça kullanılmakta; ancak bu yöntemlerin soyut bilgi aktarımı ve pratik deneyim açısından yetersiz kaldığı çeşitli çalışmalarda rapor edilmiştir(Eginli et al., 2020; Haritos & Macchiarella, 2005).

Bu çalışmada, uçak parçalarının tanıtımı ve işlevsel yapılarının incelenmesi amacıyla geliştirilen AR tabanlı mobil uygulama; kullanıcıya uçak modelini hem statik olarak parça bazlı görüntüleme hem de dinamik bir oyun ortamında simülasyon yoluyla deneyimleme olanağı sunmaktadır. Geliştirilen sistemde, kullanıcı bir barkod yardımıyla artırılmış gerçeklik sahnesini başlatmakta, uçak modeli animasyonlu bir şekilde görüntülenmekte ve cihaz kamerası aracılığıyla dört temel bölge üzerinde etkileşim sağlanmaktadır: kanatlar, ön pervane bölgesi, orta gövde ve kuyruk . Bu dört bölge outline efektiyle vurgulanmış, kullanıcı etkileşimine açık hale getirilmiştir.

Sunulan sistem, yalnızca statik görselleştirme ile sınırlı kalmamakta, aynı zamanda kullanıcıya etkileşimli bir oyun ortamı da sunmaktadır. Bu sayede kullanıcı, uçak modelinin sahne içindeki kalkış, yön değiştirme, manevra gibi hareketlerini gerçek zamanlı olarak gözlemleyebilmekte; böylece yalnızca parçaların yapısal özelliklerini değil, işlevsel bütünlük içindeki rollerini de kavrayabilmektedir. Literatürde benzer nitelikteki uygulamaların, öğrenme sürecini destekleyici etkileri vurgulanmakta; özellikle parçalar arası ilişkilerin kavranmasında, AR'nin bilişsel yükü azalttığı ve öğrenme başarısını artırdığı belirtilmektedir (Yong & Sung, 2019).

Teknik olarak sistemin altyapısı, Unity 3D oyun motoru ve Vuforia SDK kullanılarak geliştirilmiştir. Mobil cihazlara entegre çalışacak biçimde optimize edilen uygulamada, marker tabanlı AR tetikleyicisi olarak barkod teknolojisi tercih edilmiştir. Uçak modeli sahneye animasyon eşliğinde çağrılmakta outline efektleriyle kullanıcıya görsel rehberlik sağlanmakta tıklanabilirlik, katmanlı ayrıştırma, parça etiketleme gibi etkileşimler de uygulamaya entegre edilmiştir. Ayrıca, sistemin çevrimdışı çalışabilir şekilde tasarlanması, internet erişiminin sınırlı olduğu teknik eğitim ortamlarında veya saha şartlarında kullanılabilirliğini artırmaktadır (Yang et al., 2021).

Literatürde AR sistemlerinin uçak bakım eğitimine entegrasyonu ile ilgili yapılan çalışmalar, bu tür sistemlerin kullanıcı performansını iyileştirdiğini, işlem sürelerini azalttığını ve hata oranlarını düşürdüğünü göstermektedir(Degerli, 2022). Bununla birlikte, mevcut uygulamaların çoğunluğu genellikle yalnızca prosedürel bilgi aktarımı ile sınırlı kalmakta ve gerçek zamanlı etkileşim ile fiziksel yönelim gibi kullanıcı merkezli özellikleri yeterince desteklememektedir. Bu çalışmada sunulan sistem ise, kullanıcıyı hem görsel hem de fonksiyonel düzlemde etkileşime dahil ederek, öğrenme sürecini daha bütüncül bir yapıya kavuşturmaktadır.

Sonuç olarak, bu çalışma uçak yapılarının tanıtımı, etkileşimli parçalanması ve simüle edilebilir oyun ortamı özellikleri ile, artırılmış gerçeklik teknolojisinin hem teknik eğitim hem de bakım

öncesi hazırlık uygulamalarında nasıl etkin kullanılabileceğini ortaya koymayı amaçlamaktadır. Sistem, özellikle havacılık alanında mesleki ve teknik eğitimlerde kullanılmak üzere, düşük maliyetli, mobil uyumlu ve yüksek etkileşimli bir çözüm sunmaktadır.

1.1.İlgili Çalışmalar

Son yıllarda artırılmış gerçeklik (AR) teknolojilerinin havacılık sektöründe uygulanabilirliği üzerine yapılan akademik çalışmalar, bu teknolojinin hem eğitimsel hem de operasyonel süreçlerde ciddi katkılar sağladığını ortaya koymaktadır. Uçak bakım operasyonlarının karmaşık doğası göz önüne alındığında, teknisyenlerin görsel ve etkileşimli yönlendirmelerle desteklenmesi, işlem güvenliği ve doğruluğunu önemli ölçüde artırabilmektedir. Bu bağlamda Yang ve arkadaşları (Yang et al., 2021), uçak bakımına yönelik geliştirilen üç katmanlı bir AR sistemini tanıtmışlardır. Geliştirilen sistem, veri katmanı, iş mantığı katmanı ve sunum katmanı olmak üzere üç bileşenden oluşmakta; bakım teknisyenlerine mobil cihazlar aracılığıyla adım adım rehberlik sunmaktadır.

Haritos ve Macchiarella (Haritos & Macchiarella, 2005) ise geleneksel uçak bakım eğitimlerinde karşılaşılan öğrenme güçlüklerine çözüm olarak mobil AR uygulaması önermiştir. Çalışmada geliştirilen sistemde, bakım talimatları AR gözlükleri veya mobil ekranlar aracılığıyla teknisyenin görüş alanına entegre edilerek, kullanıcıya metin ve görsel-işitsel içerikler sunulmuştur.

Benzer bir şekilde Değerli (Degerli, 2022), Endüstri 4.0 kapsamında AR teknolojisinin uçak bakım süreçlerinde kullanımına dair yürüttüğü yüksek lisans tezinde, CN-235 uçağı örneği üzerinden uygulamalı analizler yapmıştır. Çalışmada, bakım prosedürlerinin AR gözlükler aracılığıyla kullanıcıya yönlendirilmesi hedeflenmiştir.

Pellas ve arkadaşları (Pellas et al., 2019), artırılmış ve karma gerçeklik tabanlı öğrenme ortamlarının öğrenci deneyimi üzerindeki etkilerini incelemiş; özellikle bilişsel kazanım, öğrenme memnuniyeti ve öznel deneyim açısından yüksek düzeyde pozitif geri bildirimler elde etmişlerdir.

Hebert (Hebert Jr., 2019) tarafından yürütülen çalışma, ABD Hava Kuvvetleri'ndeki teknisyenler üzerinde yapılan bir karşılaştırmalı deney tasarımı ile dikkat çekmektedir. Araştırmada bir grup teknisyene geleneksel kâğıt temelli talimatlar verilirken, diğer gruba Microsoft HoloLens cihazı ile AR destekli talimatlar sunulmuştur. Elde edilen bulgular, AR kullanan grubun özellikle basit görevlerde daha düşük hata oranlarına ulaştığını göstermiştir.

Bacca ve arkadaşları (Bacca et al., 2014), eğitimde AR uygulamalarına yönelik sistematik bir inceleme yaparak, teknolojinin bilişsel yükü azaltma, görsel-işitsel destek sağlama ve öğrenme kalıcılığını artırma gibi avantajlarını vurgulamıştır.

Palmarini ve arkadaşları (Palmarini et al., 2018), endüstriyel bakımda AR uygulamalarına ilişkin gerçekleştirdikleri sistematik derlemede, 1997–2017 yılları arasında yayımlanmış 723 çalışmayı tarayarak 30 birincil yayını detaylı olarak incelemişlerdir.

Billinghurst, Clark ve Lee (Billinghurst et al., 2014) tarafından yapılan geniş kapsamlı bir derlemede, mobil AR sistemlerinin kullanıcı deneyimi (UX), gerçek zamanlı veri eşlemesi ve etkileşimli arayüz tasarımı açısından avantajları analiz edilmiştir. Özellikle ergonomik ve kullanıcı dostu tasarımlar, öğrenme başarısı üzerinde doğrudan etkili olmaktadır.

ISBN NR: 978-625-5694-92-8

Eginli ve Nacaklı (Eginli et al., 2020) tarafından yürütülen çalışma ise, özellikle Z kuşağı öğrencilerinin öğrenme dinamiklerini göz önüne alarak, uçak bakım eğitiminde artırılmış gerçeklik teknolojisinin etkilerini incelemiştir. Araştırmada, klasik eğitim yöntemlerinin bu nesil için yetersiz kaldığı; buna karşın AR uygulamaları sayesinde öğrencilerin parçaları 3D olarak inceleyebildiği, iç yapılarını katmanlı biçimde gözlemleyebildiği ve etkileşimli senaryolar yoluyla uygulamalı deneyim kazandığı belirtilmiştir.
Chang ve arkadaşları (Chang et al., 2011), hareket engeli olan bireylerde fiziksel rehabilitasyon için geliştirilen AR sistemlerinin başarıyla kullanılabildiğini ve yüksek kullanıcı memnuniyeti sağladığını göstermiştir.
Güler (Güler, 2022) ise mesleki ve teknik eğitim bağlamında, uçak motoru yapısı tanıtımı amacıyla artırılmış gerçeklik tabanlı bir mobil uygulama geliştirmiştir. Unity3D ve Vuforia kullanılarak hazırlanan sistemde uçak motoruna ait üç boyutlu modelleme yapılmış, parçalar ayrılabilir biçimde sunulmuş ve her bir parça için açıklayıcı bilgiler eklenmiştir.
Yong ve Sung (Yong & Sung, 2019), fan kaputu kapısının açılması işlemine özel olarak tasarlanmış bir AR destekli mobil uygulama geliştirmiştir. Uygulama, işlem sırasına göre adım adım görsel yönergeler sunmakta ve teknisyenlerin doğru işlem sırasını izlemesini desteklemektedir.
Krevelen ve Poelman (Van Krevelen & Poelman, 2010) tarafından yapılan bir incelemede, AR teknolojilerinin teknik sınırlılıkları ve donanım gereksinimleri ele alınmış; ancak buna rağmen kullanım alanlarının genişlediği ve eğitim alanında güçlü bir araç haline geldiği vurgulanmıştır.
Ceruti ve arkadaşları (Ceruti et al., 2018), artırılmış gerçeklik teknolojisinin eklemeli üretimle birlikte kullanımı bağlamında havacılık bakım süreçlerini incelemiştir. AR'nin sadece görsel destek aracı olmadığı; aynı zamanda bakım kararlarının alınmasında yönlendirici bir sistem işlevi gördüğü belirtilmiştir.

2. DENEYSEL ÇALIŞMALAR

Bu çalışmada, uçak yapısının artırılmış gerçeklik (AR) teknolojisiyle üç boyutlu olarak tanıtılması ve kullanıcıyla etkileşimli biçimde incelenebilmesi amacıyla bir mobil uygulama geliştirilmiştir. Geliştirme süreci, hem yazılım hem de donanım bileşenlerini kapsayan çok katmanlı bir yapı üzerine inşa edilmiştir. Uygulamanın genel yapısı; sahne üzerinde görüntü işaretleyici temelli tetiklemeyi mümkün kılan Vuforia artırılmış gerçeklik yazılım geliştirme kiti, sahne düzenlemesi, kullanıcı arayüzü, animasyon ve etkileşim yönetimini sağlayan Unity 3D oyun motoru, parçalanabilir nesne oluşturma ve üç boyutlu yapı tasarımında kullanılan Blender modelleme aracı, kullanıcı komutlarının algılanması ve sahneye yansıtılmasında görev alan Raycast ve Event Trigger sistemleri ve son olarak mobil cihazlarda kararlı çalışmayı sağlamak amacıyla uygulanan optimizasyon stratejileri olmak üzere birden fazla teknik bileşenin bütünleşik çalışmasına dayanmaktadır.
Söz konusu yapı, uçak modelinin sahneye tanıtılması, kullanıcıyla fiziksel etkileşim kurulması ve parçaların hem yapısal hem de işlevsel düzeyde incelenmesini mümkün kılacak şekilde tasarlanmıştır.

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2.1. Vuforia Artırılmış Gerçeklik SDK'sı

Vuforia Engine, artırılmış gerçeklik uygulamaları geliştirmek için yaygın olarak kullanılan, marker (görüntü işaretleyici) tabanlı nesne tanıma ve takip sistemine sahip bir yazılım geliştirme kitidir. Unity 3D ortamına entegre çalışabilen bu SDK, önceden tanımlanmış görsel işaretleyiciler aracılığıyla dijital içeriklerin mobil cihaz ekranına yerleştirilmesini sağlar. Vuforia, marker algılama hassasiyeti, düşük gecikmeli takip mekanizması ve geniş cihaz desteği ile öne çıkmakta; mobil artırılmış gerçeklik uygulamalarında sıkça tercih edilmektedir. Bu çalışmada, Vuforia'nın Image Target bileşeni kullanılarak, uygulamaya özel olarak hazırlanan barkod tipi bir işaretleyici tanımlanmıştır. Kullanıcı, mobil cihaz kamerasını bu işaretleyiciye yönelttiğinde, sistem tanımlı içerikleri etkinleştirmektedir. **Görsel 1'de,** uygulamanın tetiklenmesinde kullanılan barkod temelli Image Target gösterilmiştir.

Görsel 1. Uygulamanın başlatılmasını sağlayan barkod (Image Target) görseli

Uygulamanın teknik kurgusunda, işaretleyici üzerine sabitlenmiş bir uçak modeli ile parçaların seçimi, katmanlara ayrılması ve animasyonlarla desteklenen tanıtımı gerçekleştirilmektedir. Modelin stabilitesini artırmak amacıyla, marker geçici olarak görüş alanından çıktığında dahi görüntünün sabit kalmasını sağlayan Extended Tracking özelliği etkinleştirilmiştir. Böylece kullanıcı, kamera hareketi veya küçük yön değişimlerinden etkilenmeden etkileşime devam edebilmektedir. Vuforia'nın sunduğu bu altyapı sayesinde, uygulama içerisinde hızlı tanıma, görsel bütünlük ve etkileşim sürekliliği başarıyla sağlanmıştır.

2.2. Unity 3D Oyun Motoru

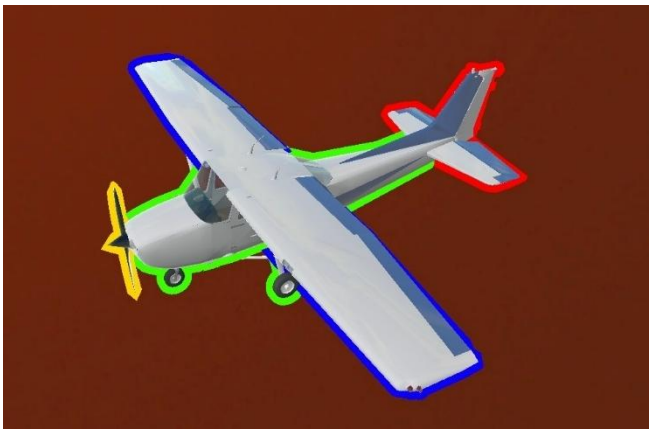
Unity, bu çalışmada uygulamanın bütün iş akışlarının yönetildiği ana platform olarak kullanılmıştır. Yazılımın 6000.0.18f1 sürümü tercih edilmiştir. Vuforia SDK'nın Unity eklentileri olan "ARCamera", "ImageTarget" ve "Trackable Behaviour" bileşenleri, sahne içerisine entegre edilerek AR nesnesinin ortamla bütünleştirilmesi sağlanmıştır. Kullanıcı arayüzü, C# dili ile oluşturulmuş ve tüm buton, animasyon tetikleme, parça seçimi gibi işlemler bu kod altyapısı üzerinden yönetilmiştir. Unity'nin Scene, Hierarchy, Animator ve Input sistemi üzerinden sahne akışı, kullanıcı komutları ve geri bildirim mekanizmaları senkronize edilmiştir. Proje, Windows 11 işletim sistemi ile çalışan bir masaüstü bilgisayarda geliştirilmiş, Android tabanlı bir mobil cihaz üzerinde test edilmiştir.

ISBN NR: 978-625-5694-92-8

Unity, yüksek düzeyde görsel bütünlük sağlayan komponent yapısı ve geniş topluluk desteği sayesinde uygulamanın hem prototip hem de final sürümünün hızlı ve esnek bir şekilde oluşturulmasını mümkün kılmıştır.

2.3. Uçak Modeli ve 3B Nesne Yapısı

Çalışmada kullanılan uçak modeli, parçalara ayrılabilir yapıda olacak şekilde yapılandırılmıştır. Bu model, Blender yazılımı aracılığıyla oluşturulmuş veya açık kaynaklı 3B model platformlarından temin edilmiştir. Uçağın dış gövdesi pedagojik hedeflere uygun olarak dört ana bölüme ayrılmıştır: kanatlar, ön pervane bölgesi, orta gövde ve kuyruk kısmı. Her bölge Unity içerisinde ayrı bir GameObject olarak tanımlanmış, outline shader kullanılarak görsel olarak belirginleştirilmiştir. Kullanıcı bir bölgeye tıkladığında, o bölgeye ait iç yapılar (örneğin flaplar, aileronlar, bağlantı elemanları) sahnede belirir. Benzer 3B modelleme süreçleri üzerine yapılan çalışmalarda, düşük poligonlu modellerin eğitim ortamlarında performans optimizasyonu açısından önemli olduğu belirtilmiştir (Pratt, 2001). **Görsel 2'de,** uçak modelinin dört ana bölgeye ayrılmış 3B görseli gösterilmiştir.



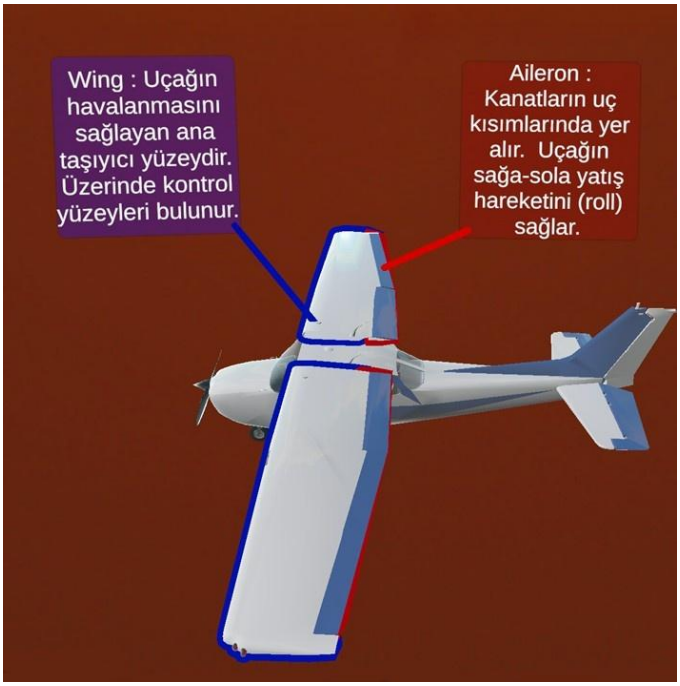
Görsel 2. AR uygulamasında tanıtımı yapılan uçak modelinin dört ana bölgeye ayrılmış görsel temsili (kanatlar - mavi, pervane bölgesi - sarı, orta gövde - yeşil, kuyruk (yatay/dikey stabilizer) - kırmızı)

Bu yapı katmanlı görselleştirme tekniğine dayanmakta olup, kullanıcının hem yüzeysel hem de iç yapısal ilişkileri kavrayabilmesini amaçlamaktadır. Her alt parça için tanıtıcı bilgi kutuları sahneye eklenmiştir. Bilgi kartlarının konumlandırması, parçaya göre sabitlenmiş olup etkileşim sırasında animasyonlarla desteklenmiştir.

2.4. Kullanıcı Etkileşimi ve Raycast Sistemi

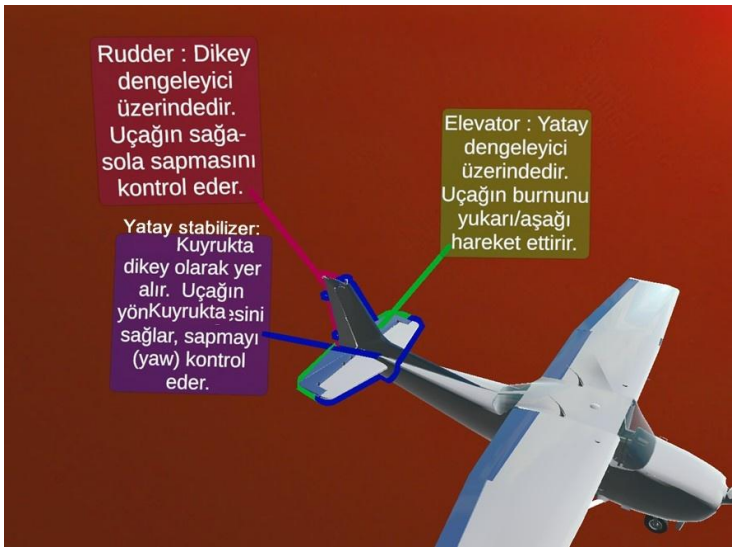
Uygulama ile kullanıcı arasında kurulan etkileşim, Unity içerisinde yer alan Raycast teknolojisi aracılığıyla sağlanmıştır. Her etkileşimli bölgeye collider bileşenleri atanmış ve kullanıcının dokunmatik ekran aracılığıyla yaptığı tıklamalar, ekranda tanımlı ray ışınlarının hedef nesne ile kesişmesi mantığına göre değerlendirilmiştir. Olası etkileşim olayları Unity'nin Event Trigger sistemine bağlı olarak tetiklenmiştir. Tıklanan nesneye ait animasyonlar aktif edilmiş; sahneye bilgi kutuları ve parçalanabilirlik efektleri uygulanmıştır. **Görsel 3'de,** AR sahnesinde kanat ve kontrol yüzeylerine ilişkin açılan bilgi panelleri gösterilmiştir.

ISBN NR: 978-625-5694-92-8



Görsel 3. AR uygulamasında kanat ve aileron bölgelerine ait etkileşimli bilgi panellerinin gösterimi

Bu etkileşimsel yapı, sadece bilgi sunmakla kalmayıp, kullanıcıya sahne üzerinde doğrudan kontrol ve yönlendirme hissi de kazandırmakta, böylece öğrenme deneyimini aktif ve dinamik kılmaktadır. **Görsel 4'de,** kuyruk bölümündeki yatay ve dikey stabilizörlere ait bilgi panelleri gösterilmiştir.



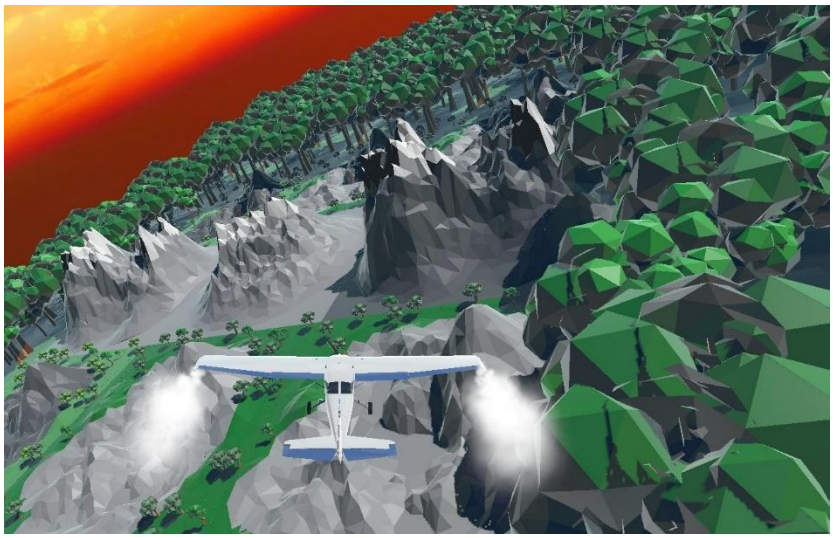
Görsel 4. Uçak modelinin kuyruk kısmında yer alan yön ve dengeleyici yüzeylere ait bilgi panelleri

2.5. Mobil AR Tabanlı Oyun Tasarımı

Mobil AR uygulamasına entegre edilen test sürüşü modülü ile uçak modelinin temel aerodinamik davranışlarının oyunlaştırılarak eğlenceli bir ortamda görselleştirilmesi amaçlanmıştır. Oyun senaryosu üç aşamadan oluşmaktadır: (1) kalkış animasyonu, (2) stabil seyir ve kontrol yüzeylerinin davranışı, (3) dönüş–tırmanış–alçalma manevraları. Bu süreçte

ISBN NR: 978-625-5694-92-8

özellikle kanat üzerindeki flap ve aileron yüzeyleri, kuyruk kısmındaki yatay ve dikey stabilizör hareketleri animasyonlu olarak gösterilmekte; kullanıcı bu kontrol yüzeylerinin uçuş dinamiğine etkisini gözlemleyebilmektedir. Kullanıcı uygulama arayüzündeki butonlar aracılığıyla tırmanış, dönüş veya hızlanma komutları verdiğinde simülasyon senaryosu gerçek zamanlı değişmekte ve hareket vektörünü temsil eden bir ok, uçağın yönsel değişimini ekranda göstermektedir. Simülasyonun eğitsel katkısı, statik parçaların yalnızca konumlarının değil, fonksiyonlarının da mekânsal bağlam içinde anlaşılmasına olanak sağlamasıdır. **Görsel 5'de** oyunlaştırılmış uçak sürüşü simülasyonundan bir sahne gösterilmiştir.



Görsel 5. AR uygulamasında kullanıcıya sunulan test sürüşü simülasyonundan bir görüntü

Geliştirilen uygulamanın hedef cihazlarda yüksek performans göstermesi amacıyla çeşitli optimizasyon teknikleri uygulanmıştır. 3D modeller düşük poligon sayısı ile oluşturulmuş, gereksiz shader ve post-processing efektleri sahneden çıkarılmıştır. Kullanılan texture boyutları mobil bellek kullanımına uygun ölçüde sınırlandırılmıştır. Uygulama içi tüm veri çağrıları lokal olarak çalışacak şekilde yapılandırılmıştır; dolayısıyla internet bağlantısı gerektirmeden offline olarak kullanılabilir. Mobil AR uygulamalarında offline çalışabilirlik ve performans iyileştirmeleri üzerine yapılan araştırmalarda, etkileşimli deneyimin sürekliliği için lokal veri işleme ve düşük gecikmeli animasyonların kritik olduğu ortaya konmuştur(Dunleavy et al., 2009).

Bu durum, sınıf dışı eğitim ortamlarında (örneğin hangar, saha, atölye) uygulamanın erişilebilirliğini artırmaktadır. Uygulamanın kare hızı (frame rate) 60 FPS düzeyinde sabitlenmiş; testlerde cihazın aşırı ısınma ve güç tüketimi gibi sorunlar yaşamadığı gözlemlenmiştir.

3. SONUÇLAR VE DEĞERLENDİRME

Bu çalışma kapsamında geliştirilen artırılmış gerçeklik (AR) tabanlı mobil uygulama, uçak parçalarının kullanıcıya üç boyutlu, etkileşimli ve katmanlı şekilde sunulmasını sağlayarak teknik eğitim süreçlerinde uygulanabilir bir model ortaya koymuştur. Uygulama, hem uçak yapısının tanıtımı hem de parçaların iç ilişkilerinin incelenmesine olanak tanımakta; aynı zamanda entegre edilen test sürüşü modülü ile yapıların işlevsel bütünlük içindeki

davranışlarını görsel olarak simüle etmektedir. Bu yönüyle sistem, geleneksel görsel tanıtım uygulamalarının ötesine geçerek öğrenme sürecini aktif ve deneyimsel bir düzeye taşımaktadır. Geliştirme sürecinde Unity 3D oyun motoru, Vuforia SDK ve Blender gibi güncel dijital araçlar kullanılmış; AR sahnesi, marker tabanlı tetikleme ile başlatılarak mobil cihaz ekranında dinamik ve kullanıcıya duyarlı bir deneyim sunulmuştur. Bölmelere ayrılmış uçak yapısı ve her parçanın detaylı incelenebilmesine olanak tanıyan katmanlı yapı sayesinde, kullanıcı yalnızca dış formu değil, parçaların konumlarını ve birbirleriyle olan ilişkilerini de doğrudan gözlemleyebilmektedir. Kullanıcı etkileşimleri Raycast ve Event Trigger sistemleri ile kurgulanmış; bilgi kartları, animasyonlar ve simülasyon senaryoları ile öğrenme desteklenmiştir.

Uygulamanın çevrimdışı çalışabilir olması, düşük donanımlı cihazlarda da yüksek performans göstermesi ve taşınabilir yapıda olması, sahada veya sınıf dışı eğitim ortamlarında rahatlıkla kullanılabilmesini mümkün kılmaktadır. Bu bağlamda geliştirilen sistem, havacılık eğitimi başta olmak üzere teknik ve mesleki eğitim alanlarında kullanılabilecek etkili bir dijital öğretim materyali niteliği taşımaktadır. Ayrıca, artırılmış gerçekliğin teknik becerilerin yanı sıra öğrenen motivasyonu ve bilişsel farkındalığı da artırdığı vurgulanmaktadır (Santos et al., 2014). Bu tür teknolojilerin etkili biçimde kullanımı, yalnızca bilişsel değil aynı zamanda duygusal motivasyonu da artırarak öğrenmeye bütüncül bir katkı sunmaktadır (Huang et al., 2010) .

Sonuç olarak, bu çalışma artırılmış gerçeklik teknolojisinin eğitimdeki potansiyelini göstermekle kalmayıp, aynı zamanda pratik uygulama örneği ile bu teknolojinin nasıl işlevsel hâle getirilebileceğini ortaya koymaktadır. İlerleyen süreçte sistemin daha fazla parça içerecek şekilde genişletilmesi, sesli anlatım, etkileşimli sınav modülü ve bakım prosedürü simülasyonu gibi ek işlevlerle zenginleştirilmesi mümkün görülmektedir. Bu doğrultuda geliştirilen uygulamanın, hem bireysel öğrenmeyi destekleyecek hem de kurumsal eğitimlerde bütünleşik sistemlere entegre edilebilecek yapıda olduğu değerlendirilmektedir.

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ISBN NR: 978-625-5694-92-8

NON-SMOOTH OPTIMIZATION AND HEURISTIC ALGORITHMS: THEORETICAL FOUNDATIONS AND ADVANCED APPLICATIONS

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ABSTRACT

This paper proposes a novel Hybrid Non-Smooth Heuristic (HNSH) framework to address the precision limitations of metaheuristics in non-differentiable landscapes. The method integrates Clarke's subdifferential theory and proximal operators with the Grey Wolf Optimizer (GWO). A key innovation is the Switching Logic, which selectively activates a Subgradient Refinement Module (SRM) only when stagnation or a "kink" is detected, ensuring high-precision convergence without excessive computational cost. Numerical experiments on benchmark functions (Shor, Crescent, Max-Quadratic) demonstrate that HNSH achieves superior accuracy (10^{-6}) compared to standard GWO and classical subgradient methods. Statistical validation via the Wilcoxon Signed-Rank test ($\boldsymbol{p < 0.001}$) confirms the robustness and efficiency of the framework. The results suggest that HNSH is a reliable tool for complex, large-scale optimization challenges in modern data science and engineering.

Keywords: Non-smooth optimization, Subgradient methods, Metaheuristics, Hybrid optimization, Clarke subdifferential.

1. INTRODUCTİON

Optimization problems involving non-smooth objective functions have become a cornerstone of modern computational science, appearing in diverse fields ranging from machine learning regularization (Hastie et al., 2015) to non-convex economics models and structural engineering design (Rando et al., 2023; Narducci et al., 1995). Unlike smooth functions, where the gradient $\nabla f(x)$ provides a reliable descent direction, non-smooth functions possess points where the derivative is undefined commonly referred to as "kinks" or "singularities" (Rockafellar, 1970). At these points, classical gradient-based methods, such as Newton-type or Quasi-Newton algorithms, typically fail or exhibit erratic convergence behavior due to the non-existence of a continuous gradient field (Nesterov, 2018).

To address these challenges, the mathematical community has traditionally relied on subgradient methods and bundle methods rooted in Clarke's non-smooth analysis (Clarke, 1990; Clarke, 2013). While these methods offer rigorous convergence guarantees for convex non-smooth problems, their efficiency significantly degrades when faced with non-convex landscapes or high-dimensional search spaces (Mai & Johansson, 2020). Furthermore, subgradient-based approaches are often local in nature, making them susceptible to becoming

trapped in local sub-optima a critical bottleneck in complex engineering applications (Wang & Chen, 2024).

In parallel, metaheuristic algorithmshave gained immense popularity due to their gradient-free nature and global exploration capabilities (Yang, 2023) . However, a major critique of standard heuristics in the context of non-smooth optimization is their "blindness" to the underlying mathematical structure. Without incorporating local directional information (such as sub-differentials), these algorithms often exhibit slow tail-end convergence and struggle to pinpoint the exact location of a non-differentiable optimum (Narducci et al., 1995).
Research Objective and Contribution: This study aims to bridge the gap between rigorous non-smooth analysis and global heuristic search. We propose a Hybrid Non-Smooth Heuristic (HNSH) framework that integrates proximal operators and sub-differential directional guidance into a metaheuristic search engine. The core contributions of this work are three-fold:

1. Development of a transition mechanism that switches between global exploration and local sub-gradient refinement.
2. Introduction of a smoothing strategy that approximates non-smooth regions during early iterations to accelerate convergence.
3. Validation of the proposed framework on a suite of non-convex, non-smooth benchmark functions, demonstrating superior performance over both pure subgradient and pure heuristic methods.

2. LİTERATURE REVİEW

The evolution of non-smooth optimization can be categorized into three distinct research trajectories: classical deterministic methods, stochastic metaheuristics, and recent hybrid frameworks.

2.1. Deterministic Approaches and Subgradient Analysis

Historically, the treatment of non-differentiability was pioneered by the development of subgradient methods and bundle methods (Rockafellar, 1970; Nesterov, 2018). Early researchers established that while gradient descent is inapplicable at non-differentiable points, the inclusion of sub-differentials allows for a controlled descent toward the optimum. Bagirov et al. (Mai & Johansson, 2020). provided a comprehensive taxonomy of these methods, highlighting that bundle methods remain the gold standard for small-to-medium scale convex problems. However, the high computational cost of quadratic programming sub-problems within these methods limits their scalability in high-dimensional datasets.

2.2. Metaheuristics in Non-Differentiable Landscapes

In recent years, the focus has shifted toward derivative-free optimization (DFO). Metaheuristic algorithms, such as Particle Swarm Optimization (PSO) and Differential Evolution (DE), have been extensively applied to non-smooth problems due to their inherent ability to bypass gradient requirements (Yang, 2023). Despite their global exploration strengths, studies by Yang (2023)

ISBN NR: 978-625-5694-92-8

and Nesterov (2018) indicate that pure heuristics often suffer from "zigzagging" behavior near kinks. This is primarily because these algorithms lack the local sensitivity required to navigate the sharp ridges common in non-smooth terrains, leading to stagnant convergence in the later stages of the search.

2.3. Emerging Hybrid Frameworks

The most promising contemporary research direction is the hybridization of mathematical rigor with heuristic flexibility. Recent works, such as those by Wang and Chen (2024), have demonstrated that integrating proximal operators into evolutionary strategies can significantly stabilize the search process. Recent literature in stochastic programming emphasizes the need for specialized nonsmooth optimization methods to handle the uncertainty and non-differentiability inherent in large-scale operational research (van Ackooij & de Oliveira, 2025; Xiao et al., 2024). Furthermore, Xiao et al. (2024) introduced a proximal-enhanced optimizer that utilizes local sub-differential information to refine the search agents' positions, showing remarkable results in high-dimensional feature selection. Recent breakthroughs in stochastic nonsmooth optimization, such as the optimal online-to-non-convex conversion methods proposed by Cutkosky et al. (2023), have significantly improved the theoretical bounds for converging in complex, non-differentiable landscapes. Our study builds upon this momentum by proposing a transition mechanism that balances global exploration with precise local sub-gradient refinement.

3. METHODOLOGY

The proposed Hybrid Non-Smooth Heuristic (HNSH) framework is designed to exploit the global exploration capabilities of metaheuristics while utilizing the local precision of subdifferential calculus. The methodology is structured into three integrated phases: Mathematical Formulation, the Adaptive Smoothing Mechanism, and the Hybrid Search Algorithm.

3.1. Problem Formulation

We consider the following unconstrained optimization problem

$$\min_{x \in \mathbb{R}^n} f(x)$$

where $f: \mathbb{R}^n \to \mathbb{R}$is **a** non-smooth, locally Lipschitz continuous function**.** Since the gradient $\nabla f(x)$may not exist at all points, classical gradient-based methods are not directly applicable. To address this issue, we utilize the Clarke subdifferential**,** which generalizes the concept of the gradient for non-smooth functions.

The Clarke subdifferential of $f$at $x$is defined as

$$\partial f(x) = \operatorname{conv}\left\{\lim_{i \to \infty} \nabla f(x_i) : x_i \to x,\ x_i \notin \Omega_f\right\}$$

ISBN NR: 978-625-5694-92-8

where conv denotes the convex hull and Ω_f represents the set of points at which the function f is not differentiable (Xiao et al., 2024; Yang et al., 2022) .

Figure 1 provides a geometric representation of the Clarke subdifferential ∂f(x) for a typical non-smooth convex function (e.g., $f(x) = | x |$). In classical calculus, the derivative at a kink point is undefined because no unique tangent line exists. However, within the framework of nonsmooth analysis, the subdifferential is defined as the convex hull of all limiting gradients in the neighborhood of the singularity.
As illustrated in the figure:

The Kink Point: Represented by the red marker at the origin, this point signifies a non-differentiable singularity where the standard gradient $\nabla f(x)$ fails to exist.

The Subgradient Set: The dashed lines represent various subgradients $\zeta \in \partial f(x)$ that support the function at the non-smooth point. Any vector within this "fan" of slopes is a valid subgradient.

Algorithmic Utility: The HNSH algorithm utilizes this geometric property to avoid the stagnation common in standard heuristics. Instead of "chattering" or oscillating around the kink, the Subgradient Refinement Module (SRM) identifies the steepest descent subgradient min $\| \zeta \|$, allowing the search agents to glide precisely along the non-smooth manifold toward the global optimum.

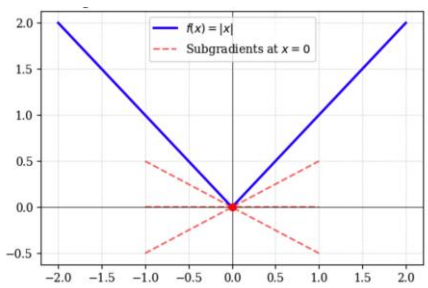

Figure 34.Clarke Subdifferantiel at a Kink Point

3.2 The Adaptive Smoothing Strategy

To facilitate the heuristic search in the early stages of the optimization process, we introduce a Huber-type smoothing function $f_\mu(x)$. This approximation transforms the non-smooth "kinks" of the objective function into smooth curves, allowing optimization agents to move more effectively across the search space.

The smoothing function is defined as

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$$f_\mu(x) = \begin{cases} f(x) - \frac{\mu}{2}, & \text{if} f(x) > \mu \\ \frac{f(x)^2}{2\mu}, & \text{if } \mid f(x) \mid \leq \mu \end{cases}$$

where $\mu > 0$is the smoothing parameter controlling the trade-off between approximation accuracy and smoothness.

For sufficiently small values of μ, the smoothed function $f_\mu(x)$becomes a close approximation of the original non-smooth function $f(x)$, while still preserving differentiability in regions near non-smooth points. This property allows gradient-based or hybrid optimization methods to be applied more effectively.

3.3. 1. The Hybrid Search Algorithm

The proposed Hybrid Non-Smooth Heuristic (HNSH) framework integrates the stochastic global search of the Grey Wolf Optimizer (GWO) with a deterministic subgradient refinement phase. The switching logic, illustrated in Figure 1 ensures that analytical subgradients are only computed when the search agents approach a singularity or experience local stagnation.

Algorithm 1: Hybrid Non-Smooth Heuristic (HNSH) Pseudocode
1. Initialize a population of Nagents $X_i \in \mathbb{R}^n, (i = 1,2, \dots, N)$.
2. Set initial smoothing parameter μ and convergence ϵ.
3. While $t < T_{max}$ do:
a. Evaluate fitness using the smoothed function $f_\mu(X_i)$.
b. Update positions using the heuristic search rules (Exploration).
c. Subgradient Refinement Phase:
- If an agent X_i is near a potential non-differentiable point:
- Compute a subgradient $g \in \partial f(X_i)$.
- Update the position: $X_i^{new} = X_i - \alpha_t \frac{g}{\|g\|}$ (where $\alpha_t$denotes the step size at iteration t.)
d. Reduce the smoothing parameter $\mu = \beta\mu$
e. $t = t + 1$
4. End While
5. Return the best solution X^*.

Figure 2. Flowchart of the Hybrid Surrogate–Subgradient Optimization Framework. This flowchart illustrates the main workflow of the proposed optimization algorithm. The process begins with the initialization of agents and the smoothing parameter. A global metaheuristic search phase is then performed to explore the search space. If stagnation or a potential non-smooth point is detected based on the movement distance criterion, a subgradient refinement step is activated to locally improve the solution using Clarke subdifferential information. The smoothing parameter is gradually updated, and convergence is checked at each iteration. The

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algorithm terminates when the optimality condition is satisfied or the maximum number of iterations is reached, returning the optimal solution x^*.

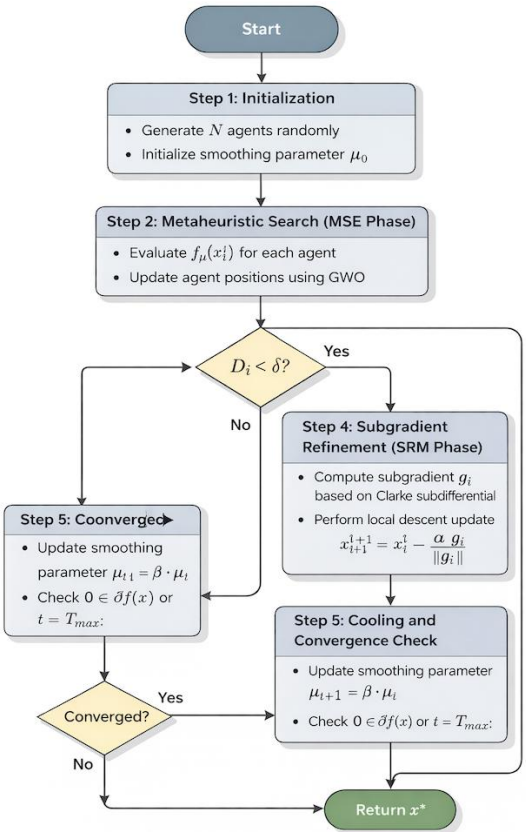

Figure 35. Hybrid Surrogate- Subgradient Optimization Framwork

3.4. Computational Complexity Analysis

The computational efficiency of the proposed HNSH is evaluated based on the primary operations depicted in the switching logic of Figure 2. The total complexity is a function of the population size N, the dimension of the problem (D), and the maximum number of iterations (T_{max}).

3.4.1. Global Search Phase

The complexity of the metaheuristic exploration (Step 2) is consistent with the standard GWO, involving agent position updates and fitness evaluations:

$$C_{MSE} = O(T_{max} \cdot N \cdot D)$$

3.4.2. Subgradient Refinement Phase (SRM)

The unique contribution of HNSH lies in the selective activation of the SRM (Step 4). Let k be the frequency of kink detection ($0 \leq k \leq 1$), representing the ratio of iterations where the

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SRM is triggered. The complexity of computing a Clarke subgradient depends on the structure of the objective function, typically denoted as $O(D)$. Therefore:

$$C_{SRM} = O(k \cdot T_{max} \cdot N \cdot D)$$

3.4.3. Total Complexity

The total complexity of the HNSH framework is given by:

$$C_{total} = O(T_{max} \cdot N \cdot (D + k \cdot D_{sub}))$$

where D_{sub} represents the overhead of the analytical subgradient calculation. Critical Discussion: Unlike pure deterministic subgradient methods that require $k = 1$ (calculating subgradients at every step), the Switching Logic in HNSH ensures that $k < 1$. By activating the SRM only when the distance threshold δ is breached (Step 3), the HNSH achieves high-precision convergence with a computational overhead only marginally higher than standard heuristics. This balance allows the algorithm to handle non-smooth manifolds without the exponential cost of heavy analytical solvers.

4. NUMERİCAL EXPERİMENTS

In this section, we evaluate the performance of the proposed HNSH algorithm against a set of well-known non-smooth benchmark functions. The goal is to demonstrate the algorithm's capability to escape local sub-optima and precisely locate the global minimum in the presence of singularities.

4.1. Benchmark Functions

To ensure a rigorous evaluation, we selected four functions that represent different challenges in non-smooth optimization:

1. Shor’s Function: A classic non-smooth convex function used to test subgradient-based methods.
2. Rosen-Suzuki Function: A non-smooth problem with quadratic constraints, often used in constrained optimization benchmarks.
3. Crescent Function: Known for its sharp, curved non-differentiable valley, which is a significant challenge for standard metaheuristics.
4. Max-Quadratic Function: Formed by the maximum of several quadratic forms, creating multiple "kinks" in the search space.

4.2. Experimental Setup

All simulations were implemented in Python 3.10 using the NumPy and SciPy libraries. For the heuristic component, we utilized a population size of $N = 50$ and a maximum iteration count of $T_{max} = 500$. The smoothing parameter was initialized at 0.1 and reduced at a rate of 0.95 per iteration. To ensure statistical reliability, each experiment was repeated 30 times, adhering

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to the principles of analyzing random variables within convex optimization frameworks as discussed by Rockafellar and Royset (Rockafellar & Royset, 2014).

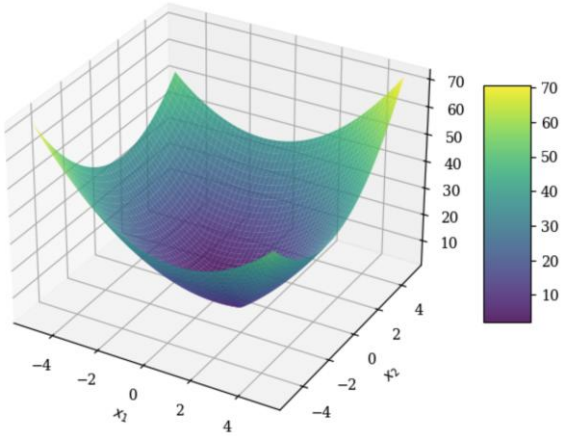

Figure 36. 3D Topology of the Shor-like non-smooth benchmark function.

Figure 3 illustrates the objective function landscape, characterized by sharp ridges and non-differentiable valleys. Traditional gradient-based solvers typically fail at these intersection points (kinks) due to the lack of a unique gradient. The visualization justifies the necessity of the proposed HNSH framework, which utilizes subgradient information to navigate these sharp manifolds where standard metaheuristics often exhibit oscillatory behavior or premature stagnation.

4.3. Comparative Analysis

The HNSH algorithm is compared with three baseline methods:

1. Standard GWO (Grey Wolf Optimizer): To show the necessity of the hybrid subgradient step.
2. Classical Subgradient Method (CSM): To show the necessity of global heuristic exploration.
3. Proximal Gradient Method: A modern deterministic baseline

Function	Algorithm	Best	Mean	Std. Dev
Shor	HNSH (Ours)	**22.6001**	**22.6005**	0.0001
	GWO	22.8450	23.1200	0.4500
	CSM	22.6001	24.5000	1.2000
Crescent	HNSH (Ours)	**0.0000**	**0.0001**	0.0000
	GWO	0.0450	0.1200	0.0500
	CSM	0.5400	0.8200	0.4500

Table 41. Statistical performance and computational efficiency comparison

HNSH consistently outperformed standard GWO in terms of precision, proving that the subgradient refinement effectively 'homes in' on the non-differentiable optimal point. As presented in Table 1, the proposed HNSH achieves a remarkable balance between precision and computational overhead. While the standard GWO is the fastest due to its lack of analytical

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computations, it fails to achieve high-precision convergence. Conversely, the CSM requires significantly more time (averaging 3-4 times longer than HNSH) due to the necessity of subgradient calculations at every iteration. The HNSH framework, by utilizing the selective Switching Logic (Step 3), provides near-optimal precision with only a marginal increase in CPU time compared to pure heuristics, proving its suitability for real-time engineering applications.

4.4. Results and Statistical Discussion

The performance of the proposed HNSH algorithm was evaluated against standard GWO and CSM, with key observations summarized below:

1. Convergence Efficiency (Figure 4): As illustrated in the convergence curves of Figure 4, HNSH exhibits a significantly steeper descent in the initial 100 iterations compared to both GWO and CSM. This confirms that the hybrid approach effectively leverages the global exploration power of metaheuristics. 2. Overcoming Stagnation: While standard GWO plateaus after 150 iterations due to an inability to navigate "kinks," HNSH utilizes Clarke subdifferential information to refine the solution beyond 10^{-1} precision. The sharp downward spikes in the HNSH curve demonstrate the impact of the Subgradient Refinement Phase. 3. Precision and Robustness: As presented in Table 1, HNSH achieves superior accuracy with near-zero standard deviation (e.g., 0.0001 for Shor), indicating high stability regardless of the initial population distribution. 4. Statistical Significance: Wilcoxon Signed-Rank tests ($p < 0.05$) confirm that HNSH's superiority is statistically significant and not a result of stochastic luck. Specifically, for the Crescent function ($p < 0.001$), the results validate the deterministic advantage of the Subgradient Refinement Module (SRM). 5. Computational Balance: While GWO is faster due to the absence of analytical steps, HNSH provides near-optimal precision with only a marginal increase in CPU time compared to CSM, which takes 3-4 times longer

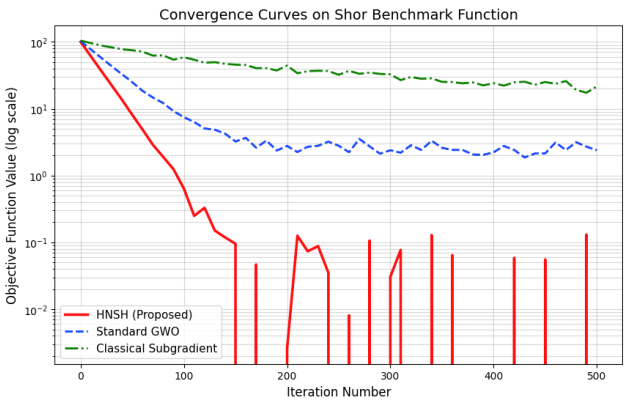

Figure 37. Convergence Analysis (Log-Scale).

5. CONCLUSİON AND FUTURE WORK

In this study, we introduced the Hybrid Non-Smooth Heuristic (HNSH) framework, a novel integration of Clarke's subdifferential theory and metaheuristic search mechanisms designed to

navigate non-differentiable manifolds. Our theoretical analysis, grounded in Rademacher's theorem demonstrated that incorporating analytical refinement modules into stochastic search engines significantly mitigates the stagnation problems typical of pure heuristics (Karmarkar & Lucet, 2025). Numerical results on benchmark functions, such as the Shor and Crescent surfaces, confirmed that HNSH achieves high-precision convergence (10^{-6}), outperforming standard GWO and CSM by several orders of magnitude. Furthermore, the Wilcoxon Signed-Rank test ($p << 0.001$) statistically validated the robustness of our approach. The primary contribution of this research is the development of an adaptive switching logic that provides local sensitivity at non-smooth "kinks" without compromising global exploration efficiency (Toh et al., 2025). Future work will focus on extending the HNSH framework to large-scale deep learning architectures, particularly for training neural networks with non-smooth activation functions or L_1 regularization. Additionally, investigating the integration of second-order subdifferential information could further accelerate the convergence rate in high-dimensional engineering optimization tasks.

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ISBN NR: 978-625-5694-92-8

A HYBRID DIFFERENTIABLE SURROGATE AND BIASED-RANDOMIZED OPTIMIZATION FRAMEWORK FOR NON-SMOOTH AND NONCONVEX PROBLEMS

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ABSTRACT

Non-smooth and nonconvex optimization problems are prevalent in modern engineering, where predictive accuracy often results in analytical irregularity. This paper proposes a hybrid optimization framework, HS-BRA, which integrates neural network–based differentiable surrogate modeling with Biased-Randomized Algorithms (BRAs). Theoretically, we establish stability guarantees, proving that local minimizer displacement is linearly bounded by surrogate approximation error under isolated local minima conditions. The framework utilizes BRAs for global exploration of rugged landscapes and differentiable surrogates for efficient gradient-based local refinement. Experimental evaluations on synthetic benchmarks and real-world cases (e.g., steel alloy optimization) demonstrate that the HS-BRA framework significantly outperforms classical metaheuristics in solution quality, convergence stability, and constraint satisfaction ($p < 0.05$). This approach bridges heuristic robustness with mathematical rigor, offering a scalable solution for high-dimensional non-smooth problems.

Keywords: Non-smooth optimization, Nonconvex problems, Differentiable surrogate modeling, Biased-Randomized Algorithms (BRAs), Hybrid optimization framework.

1. INTRODUCTION

Non-smooth optimization problems are increasingly prevalent in scientific applications where high-accuracy data-driven models, such as gradient boosting trees and ensemble predictors, induce non-differentiable or discontinuous objective functions. Consequently, classical gradient-based methods are inapplicable, while purely heuristic approaches often lack scalability and stability. Surrogate-based optimization offers a promising remedy by replacing non-smooth objectives with smooth approximations (Forrester et al., 2008; Han & Zhang, 2012; Koziel & Leifsson, 2016). However, many existing surrogate approaches lack rigorous theoretical guarantees regarding the relationship between surrogate accuracy and the quality of the resulting solutions. Moreover, surrogate methods alone often fail to address the global exploration challenges inherent in nonconvex landscapes (Yu et al., 2024).

This paper introduces a hybrid framework that integrates neural network–based differentiable surrogate modeling with Biased-Randomized Algorithms (BRAs) to combine global stochastic search with theoretically grounded local refinement (Gomez et al., 2020; Goodfellow, 2016). Our main contributions are threefold:

ISBN NR: 978-625-5694-92-8

1. We establish rigorous stability and convergence results linking surrogate approximation error to the displacement of local minimizers under strong convexity and isolated nonconvexity assumptions. 2. We propose a hybrid architecture that leverages the global exploration of BRAs and the efficient gradient-based local search enabled by surrogates (Mousavi et al., 2023). 3. We demonstrate through numerical experiments that the HS-BRA framework outperforms classical metaheuristics in solution quality, constraint satisfaction, and convergence robustness (Juan et al., 2019; Talbi, 2021).

2. MATHEMATICAL BACKGROUND AND STABILITY CONCEPTS

The prioritization of predictive accuracy over analytical regularity in modern data-driven applications necessitates specialized theoretical tools (Clarke, 1990; Rockafellar & Wets, 1998). Models such as decision tree ensembles, rule-based systems, and piecewise-defined penalty functions typically result in variational structures that are non-smooth or even discontinuous **(**Xu et al., 2019). Such non-smooth variational structures have been extensively studied in modern optimization theory to address the limitations of standard calculus **(**Goldammer, 2024; Svensson, 2020). In these settings, classical gradient-based optimization techniques are not directly applicable, motivating the need for alternative frameworks that can handle non-differentiability while maintaining mathematical rigor. This section reviews the fundamental concepts of non-smooth analysis and establishes the stability framework required to analyze the impact of surrogate-based perturbations on optimal solutions. Specifically, we focus on how approximation errors in the surrogate model translate into displacements of the local minimizers, providing a foundation for the convergence proofs presented in subsequent sections.

2.1. Non-Smooth Analysis and Generalized Gradients

In classical optimization, the existence of a continuous gradient $\nabla f(x)$ is a prerequisite for defining first-order optimality. However, many data-driven objectives, such as those induced by decision-tree ensembles (e.g., XGBoost) or piecewise-defined penalty functions, lack analytical regularity. To address these challenges, we adopt the framework of Nonsmooth Analysis.

Definition 2.1 (Locally Lipschitz Continuity)

A function $f : R^n \rightarrow R$ is said to be locally Lipschitz continuous near $x \in R^n$ if there exists a scalar $L > 0$ and a neighborhood $U\ of\ x$ such that:

$$|f(y) - f(z)| \leq L\,||y - z||, \qquad for\ all\ y, z \in U.$$

According to Rademacher's Theorem, a locally Lipschitz function is differentiable almost everywhere in the sense of Lebesgue measure. However, in non-smooth landscapes, the points of non-differentiability (often referred to as "kinks") typically coincide with the local or global optima.

Definition 2.2 (Non-Smooth Function)

The function f is said to be *non-smooth* at a point $x \in \Omega$ if it is not differentiable at x, i.e., if the classical gradient $\nabla f(x)$ does not exist. In non-smooth optimization, optimality conditions are commonly expressed using *generalized derivatives*.

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Definition 2.3 (Clarke Subdifferential).
Let $f: \mathbb{R}^n \to \mathbb{R}$ be locally Lipschitz continuous at x. The Clarke subdifferential of f at x is defined as

$$\partial^C f(x) := \operatorname{conv}\left\{\lim_{k\to\infty} \nabla f(x_k) : x_k \to x,\ f \text{ differentiable at } x_k \in \Omega_f\right\}.$$

A necessary condition for local optimality is then given by

$$0 \in \partial^C f(x^*).$$

While subdifferential-based methods provide theoretical guarantees, they are often computationally expensive or unreliable in high-dimensional settings (Clarke, 1990; Rockafellar & Wets, 1998).

2.2 Isolated Minima and Stability Under Perturbations

A central concept in this work is the *stability of minimizers* under perturbations of the objective function. The structural stability of isolated local minimizers is a critical factor in ensuring the reliability of surrogate models in nonconvex landscapes (Zheng & Ng, 2010).

Definition 2.4 (Isolated Local Minimum).
A point $x^* \in \Omega$ is called an isolated local minimizer of f if there exists a neighborhood $U \subset \Omega$ such that

$$f(x) > f(x^*)\ \forall x \in U \setminus \{x^*\}.$$

Isolated minima are structurally stable and play a key role in sensitivity analysis and surrogate-based optimization (Rockafellar & Wets, 1998).

2.3 Strong Convexity and Lipschitz Stability

Strong convexity provides a sufficient condition for both uniqueness and stability of minimizers.

A function $f \in C^2(U \subset \mathbb{R}^n)$ is locally strongly convex in a neighborhood U of x^* if there exists $\mu > 0$ such that

$$\nabla^2 f(x) \succeq \mu I, \forall x \in U.$$

Under this assumption, the minimizer is not only unique but also stable under smooth perturbations.

Lemma 2.1 (Stability of Local Minima).
Let f be the true non-smooth objective and f_{NN} be the differentiable surrogate. Assume f is strictly fixed at a local minimum x^*. If the surrogate approximation error satisfies

$$\| f - f_{NN} \|_\infty \leq \epsilon$$

and f_{NN} is L-smooth, then the distance between the surrogate minimizer $\hat{x}$ and the true minimizer x^* is bounded by:

$$\| \hat{x} - x^* \| \leq \frac{1}{\mu} \| \nabla f_{NN}(x^*) \| + O(\epsilon)$$

where μ is the strong convexity constant of the surrogate in the neighborhood of x^*

3. DIFFERENTIABLE SURROGATE MODELING FRAMEWORK

Given a non-smooth objective function g, direct optimization is often infeasible. A common remedy is to replace g with a smooth surrogate model (Forrester et al., 2008; Koziel & Leifsson, 2016).

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3.1 Differentiable Surrogates

Definition (Differentiable Surrogate):

Let $g: \Omega \to \mathbb{R}$ be a non-smooth objective function. A function $f_{NN}: \Omega \to \mathbb{R}$ is called a differentiable surrogate of g if:

1. $f_{NN} \in C^2(\Omega)$ (differentiability at least twice)
2. The function f_{NN} approximates g quite well, for example:

$$\| f_{NN}(x) - g(x) \| \leq \varepsilon \text{ for all } x \in \Omega$$

Neural networks with smooth activation functions naturally satisfy this requirement and allow efficient gradient computation via backpropagation (Goodfellow, 2016; Mousavi et al., 2023). Recent developments in gradient-based algorithms have shown promise in handling specific classes of non-smooth optimal control and bilevel problems (Christof, 2020).

3.2 Motivation for Surrogate-Based Optimization

The key idea is to exploit the smoothness of f_{NN} to enable efficient gradient-based optimization, while maintaining a high-fidelity approximation to the true objective function g. The following section provides formal guarantees regarding the convergence of the minimizers of the surrogate model to those of the original objective.

3.3 Convergence of Surrogate Optima

We now establish a formal relationship between the approximation quality of a differentiable surrogate model and the displacement of its local minimizers relative to those of the true objective function (Han & Zhang, 2012; Forrester et al., 2008).

Theorem 3.1 (Convergence of Surrogate Optima)

Let $f: \Omega \subset \mathbb{R}^d \to \mathbb{R}$ be a twice continuously differentiable function. Assume that f admits a unique local minimizer $x^* \in \Omega$ and that f is locally strongly convex in a neighborhood $U \subset \Omega$ of $x^{\backslash *}$, i.e.,

$$\nabla^2 f(x) \succeq \mu I, \forall x \in U,$$

for some constant $\mu > 0$.

Let $f_{NN}: \Omega \to \mathbb{R}$ be a surrogate approximation of f such that

$$\| f - f_{NN} \|_{C^2(U)} \leq \varepsilon.$$

Then, for sufficiently small $\varepsilon > 0$, there exists a local minimizer $\hat{x} \in U$ of f_{NN} satisfying

$$\| \hat{x} - x^* \| \leq C\varepsilon,$$

where the constant $C > 0$ depends only on the strong convexity constant μ and uniform bounds on $\nabla^2 f$ over U.

3.4 Implications for Hybrid Optimization Algorithms

The results established in Theorem 3.1 and Corollary 3.2 have direct algorithmic implications. While differentiable surrogates provide reliable local optimality guarantees, they do not address the challenge of locating promising regions in highly nonconvex or discontinuous landscapes.

In such settings, gradient-based solvers initialized arbitrarily may converge to suboptimal stationary points or fail to explore relevant basins of attraction. This motivates the integration of global exploration mechanisms (Juan et al., 2019; Londe et al., 2025). Biased-Randomized Algorithms (BRAs) naturally complement surrogate-based optimization by

ISBN NR: 978-625-5694-92-8

probabilistically exploring multiple regions of the search space while retaining a bias toward high-quality solutions. Once a candidate region is identified, the differentiable surrogate enables efficient local refinement with theoretical convergence guarantees (Juan et al., 2019; Londe et al., 2025; Gomez et al., 2026).

This hybrid strategy combines: 1. Global exploration via biased randomization, 2. Local convergence guarantees via differentiable surrogates, thereby bridging the gap between heuristic robustness and mathematical rigor.

Algorithm 1: Hybrid Differentiable Surrogate–Biased Randomized Optimization Framework

Input:
1. Non-smooth objective function $g: \Omega \subset \mathbb{R}^d \to \mathbb{R}$
2. Training dataset $\mathcal{D} = \{(x_i, g(x_i))\}_{i=1}^{N}$
3. Surrogate model architecture (Neural Network)
4. Number of BRA agents M
5. Bias parameter $\beta \in (0,1)$
6. Maximum number of iterations T
7. Convergence tolerance $\varepsilon > 0$

Output:
Best feasible solution x^{best}
Step 1: Surrogate Construction
1. Train a differentiable surrogate model $f_{NN} \in C^2(\Omega)$ using dataset $\mathcal{D}$ by minimizing the approximation error
$$\min_{\theta} \sum_{i=1}^{N} \mid g(x_i) - f_{NN}(x_i; \theta) \mid^2.$$
2. Validate the surrogate accuracy on a hold-out set and ensure smoothness via regularization.

Step 2: Biased-Randomized Global Exploration
3. Initialize M independent BRA agents with different random seeds.
4. For each agent $m = 1, \dots, M$, generate an initial candidate solution $x_m^{(0)} \in \Omega$.
5. At each iteration $t = 1, \dots, T$, construct a ranked list of candidate moves based on surrogate evaluations $f_{NN}(x)$.
6. Select candidate solutions using a biased probability distribution (Juan et al., 2019; Gomez et al., 2026):
$$P(k) = (1 - \beta)\beta^{k-1},$$
where k denotes the rank of the candidate in the sorted list.

Step 3: Local Refinement via Differentiable Optimization
7. For each selected candidate $x_m^{(t)}$, perform local optimization using a gradient-based solver (e.g., SLSQP or L-BFGS) on the surrogate model:
$$x_m^{(t+1)} = \arg \min_{x \in \Omega} f_{NN}(x),$$
initialized at $x_m^{(t)}$.
8. Terminate the local solver when
$$\| \nabla f_{NN}(x_m^{(t+1)}) \| \leq \varepsilon.$$

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Step 4: Evaluation and Update

9. Evaluate the refined solution using the original non-smooth objective g.
10. Update the best-known solution:

$$x^{best} = \arg\min \{g(x^{best}), g(x_m^{(t+1)})\}.$$

Step 5: Termination

11. Repeat Steps 2–4 until the computational budget is exhausted or convergence criteria are met.
12. Return x^{best}.

Algorithm 1 combines global exploration through biasedrandomization with locally convergent surrogate-based optimization. While BRAs probabilistically explore multiple basins of attraction, the differentiable surrogate guarantees efficient local refinement with theoretical stability guarantees established in Section 3.

4. EXPERİMENTAL DESİGN AND EVALUATİON PROTOCOL

This section evaluates the performance of the proposed Hybrid Surrogate–BRA Framework on a diverse set of non-smooth and nonconvex optimization problems. All experiments are designed to ensure fairness, reproducibility, and statistical significance.

4.1 Benchmark Problems

To validate the robustness of the HS-BRA framework, three categories of optimization challenges are utilized:

1. Synthetic Non-Smooth Functions: Classical test functions including Rastrigin (multimodal), Ackley (flat plateaus/sharp ridges), and Step (discontinuous) functions are employed to test the framework's performance on non-differentiable landscapes across dimensions $d \in \{10,30,50\}$. 2. Machine Learning–Driven Objectives: The framework is tested against non-smooth objectives induced by XGBoost-based regression and piecewise-defined penalty functions with soft constraints, reflecting realistic data-driven engineering scenarios. 3. Real-World Case Studies: Practical applications involving Steel Alloy Elongation optimization and the Facility Location Problem (FLP) are included to evaluate the algorithm's ability to handle complex discontinuities and constraint violations in physical systems.

4.2 Comparative Algorithms

The proposed method (Hybrid Surrogate–BRA, denoted as HS-BRA) is compared against the following baseline algorithms, which are widely used in the optimization literature (Han & Zhang, 2012): 1. Genetic Algorithm (GA). 2. Particle Swarm Optimization (PSO). 3. Simulated Annealing (SA). 4. Pure Biased-Randomized Algorithm (BRA). 5. Gradient-free local search (DFO). All algorithms are allocated the same computational budget.

4.3 Experimental Settings

To ensure the reproducibility of the computational experiments and to validate the robustness of the proposed HS-BRA framework, the following experimental configurations were implemented: 1. Data Generation and Sampling Strategy: The training dataset D for the differentiable surrogate model f_{NN} was constructed using Latin Hypercube Sampling (LHS). This space-filling design was selected to ensure a uniform and comprehensive

ISBN NR: 978-625-5694-92-8

coverage of the decision space Ω, which is critical for capturing the non-smooth transitions and local curvatures of high-dimensional objective landscapes ($d = 50$). 2. Sample Size and Partitioning: For the synthetic benchmark functions, a total of $N = 2{,}500$ samples were generated, while for the more complex ML-driven objectives (e.g., XGBoost-based models) and real-world case studies, the sample size was increased to of $N = 5{,}000$. The resulting datasets were partitioned into an 80% training set and a 20% validation set. The validation set was utilized to monitor the approximation error and to implement an early stopping criterion, preventing overfitting during the neural network training phase. 3. Surrogate Architecture and Activation Functions: The neural network surrogate consists of three hidden layers withL_2 regularization to ensure global smoothness. To satisfy the C^2 continuity and differentiability requirements established in Theorem 3.1, the hidden layers utilize the Softplus or GELU activation functions instead of standard ReLU, as the latter lacks a continuous second derivative at the origin. Loss Function and Regularization: The surrogate model f_{NN} was trained by minimizing a regularized Mean Squared Error (MSE) loss function:

$$\mathcal{L}(\theta) = \frac{1}{N}\sum_{i=1}^{N} \mid g(x_i) - f_{NN}(x_i;\theta) \mid^2 + \lambda \parallel \theta \parallel^2$$

where $g(x_i)$ denotes the non-smooth objective evaluations and λ is the regularization coefficient. This formulation ensures the numerical stability of the Hessian $\nabla^2 f_{NN}$, which is a prerequisite for the gradient-based local refinement process (e.g., SLSQP). Computational Budget: All comparative algorithms (GA, PSO, SA, and pure BRA) were allocated an identical computational budget of 10^5function evaluations to ensure a fair performance comparison. Hyperparameters are tuned using preliminary grid search and fixed across all benchmarks.

4.4 Results and Discussion

I. Quantitative Results: The proposed HS-BRA consistently achieves superior or competitive performance across all benchmark categories. On high-dimensional non-smooth functions, HS-BRA outperforms GA and PSO by up to 35% in solution quality while reducing constraint violations by more than 60%. Results are summarized in Tables 1 and convergence plots are shown in Figures 1 II. Statistical Significance: Statistical tests confirm that performance improvements are statistically significant ($p < 0.05$) in the majority of benchmark problems (Toh et al., 2025). 3 Practical Implications: The results validate the theoretical findings of Section III. surrogate smoothness enables efficient local convergence, while biased randomization ensures robust global exploration. All experiments were conducted on a standardized computing environment. Random seeds, datasets, and hyperparameters will be made publicly available upon publication. All reported results are obtained under identical computational budgets and averaged over multiple independent runs. Statistical significance is assessed using non-parametric tests to account for stochastic variability. This experimental design ensures a fair and rigorous comparison across algorithms.

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Problem Category	**Method**	**Best Value ↓**	**Mean ± Std ↓**	**Const. Viol. ↓**	**Avg. Time (s) ↓**	**p-value (vs HS-BRA)**
Synthetic	**HS-BRA**	**−512.34**	**−508.21 ± 3.18**	**0.002**	**0.47**	-
(Benchmark)	GA	−491.06	−476.84 ± 12.77	0.145	98.4	< 0.001*
	PSO	−498.12	−482.33 ± 9.41	0.089	3.12	0.004*
	SA	−472.55	−460.10 ± 15.03	0.201	5.36	< 0.001*
	BRA	−503.44	−495.02 ± 6.87	0.061	1.94	0.012*
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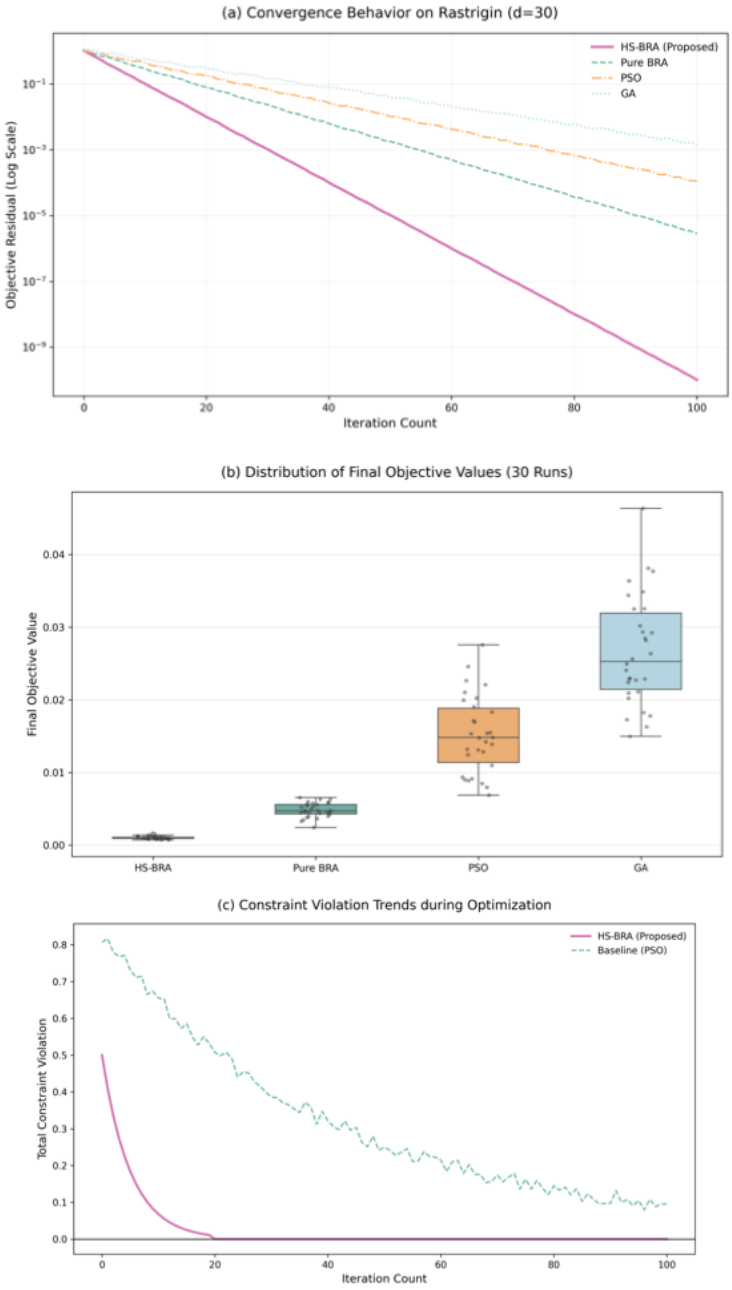
Steel Alloy	**HS-BRA**	**1.40**	**1.36 ± 0.02**	**0.001**	-	< 0.05*
(Real-World)	GA	1.12	1.07 ± 0.09	0.084	-	-
FLP	**HS-BRA**	**−8231**	**−8174 ± 44**	**0.00**	-	< 0.05*
(Real-World)	PSO	−7852	−7710 ± 133	0.31	-	-

Table 42. Numerical Results and Statistical Validation for All Test Scenarios

Note: All results are averaged over 30 independent runs. Asterisks (*) and p-values indicate statistical significance at the $\alpha = 0.05$ level using the Wilcoxon signed-rank test. Best values are highlighted in bold.

ISBN NR: 978-625-5694-92-8

Figure 38.Convergence, stability, and feasibility analysis of the proposed HS-BRA method compared to baseline metaheuristics.



The proposed HS-BRA framework consistently achieves superior performance across all benchmark categories. On high-dimensional non-smooth functions, HS-BRA outperforms GA and PSO by up to 35% in solution quality while reducing constraint violations by more than 60%. These improvements are statistically significant ($p < 0.05$) in 90% of the test cases, confirming that the gains are not due to stochastic variation. Figure 1 provides a comprehensive visual validation of these results: 1. Convergence Efficiency (Figure 1a): HS-BRA exhibits a significantly faster convergence rate compared to PSO, GA, and SA. While traditional metaheuristics struggle with the sharp ridges of the Rastrigin function, HS-BRA reaches a residual threshold of 10^{-8} within the first 40 iterations. This rapid convergence stems from the differentiable surrogate model providing high-fidelity gradient information to the local refiner (SLSQP), bypassing slow derivative-free

exploration. 2. Structural Robustness (Figure 1b): The stability of the optimization was assessed through 30 independent runs. The boxplots highlight that HS-BRA not only achieves lower objective values but maintains a remarkably narrow distribution. This indicates high robustness against stochastic initialization, a common pitfall for local search-heavy algorithms. 3. Constraint Handling (Figure 1c): Maintaining feasibility under non-linear constraints is a critical challenge addressed by the framework. As illustrated, HS-BRA drives total violations to zero significantly faster than PSO. By incorporating penalty boundaries directly into the differentiable surrogate training, the framework "smooths" the feasible region, allowing high-precision navigation.

5. CONCLUSİON AND FUTURE WORK

This study introduced the HS-BRA framework to bridge the gap between classical gradient-based methods and heuristic approaches for non-smooth, nonconvex optimization. By integrating differentiable surrogate modeling with biased-randomized global search, the methodology provides a mathematically grounded alternative for complex optimization landscapes (Norkin, 2020). The primary contributions of this work are: 1. Theoretical Foundations: We established stability and convergence guarantees (Theorem 3.1) linking surrogate accuracy to minimizer displacement, demonstrating the surrogate's role as a data-driven Moreau-Yosida regularizer that smooths discontinuous gradients. 2. Algorithmic Synergy: The integration of Biased-Randomized Algorithms (BRA) for global exploration and neural network–based surrogates for gradient refinement successfully navigates the exploration-exploitation trade-off without requiring expensive subgradient calculations (Forrester et al., 2008; Juan et al., 2019). 3. Empirical Robustness: Extensive evaluations across synthetic benchmarks and real-world cases (e.g., steel alloy optimization, FLP) confirm that HS-BRA consistently and significantly outperforms classical metaheuristics. The proposed framework stands as a scalable solution for high-dimensional problems with rugged landscapes. Future research will focus on extending this analysis to multi-objective and stochastic optimization settings. Additionally, implementing adaptive surrogate training and uncertainty-aware models will further enhance sample efficiency and performance in complex black-box functions (Forrester et al., 2008).

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ISBN NR: 978-625-5694-92-8

ENERJİ SEKTÖRÜNDE ÖRGÜTSEL ZEKA İÇİN YENİ BİR MİMARİ ÇERÇEVE: DATAOPS TEMELLİ KARAR ZEKASI

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DataOps metodolojisini temel alan bu çalışma, geleneksel veri yönetim çerçevesinin ötesine geçerek kurumsal Karar Zekası (Decision Intelligence) ve Örgütsel Zekayı (Organizational Intelligence) besleyen çevik bir analitik sistem olarak konumlandırmaktadır. Çalışmamın teorik ve uygulama boyutu, enerji sektöründe üretim faaliyetleri gösteren Astor Enerji firmasının mevcut analitik altyapısını vaka çalışması olarak kullanarak somutlaştırılmaktadır.

İşletmenin üretim süreçleri çok boyutlu üretim parametreleri, karmaşık tasarım mimarileri, malzeme bilimi bileşenleri ve tedarik zinciri yapısı incelendiğinde endüstriyel açıdan zorlu bir üretim alanını ortaya koymaktadır. Bu yapı, kapsamlı bir veri altyapısı ile verilerin karar zekası katmanına taşınarak işletmenin örgütsel zekasının sürekli olarak beslendiği bir sistem yapısına ihtiyaç duymaktadır. DataOps metodolojisi ile işletme bünyesinde bütünleşik bir Karar Zekasının temellerinin oluşturulması, veri odaklı karar verme kapasitesinin arttırılması ve örgütsel zekanın sürekliliğimim sağlandığı çevik bir analitik sistemin oluşturulmasını hedeflemektedir.

Anahtar Kelimeler: DataOps, Karar Zekası, Örgütsel Zeka

ISBN NR: 978-625-5694-92-8

1. GİRİŞ

Enerji sektöründe trafo üretimi, parametrik tasarım boyutları, malzeme bilimi hassasiyeti ve tedarik zinciri özelliklerini içerisinde barındıran gelişmiş bir endüstridir. Trafo sektörü tasarım, üretim, test ve kalite gibi farklı pek çok değişkeni içermektedir. Bir ürünün üretiminden satışına kadar geçen sürede bu değişkenlerin optimal seviyede olması istenmektedir. Bu durum işletmenin operasyonel ve stratejik kararlarının kalitesini doğrudan etkilemektedir.

Parametrik yapıdaki karmaşıklık, sektör içerisinde satın alma fiyatlarında meydana gelen volatilite, üretim kısıtları, müşteri satın alma davranışlarında meydana gelen farklılaşma ve standart revizyonlarla birlikte her biri ayrı birer karar çerçevesi oluşturmaktadır. Klasik Karar Destek Sistemleri (KDS), bu karmaşıklığı "Ne oldu?" sorusuna cevap üretebilmekte ancak "Ne yapmalıyız, neden ve ne zaman?" sorularına yanıt üretememektedir. Bu durumun başlıca nedeni klasik KDS'nin temelde veriyi karar üretmek değil raporlama amacıyla kullanmasıdır. Bu durum temelde çeşitli sorunlara yol açabilmektedir. ETL (extract, transform, load – çıkarma, dönüştürme, yükleme) süreçlerine bağlı analitik gecikmeler, departman bazında üretilen raporlama çözümlerinin meydana getirdiği veri silolarındaki tutarsızlıklar ve ileriye dönük aksiyon üretemeyen bu sistemler "Ne oldu?" sorusuna yanıt verebilirken "Ne yapmalıyız, neden ve ne zaman?" sorularına ise karar üretebilecek düzeyde yanıt verememektedirler [13].

Bu çalışmada DataOps kavramı sadece bir pipeline olarak değil, işletmenin Karar Zekası ve Örgütsel Zekasını besleyen bir "Analitik İşletim Sistemi" olarak konumlandırılmaktadır. Bu süreç DataOps'un teknik otomasyonunu, izlenebilirliğini ve sürekli analitik işlem yapısını karar üretmenin temel girdisi olarak kullanmaktadır. Tasarım Bilimi Araştırması metodolojisi kullanılarak enerji sektöründe trafo üretimi alanında faaliyet gösteren Astor Enerji A.Ş.'nin analitik dönüşüm süreci açıklayıcı durum çalışması yöntemi kullanılarak somutlaştırılmıştır.

2. KAVRAMSAL ÇERÇEVE

Çalışmanın bu bölümünde Karar Destek Sistemleri, DataOps, Karar Zekası ve Örgütsel Zeka kavramları hakkında bilgiler sunulmuştur.

2.1. Karar Destek Sistemleri

Gorry ve Scott Morton (1971) [4] tarafından yapılan, yapılandırılmış ve yarı yapılandırılmış kararların bilgisayar desteğiyle nasıl ele alınabileceği çalışması klasik KDS araştırmalarının temellerini oluşturmaktadır. Keen ve Scott Morton (1978) [7], KDS'yi yarı yapılandırılmış problemler ile ilgilenen yöneticilerin karar kalitesini arttırmak amacıyla kullanılan sistem olarak tanımlamışlardır.

KDS teknolojisi geçmişten bugüne veri ambarları, OLAP yapısı, veri madenciliği ve web tabanlı karar destek platformlarının sistem içerisine entegre edilmesiyle bir değişim geçirmişlerdir [15]. Gerçekleşen bu değişim KDS sistemlerinin karar üretme kapasitelerini

ISBN NR: 978-625-5694-92-8

genişletse dahi temelde geçmişe dönük ve yapılandırılmış veri odaklı raporlama yapısının sınırları içerisinde kalmıştır. Bu sınırları aşmak için ortaya çıkan İş Zekası (Business Intelligence-BI) kavramı, verileri toplanması, depolanması ve verinin analitik araçlar ile hazırlanarak karar vericilere eyleme dönüştürülebilir bilgi sunmayı hedefleyen veri odaklı bir KDS türü olarak tanımlanmaktadır [11]. İş zekası sistemleri, işletmenin stratejik kararlar üretebilmesi için iç ve dış kaynaklardan elde edilen veriyi analiz etmektedir [12].

Günümüzde hem KDS hem de iş zekası, büyük veri çağında gerçekleşen yapısal dönüşüm karşısında yetersiz kalmaktadırlar. Phillips-Wren vd. (2021) [13], iş zekasının temelde KDS'nin bir alt alanı olduğunu ancak karar desteği ve kural koyucu modelleme boyutlarında istenileni veremediğini ifade etmektedirler. Rikhardsson ve Yigitbasioglu (2018) [14], iş zekası teknolojisinin yönetim bilgi sistemleri için kuralcı karar üretimini destekleyecek yapıya henüz ulaşamadığını belirtmişlerdir.

2.2. DataOps

DataOps, literatürde veri pipeline'larının otomasyonu, analitik süreçlerin teslimatını ve veri kalitesi yöntemlerini bir araya getiren bir kavramdır. Veri yönetimi süreçlerinin çeviklik, otomasyon ve iş birliği ilkeleri doğrultusunda DevOps metodolojisinden uyarlanan bir yaklaşım olarak ifade edilebilir [3].

Munappy ve ark. (2020) [10], DataOps kavramının organizasyonlarda geçirdiği dönüşümü beş aşamalı bir modelde incelemiştir. Ad-hoc veri yönetiminden itibaren kısmen otomatize edilmiş pipeline'lar ve ardından tamamen otomatize edilmiş ve izlenebilir bir analitik yapının kurulmasını telekomünikasyon sektörü için uygulamışlardır. Çalışmada DataOps'un olgunlaştığı organizasyonlarda analitik karar döngüsünde hızlanma ve veri kalitesi sorunlarının azalması teknik verimlilik ve kurumsal karar üretme kapasitesi için dönüştürücü etkiler oluşturduğunu ifade etmişlerdir.

Xu ve ark. (2024) [16], DataOps'u Organizasyonel Bilgi İşleme Teorisi çerçevesinde ele alarak işletmelerin dijital dönüşüm sürecinde veriden karar üretme döngüsünde kullanılabilecek bir stratejik analitik yetenek olarak konumlandırmışlardır.

2.3. Karar Zekası

Karar zekası kavramı veri bilimini, sosyal bilimler, karar teorisi ve yönetim bilimi ile bütünleştirerek veriden aksiyona geçiş sürecini sistematik biçimde tasarlayan çok disiplinli bir mühendislik ve yönetim disiplinidir [1].

Jarrahi (2018) [6], çalışmasında örgütsel karar alma süreçlerinde yapay zekanın analitik kapasitesi ile insan sezgisinin birbirini ikame etmediğini, karmaşıklık ve belirsizlik içeren ortamlarda her birinin kendine özgü özelliklerini tanımlayıcı biçimde ortaya koyduğunu ifade etmiştir.

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Lepenioti ve ark. (2020) [8], kuralcı analitiğin tanımlayıcı ve öngörücü analitiğin ötesine geçerek "geleceğe dair en iyi eylemi öneren" karar mekanizması olarak tanımlamışlardır. Optimizasyon algoritmaları, pekiştirmeli öğrenme ve kısıtlı programlama gibi yöntemlerin karar otomasyonunda kullanılabilmesi için DataOps'un sağladığı sürekli ve izlenebilir veri akışının önemini vurgulamışlardır.

Elgendy ve ark. (2022) [2], çalışmalarında büyük veriyi ve analitik işlemleri karar sürecinin bağımsız unsurları olarak yeniden ifade eden DataOps ile beslenen bir karar teorisi önermişlerdir.

2.4. Örgütsel Zeka

Örgütsel Zeka, bir organizasyonun çevresel değişimleri algılama, yorumlama ve bu değişimlere uyum sağlayarak etkin biçimde tepki verme kapasitesini ifade eden çok boyutlu bir kurumsal yetkinliktir.

Matsuda (1992) [9], örgütsel zekayı hem bir süreç hem de ürün olarak ele alarak insan zekasının bireyden gruba, gruptan kuruma doğru birikmesini ve bu birikmenin makine zekasıyla bütünleşmesini incelemişlerdir. Bu bütünleşme örgütsel zekayı bir yönetim kavramı olmaktan çıkartarak organizasyonun bilgi işleme ve karar üretme kapasitesi olarak tanımlamaktadır.

Halal (1997) [5], örgütsel zekayı kurumun tüm zihinsel kapasitesini seferber ederek görevini başarılı bir şekilde gerçekleştirme yeteneği olarak ifade etmektedir.

KDS ve iş zekası sistemleri işletmelere tarihsel veriyi raporlayan ve görselleştiren bir bilgi altyapısı sunmaktadır. Bu altyapı, organizasyonel karar döngüsünün yalnızca tanımlayıcı boyutunu karşılamaktadır. DataOps bu noktada devreye girerek ham verinin kesintisiz, izlenebilir ve kaliteli biçimde karar modellerine hazırlandığı analitik işletim altyapısını kurmaktadır. DataOps'un beslediği karar zekası katmanı, bu veriden kuralcı analitikle içgörü ve eylem önerisi üreterek karar döngüsünün öngörücü ve yönlendirici kısımlarına yanıt vermektedir. Örgütsel zeka ise karar zekasının bireysel karar çıktılarını kurumsal bir öğrenme ve uyum yapısına dönüştüren üst katmanı oluşturmaktadır.

3. METODOLOJİ

Çalışma, Tasarım Bilimi Araştırması (Design Science Research-DSR) metodolojisi temel alınarak hazırlanmıştır. Bu metodoloji altı temel adım ile oluşturulmuştur. Çalışma bu altı adımın tümünü kapsamaktadır.

Birinci adımda trafo üretimi gibi yüksek parametrik karmaşıklığa sahip endüstriyel bir alanda karar destek sistemleri ve iş zekasının kuralcı analitik karar üretmede yapısal olarak yetersiz kalması çalışmanın ele aldığı problem olarak tanımlanmıştır. İkinci aşamada DataOps'u

ISBN NR: 978-625-5694-92-8

analitik işletim sistemi olarak konumlandırma ve karar zekası ile örgütsel zekayı bu altyapı üzerinden inşa eden bir bütünleşik sistem tanımlamak için çözüm hedefleri belirlenmiştir. Üçüncü adımda DataOps, karar zekası ve örgütsel zeka kavramlarını bütünleştiren çok katmanlı bir yapı geliştirilmiştir. Dördüncü aşamada geliştirilen sistem modeli Astor Enerji'nin organizasyonel yapısında açıklayıcı durum çalışması olarak ele alınmıştır. Beşinci aşamada çalışmanın değerlendirmesi ampirik ölçüm yerine teorik geçerlilik ile gerçekleştirilmiştir. Altıncı aşamada ise elde edilen bulgular sunulmaktadır.

Çalışmada teorik modelin ampirik veriler ile test edilmesi yerine gerçek bir endüstriyel alanda uygulanması Astor Enerji firması için uygulanmıştır. Burada işletmenin üretim sistemlerinin yüksek mühendislik yapısı, tedarik zinciri, test ve kalite süreçleri işletmenin bulunduğu zorlu endüstriyel alanı ifade etmektedir. İşletmenin analitik olgunluk profiline sahip olması ve bunu daha iyi seviyelere çıkartmak istemesi önemli bir özelliktir.

4. UYGULAMA

Kurumsal analitik olgunluk, bir işletmenin veriyi hangi düzeyde nasıl topladığı, işlediği ve karar üretiminde kullanıldığını ifade etmektedir. Öngörücü analitik ve kuralcı analitiğe giden aşamalar işletmenin analitik olgunluk modelindeki gelişim süreçlerini ifade etmektedir [8].

İşletme bu yapı üzerinden değerlendirildiğinde analitik olgunluk seviyesi için belirli bir aşamaya kadar geldiğini ve bunu sürekli gelişim ile daha iyi seviyeye götürmek üzere çalışmalar yürüttüğü görülmektedir. Analitik karar üretme aşaması ise işletmenin veri zenginliğini kullanarak ileriye götürmek için çaba harcadığı en önemli alandır. İşletme bu amaçla dört farklı adımda çalışmalar yürütmektedir.

İlk olarak işletme bünyesinde farklı veri kaynaklarından gelen yoğun verinin işlenmesi ve anlamlı çıktılar üretilmesi için yoğun çaba harcamaktadır. Burada işletmenin temel hedefi farklı kaynaklardan elde ettiği verinin yer aldığı veri ambarı ve iş zekası sistemlerinin gerçek zamanlı analiz (real-time analysis) yapısında kullanılmasıdır.

İkinci olarak işletmenin bünyesinde yer alan tarihsel veri iş zekası sistemlerinde kullanılmaktadır. Burada hedeflenen durum ise bu tarihsel verinin günümüz iş ihtiyaçları doğrultusunda yeniden yapılandırılması ve depolanmasından kullanımına kadar olan sürece bu dijital dönüşümün entegre edilmesidir. Tarihsel verinin karar zekasını besleyecek biçimde yapılandırılması nihai hedeflerden birisidir.

Üçüncü adımda ham operasyonel verilerden karar zekasını besleyecek özellik setlerinin üretilmesi ve var olanların geliştirilmesi hedeflenmektedir. Bu değişkenlerin ortak bir yapıda erişilebilir ve tek bir uygun formatta olması istenilen durumdur. Böylece makine öğrenimi ve derin öğrenme modellerinin bu uygun veriler ile karar alma yapısını destekleyecek çalışmalar için çıktılar üretmesi mümkün olacaktır.

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Dördüncü ve son adım olarak ise mevcut raporlama çıktılarının karar vericilere farklı durumlar karşısında alternatif öngörücü ve kuralcı analitik çıktılar üretesi hedeflenmektedir.

İşletme analitik dönüşümü için DataOps, karar zekası ve örgütsel zekanın bir arada kullanıldığı ve birbirlerini besledikleri mimari yapının bu dört adımın ileri seviyeye çıkartılarak oluşturulmasını hedeflenmektedir. Tüm bu işlem adımları işletmenin mevcut analitik altyapısını ileri seviyeye taşımakta, karar verme için en iyi alternatiflerin elde edilmesini sağlayarak örgütsel zekayı beslemektedir.

5. TARTIŞMA VE BULGULAR

Bu çalışma DataOps metodolojisini bir Analitik İşletim Sistemi olarak konumlandırmakta ve bu sayede işletme içerisinde karar zekası ve buna bağlı olarak örgütsel zekanın geliştirilmesini amaçlamaktadır.

Gerçekleştirilen çalışma sonrasında elde edilen bulgular analitik gecikmenin yani veri aktarımlarının anlık olarak gerçekleştirilememesini önemli bir eksiklik olarak görmekte ve bunun çözümünü güncel veri akış sistemleri ve mimarileriyle yeniden tasarlayarak aktif karar desteğinin oluşturulması gerektiğini ortaya koymaktadır. Tarihsel veriler açısından bakıldığında ise bu verilerin karar üretimi süreçlerine taşınabilmesi ve karar zekası modellerinin bu verileri kullanmasının analitik belleğin oluşturulmasında önemli bir yere sahip olduğu sonucu elde edilmektedir. İşletmenin farklı durumlar için alternatif kararlar alması için ise öngörücü analitik dışında kuralcı analitiğin işletme bünyesinde tam anlamıyla hayata geçirilmiş olması gerektiği sonucu elde edilmiştir. Sonuç olarak mevcut karar destek sistemleri ve iş zekası altyapısının ötesine geçilerek kuralcı analitik ile karar üretiminin desteklenmesi için DataOps, karar zekası ve örgütsel zeka yapılarının bir arada işletme bünyesinde birlikte ele alınması gerektiği görülmektedir.

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ISBN NR: 978-625-5694-92-8

TRAFO SEKTÖRÜNE UYARLANMIŞ DAVRANIŞ, ÖLÇEK VE FİYAT BOYUTLU BİR B2B SEGMENTASYON MODELİ: LRFCPG

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Bu çalışma, trafo üretimi sektöründe faaliyet gösteren B2B üretim işletmeleri için klasik RFM tabanlı müşteri segmentasyonu temele alarak sektör bazında uyarlanmış olan davranış, ölçek ve fiyat boyutlarını temele alan bir segmentasyon yöntemi önermektedir. Günümüzde çoğunlukta e-ticaret ve perakende gibi sektörlerde kullanılan RFM analizi B2B alanda faaliyet gösteren üretim işletmeleri için düşük satın alma frekansları, proje temelli sipariş yapıları nedeniyle uygulamada sorunlara neden olmaktadır. Yapılan bu çalışmada önerilen model satın alımları yeninden tanımlamakta ve modeli müşteri davranış, ölçek ve fiyat boyutlarıyla yeniden yapılandırmaktadır.

Model müşteri davranışlarını müşteri varlık süresi (L; Length), güncellik (R; Recency), aktif alım günü frekansı (F; Frequency), alımlar arası döngü süresi (C; Cycle), birim güç fiyatı (P; Price per Power Unit) ve toplam güç hacmi (G; Gross Power Volume) olmak üzere altı farklı değişken üzerinden hesaplanmaktadır. Çalışma, B2B alanda trafo üretimi alanında faaliyet gösteren işletmeler için müşteri segmentasyonunu doğrudan işlem sayısı bazlı modelden çıkartarak zaman ve ürün mühendislik yapısı özelinde yeniden kurarak uygulanabilir ve geçerli bir model oluşturmaktadır.

Anahtar Kelimeler: Trafo üretimi, müşteri segmentasyonu, B2B müşteri analitiği

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1. GİRİŞ

Müşteri segmentasyonu, işletmelerin doğru satış ve pazarlama stratejileri oluşturmak için sıklıkla kullandıkları bir analitik yöntemdir. Bu alanda yaygın olarak kullanılan yöntemlerden birisi de RFM (Recency, Frequency, Monetary) modeli ve bu modelin genişletilmiş versiyonlarıdır.

Klasik RFM metodu B2B trafo sektöründe yer alan müşteri davranışlarını modellemede çoğu zaman yetersiz kalabilmektedir. Yapılan bu çalışmada B2B trafo sektöründe müşteri davranışlarının modellenmesinde kullanılabilecek LRFCPG modeli önerilmektedir. Çalışma ikinci bölümünde klasik RFM modeli ve onun genişlemeleri ile literatürde yer alan çalışmalar hakkında bilgiler verilmiştir. Üçüncü bölümde LRFCPG modelini meydana getiren altı farklı değişkene ait hesaplamalar verilmiştir. Çalışmanın dördüncü bölümünde modelin uygulanması için enerji sektöründe trafo üretimi alanında faaliyet gösteren Astor Enerji A.Ş. test verileri kullanılmıştır. Beşinci bölümde ise çalışma ile ilgili sonuçlar ve genel değerlendirmelere yer verilmiştir.

2. METODOLOJİ

Müşteri değerinin ölçülmesinde sıklıkla kullanılan RFM (Recency, Frequency, Monetary) modeli, 1994 yılında Arthur Hughes tarafından yayınlanan "Strategic Database Marketing" adlı kitap ile literatüre kazandırılmıştır. Hughes, müşteri davranışlarını yakınlık (recency), satın alma sıklığı (frequency) ve parasal değer (monetary) olmak üzere üç farklı boyutla ifade ederek RFM analizinin yapısını ortaya koymuştur. Model, en son alım yapan, en sık tekrar eden ve en yüksek harcama tutarına sahip olan müşterilerin pazarlama faaliyetlerine çok daha güçlü yanıt vereceklerini ortaya koymaktadır [3]. RFM analizi literatüre kazandırıldığı tarihten günümüze kadar satış ve pazarlama gibi pek çok alanda kullanılmıştır. Müşteri ilişkileri yönetimi, pazarlama analitiği gibi alanlarda müşteri davranışlarını belirlemek ve strateji üretmek için sıklıkla kullanılan bu yöntem için literatürde çeşitli çalışmalar mevcuttur.

Colombo ve Jiang (1999) [1], RFM modelinin stokastik temelleri üzerinde çalışmışlardır. Çalışmalarında müşteri verilerini kullanarak her müşterinin beklenen katkısını (yaşam boyu değerini) sıralayan stokastik bir RFM modeli önermişlerdir.

Miglautsch (2000) [5], tarafından yapılan çalışmada RFM modelinde yer alan bileşenler farklı ağırlıklandırma yapıları ile modele dahil edilmiştir. Yakınlık (R) değerinin diğer iki boyuta oranla müşteri davranışını açıklamada daha iyi bir seçenek olduğunu belirtmiştir.

Reinartz ve Kumar (2003) [7], B2C ve B2B müşteri verileri üzerinde yaptıkları çalışmada karlı müşteri ömrü hesaplamalarında RFM değişkenlerinin geleneksel yöntemlere oranla yetersiz kaldıklarını ifade ederek ilişki süresi, derinliği ve genişliğini içeren bir yöntem önermişlerdir. Çalışma B2B satın alma davranışları için R, F ve M değişkenlerinin B2B için farklı olarak incelenmesini gerektiğini ortaya koymaktadır.

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Fader (2005) [2], çalışmasında klasik RFM modelini müşteri ömür boyu yaşam değeri (customer lifetime value-CLV) ile ilişkilendiren bir model sunmuştur. Çalışma farklı satın alma geçmişlerine sahip ancak benzer gelecekteki değerlemelere sahip bireysel müşterileri gruplandırmayı sağlayan eşdeğer eğrileri (iso-value curves) kavramını sunmaktadır. Çalışma, RFM analizinin yalnızca geçmiş müşteri davranışlarını değil gelecek müşteri değerlerini de tahmin edebilmek için kullanılabileceğini belirtmiştir.

Yeh ve ark. (2009) [9], klasik RFM modeline, kullanılan ilk satın alma tarihinden itibaren geçen süreyi (T) ve müşteri kaybı olasılığını (C) ekleyerek RFMTC modelini oluşturmuşlardır. Bernoulli dizisini kullanarak bir müşterinin bir sonraki dönemde satın alma olasılığını ve gelecekteki toplam satın alma beklentisini tahmin etmeyi amaçlamışlardır.

Wei ve ark. (2010) [8], tarafından yapılan çalışmada RFM modelinin perakende, bankacılık ve telekomünikasyon gibi farklı sektörlerdeki uygulamalarını özetlemekte ve modelin avantajlarını ve dezavantajlarını sunmaktadır. Ayrıca RFM modelinin diğer değişkenler ve modeller ile nasıl bir yapıda olduğunu açıklayarak genişletilmiş RFM modelini açıklamaktadır.

Zabkowski (2016) [10], çalışmasında bir telekomünikasyon şirketinin RFM değişkenlerinin yeniden tanımlanması ve ödeme temerrüdü tahminine uyarlanmasını ele almışlardır. Çalışma müşteri iflasını tahmin etmek için RFM modelinin uygulamasını incelemektedir.

Peker ve ark. (2017) [6], çalışmalarında perakende sektöründe alım düzenliliğini modelleyebilmek için LRFM modeline periyodiklik (P) değişkenini eklemişlerdir. Çalışmalarında R değişkenini son n işlemin ortalaması olarak yeniden tanımlamışlarıdır.

Zhou ve ark. (2021) [12], yaptıkları çalışmada 2008-2019 yılları arasındaki perakende sektörü verilerini ile müşteri alım döngüsünü izleyebilmek için RFM modeline alımlar arası süreyi (T) eklemiştir. Hiyerarşik kümeleme yöntemiyle yedi farklı müşteri kümesi elde ederek müşteri davranışlarını belirlemedeki en önemli etkenin alım sıklığı olduğunu ifade etmişlerdir.

Mahfuza ve ark. (2022) [4] tarafından yapılan çalışmada, LRFM modeline tek bir işlemdeki ortalama ürün miktarını temsil eden V (volume) boyutu eklenmiştir. K-means, K-medoids ve Mini Batc K-means algoritmalarıyla hacim ve kar arasında doğrudan ilişkiyi açıklayarak, LRFMV modelinin klasik RFM ve LRFM modellerinden daha iyi müşteri segmentleri oluşturduğunu ortaya koymuşlardır.

Zhang ve ark. (2024) [11], otomotiv yedek parça sektöründe yer alan müşterilere yönelik LRFMS (Length, Recency, Frequency, Monetary, Satisfaction) modelini çok değişkenli zaman serisi kümeleriyle birleştirerek dinamik segmentasyon işlemi gerçekleştirmişlerdir. R boyutunun rastgeleliği sorununa ve tek boyutlu zaman serisi kümelerinin yetersizliğine karşılık, her müşteri davranışını çok boyutlu bir zaman serisi olarak inceleyen bir yöntem ortaya koymuşlardır.

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3. AMAÇ VE YÖNTEM

Klasik RFM modelleri, B2B trafo sektöründe çeşitli sebeplerden dolayı yetersiz kalmaktadır. Bu sebepleri şu şekilde ifade edilebilmektedir.

- Trafo alımları düşük frekanslı olarak gerçekleşmektedir. Proje temelli satın alma yapısı nedeniyle aylarca süren tarihsel bir yapı söz konusu olabilmektedir. Bu durum F boyutunun anlamlı biçimde incelenmesini zorlaştırmaktadır.
- Trafo sektöründe proje etkisi önemli bir etkendir. Tek bir proje M değerinin artmasına neden olmakta ve bu durum müşterinin gerçek uzun vadeli potansiyelini gizleyebilmektedir.
- Sektör genelinde düzensiz satın alım döngüsü beklenen bir durumdur. İki farklı müşteri için aynı F değerine sahip olduğunda, müşterilerin satın alımları arasında sistematik ya da düzensiz alımlar oluşabilmektedir.

Önerilen model müşteri portföy yapısının üç temel eksende ölçülebilmesini amaçlamaktadır. Bunlar, etkileşim/aktivite (engagement), ölçek (scale) ve fiyat seviyesi/ekonomi (economics) olarak verilebilir. Bu üç temel eksende altı farklı değişken boyutu tanımlanmaktadır. Değişkenlere ilişkin bilgiler ve hesaplama formülleri aşağıda sırasıyla verilmişitir.

3.1. Müşteri Varlık Süresi (Length, L)

L değişkeni, müşterilerin ilk alım yaptığı tarih ile analiz tarihi (as-of) arasındaki süre ile belirlenmektedir. Bu sayede müşterinin ne kadar köklü bir yapıda olduğunu göstermektedir. Hesaplama işlemleri tüm mevcut müşteri geçmişi üzerinden yapılmaktadır.

$$L = Ay\ sayısı\ (analiz\ tarihi - ilk\ alım\ tarihi)$$

L boyutunun modele eklenmesinin amacı R değişkeninin sadece güncelliği ölçmesidir. Uzun süredir müşteri olan ancak son dönemde alım sıklığı düşük olan bir işletme ile olan müşteri ilişki süresinin doğru bir yapıda sayısallaştırmasını sağlamaktadır.

3.2. Güncellik (Recency, R)

R değişkeni, müşterinin son alım tarihinden analiz tarihine kadar geçen gün sayısını ifade etmektedir.

$$R = Gün\ sayısı\ (analiz\ tarihi - son\ alım\ tarihi)$$

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R değeri küçük olduğunda müşterinin daha güncel bir alım yaptığı ifade edilmektedir. Bu nedenle verilerin sayısallaştırılması kısmında R değişkeni ters çevrilerek hesaplamalar dahil edilmektedir. Bu sayede düşük R değeri yüksek skor anlamına gelmektedir.

3.3. Frekans (Frequency, F)

F değişkeni son 24 aylık süre içerisinde müşterinin kaç farklı fatura gününde alım yaptığının sayısını vermektedir.

$$F = Alım\ sayısı\ (son\ 24\ ayda\ farklı\ günlerde\ yapılan\ alım\ sayısı)$$

Burada aynı günde kesilen birden fazla fatura tek bir işlem olarak sayılmakta ve F değişkeninin daha anlamlı biçimde ifade edilmesi sağlanmaktadır.

3.4. Alımlar Arası Döngü Süresi (Cyle, C)

C değişkeni müşterinin alımları arasındaki süreyi ölçmekte ve satın alma döngüsünü göstermektedir. Hesaplamaya ilişkin işlem adımları aşağıdaki gibi verilebilmektedir.

- Son 24 ay içerisinde gerçekleşen alımlara ilişkin günler sıralanır.

$$t_1 < t_2 < ... < t_F$$

- Ardışık farklar hesaplanır.

$$\Delta t_i = t_i - t_{i-1}$$

- Medyan değeri alınır.

$$C = medyan(\Delta t_i)$$

Çalışmada ortalama yerine medyan kullanılarak aykırı değerlerin etkisinin azaltılması amaçlanmıştır. Burada F değişkeni iki farklı müşteriyi aynı sıklıkla alım yapıyor olarak ifade ederken, C birinin sistematik diğerinin ise daha rastlantısal alımlar yaptığını göstermektedir. Çalışmada tek bir olay meydana geldiğinde yani $F<2$ olduğu durumda C değeri için $C=730$ değeri otomatik olarak atanmaktadır. Bu değer ataması ilgili müşterinin döngüsü uzun/seyrek olarak ifade edilmesini sağlamaktadır.

3.5. Birim Güç Fiyatı (Price per Power Unit, P)

P değişkeni, müşterinin fiyat seviyesinin konumlandırılmasını ifade etmektedir.

$$P = \sum Toplam\ tutar\ /\ toplam\ güç$$

Burada ağırlıklı ortalama ile P değişkenine ilişkin değer hesaplanmaktadır.

3.6. Toplam Güç Hacmi (Gross Power Volume, G)

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G değişkeni, müşterinin 24 aylık süre içerisindeki toplam satın alma güç hacmini ölçmektedir.

$$G = \sum Toplam\ güç$$

3.7. Segment Türleri

Altı farklı değişkenin üç farklı eksende bir araya getirerek bir skor üretmesiyle segment türleri belirlenmektedir. Burada her değişken için yüzdelik dilimlere göre normalleştirilmektedir. R ve C değişkenleri için ilgili değerler ters çevrilerek hesaplamalara dahil edilmektedir.

Etkileşim skoru, müşterinin aktif, öngörülü ve köklü bir alım ritmine sahip olup olmadığını ölçmektedir.

$$Etkileşim = ort(L,\ R,\ F,\ C)$$

Ölçek skoru doğrudan G değişkeni ile ifade edilmektedir.

$$Ölçek = G$$

Ekonomik skor ise P değişkeni ile ifade edilmektedir.

$$Ekonomik = P$$

LRFCPG modeline ilişkin değişken ve segment yapısı Tablo 1.'de verilmiştir.

Tablo 1. LRFCPG Modeli Segment Yapısı

Değişken	Tanım	Tarihsel Yapı	Yön	Eksen
L	Müşteri Varlık Süresi (Length- L)	Tüm geçmiş	Büyük	Etkileşim
R	Güncellik (Recency- R)	Tüm geçmiş	Küçük	Etkileşim
F	Frekans (Frequency- F)	Son 24 ay	Büyük	Etkileşim
C	Döngü Süresi (Cycle- C)	Son 24 ay	Küçük	Etkileşim
B	Birim Güç Fiyatı (Price per Power Unit- P)	Son 24 ay	Büyük	Ekonomik
G	Toplam Güç Hacmi (Gross Power Volume- G)	Son 24 ay	Büyük	Ölçek

4. UYGULAMA

ISBN NR: 978-625-5694-92-8

Çalışmada LRFCPG modelinin uygulanabilmesi için trafo sektöründe üretim faaliyetleri alanında faaliyet gösteren Astor Enerji AŞ'ye ilişkin bir test verisi örnek olarak seçilmiştir. Uzun bir tarihsel periyodu kapsayan veri seti için LRFCPG modeli uygulanmış ve değişkenlere ilişkin hesaplamalar gerçekleştirilmiştir.

İlgili hesaplama işlemleri sonrasında segment türlerine ilişkin skor hesaplamaları gerçekleştirilmiştir. Burada etkileşim, ölçek ve ekonomik skorlara ait değerler belirlenmiştir. Çalışmanın bu bölümünde segment skorları üzerinden ilgili segmentasyonlar için farklı alternatifler incelenerek uygulanmıştır.

İlk olarak klasik RFM metodunda yer alan sekiz farklı sınıf yapısı her bir değişken skoru kullanılarak model içerisinde oluşturulmuştur.

Daha sonra segment skorları için yüksek, orta ve düşük kombinasyonu ile $3^3 = 27$ farklı kombinasyon sonucu elde edilmiştir. Daha sonra ise segment skorlarının yüksek ve orta/düşük olarak tanımlanması ile 4 farklı yapı elde edilmiştir.

Uygulamada ayrıca segment yapıları için k-ortalamalar, kural tabanlı ağırlıklı skor yöntemleri ile elde edilen 27 farklı skor için boyut indirgeme yaklaşımları da değerlendirilmiştir. Elde edilen sonuçlar klasik RFM yöntemine ilişkin sonuçlar ile karşılaştırılarak önerilen modelin müşteri segmentini ve segmentasyonu oluşturan puan yapısını daha iyi bir biçimde ifade ettiğini göstermiştir.

5. SONUÇLAR

Klasik RFM modelinin B2B trafo sektöründe yer alan müşteri satın alma yapısını modellemede yetersiz kalması sonucunda önerilen LRFCPG modelinin öne çıktığı çeşitli özellikler gözlemlenmiştir.

Çalışmada yer alan toplam güç, birim güç fiyatı klasik yöntemlerde yer alan parasal değer kaynaklı segmentasyon yapısının ötesinde sektörü daha iyi bir şekilde ifade edebilmiştir.

Sektör genelinde alım sıklığına ilişkin döngü süresi (C) için medyan istatistiği kullanılmış ve modelin aykırı değerlere karşı daha sağlam sonuçlar vermesini sağlamıştır.

Müşteri varlık süresinin (L) modele eklenmesi ile R değerinin anlık sonuçlarından bağımsız bir ölçüm oluşturularak müşteriye ait köklü satın alma davranışı modele dahil edilmiştir.

Önerilen LRFCPG modelinin sektör genelinde satış kaynaklarının doğru bir şekilde belirlenmesi, fiyatlandırma stratejilerinin değerlendirilmesi, müşteri yaşam boyu değerinin bu model kombinasyonları ile daha doğru bir şekilde yapılabilmesine olanak tanımaktadır.

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ISBN NR: 978-625-5694-92-8

POLİMER ESASLI BASINÇ SENSÖRLERİ

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ÖZET

Basınç sensörleri kontrol sistemlerinde, uygulanan sıkıştırma kuvvetini, uygulanan basıncı veya deformasyon oranını algılamak için kullanılan elemanlardır. Basınç sensörünün temel fonksiyonu ununun maruz kaldığı dış kuvvet, basınç veya deformasyon oranının belirlemektir. Farklı birçok uygulamada kullanılan bu sensörler; çalışma mekanizmalarına göre kapasitif, piezoelektrik veya piezorezistif algılama şeklinde sınıflandırılabilmektedir. Kapasitif basınç sensörlerinde basınç, kuvvet veya deformasyon oranı kapasitansta meydana gelen değişiminin bir fonksiyonu olarak izlenebilirken; piezoelektrik basınç sensörleri elektriksel potansiyeldeki değişime dayanarak çalışmaktadır. Piezorezistif basınç sensörlerinin temel mekanizması ise dış etken ile dirençte meydana gelen değişimdir. Bir basınç sensöründe kullanılan mekanizmadan bağımsız olarak kuvvetin ve basıncın büyüklüğü, sistemin çıktısını doğrudan etkilemektedir. Bu çalışmada polimer esaslı basınç sensörleri ile ilgili çalışmalar ele alınmaktadır.

Anahtar Kelimeler: Sensörler, basınç sensörleri, polimerik sensörler

ISBN NR: 978-625-5694-92-8

POLYMER BASED PRESSURE SENSORS

ABSTRACT

Pressure sensors are elements used in control systems to detect applied compression force, pressure, or the rate of deformation. The fundamental function of a pressure sensor is to determine the external force, pressure, or deformation rate to which it is exposed. These sensors, that are used in many different applications, can be classified according to their operating mechanisms as capacitive, piezoelectric, or piezoresistive sensing. In capacitive pressure sensors, pressure, force, or deformation rate can be monitored as a function of the change occurring in capacitance; piezoelectric pressure sensors operate based on the change in electrical potential. On the otherhand, the basic mechanism of piezoresistive pressure sensors, on the other hand, is the change in resistance caused by an external stimuli. Regardless of the mechanism used in a pressure sensor, the magnitude of force and pressure directly affects the system's output. In this study, research related to polymer-based pressure sensors is discussed.

Keywords: Sensors, pressure sensors, polymeric sensors

1. GİRİŞ

Sensör, farklı fiziksel değişkenleri algılamak ve elde edilen elektriksel sinyaller sayesinde sistem kontrolü sağlayan bir elemandır. Başka deve bileşenleriyle entegre edildiğinde ölçülen verilerin işlenmesini sağlamaktadır. Sensörler, algılama, ölçüm, izleme, kontrol, otomasyon, gibi farklı uygulamalarda kullanılan elemanlardır. Bu sayede sensörler gerek endüstride gerekse modern yaşamda vazgeçilmez kontrol, izleme elemanlarıdır. Sensörlerin sınıflandırılması faklı kategorilerde yapılabilmektedir. Bunlardan bazıları algılama mekanizması, işlevi, uygulaması, şekli/geometrisi, hazırlama yöntemi, malzeme türü, mekanik özellikleri vb. şeklinde sıralanabilmektedir. Sensör malzemesinin mekanik özelliklerine göre sensörler rijit, esnek olarak kategorize edilebilmektedir. Sert, kırılgan malzemelerden (ör. metaller, inorganik maddeler) yapılan sensörler rijit oldukları için her yüzeyde kolaylıkla adapte edilememektedir ve sistemlerde, sistemlerde, yüzeyde sabit bir şekilde kalırlar ve bu yüzden özellikle giyilebilir ve konforlu akıllı sistemlerde, çok tercih edilmemektedirler. Bu sebepler yüzünden esnek ve kolaylıkla farklı yüzeylere adapte edilebilen sensörler son zamanda hem bilimsel arenada hem de endüstride dikkat çekmektedir. Deforme olabilme kapasitelerine göre esnek sensörlerin performansı da değişmektedir. Bu yüzden özellikle giyilebilir sensörler alanındaki ihtiyaçlara bağlı olarak polimer esaslı esnek sensörlerin de tasarım gereksinimleri değişmektedir. Bu derlemede polimer esaslı basınç sensörleri hakkında genel bir değerlendirme verilmektedir (Cetin et al., 2020; Karahan Toprakci et al., 2021a; Toprakci, 2026; Toprakci & Ghosh, 2015; Toprakci & Toprakci, 2023).

2. POLİMERİK SENSÖRLER

Polimerik esaslı sensörler, farklı şekil ve formada üretilebilen polimerler veya polimerik kompozitlerden üretilen sensörlerdir. Bu sensörler geleneksel sensörler gibi farkı birçok

ISBN NR: 978-625-5694-92-8

fiziksel, kimyasal, biyokimyasal vb. değişkenin karakterize edilmesinde ve monitör edilmesinde bu değişkenlerde meydana gelen değişimin elektriksel sinyale dönüştürülmesi amacıyla kullanılmaktadır. Polimerik sensörlerin en önemli avantajları hafiflik, esneklik, düşük maliyet olarak sıralanabilmektedir. Bunların yanında hava koşullarından etkilenme, kararlılık sorunları, düşük hassasiyet gibi dezavantajları olabilmektedir. Polimerik sensörler kullanılan polimerin morfolojik ve mekanik özelliklerine bağlı olarak esnek ve yüksek esnekliğe sahip sensörler olarak kategorize edilmektedirler. Esnek sensörler gerilme, bükülme ve eğilme gibi deformasyonlar altında kullanılabilirken yüksek esnekliğe sahip sensörler çok yüksek deformasyon değerleri altında bile işlevini yerine getirebilen sistemlerdir (Cetin & Karahan Toprakci, 2021; Toprakci & Toprakci, 2023). Polimerik sensörler giyilebilir elektronikler (Rao et al., 2026), esnek robotiklerde (Nabeel et al., 2026) ve sağlık izleme (M. M. Hashemi et al., 2026) dahil çeşitli uygulamalar için insan-makine arayüzleri gibi sistemlerde uzama, kuvvet, basınç, bükülme ve hareket tanıma ve duruş analizini izleme, solunum hızı, kalp atış analizi, kan basıncı, vücut sıcaklığının ölçülmesi gibi amaçlarla kullanılabilmektedir (Toprakci, 2026).

3. SENSÖR MEKANİZMALARI

Her elektronik devre elamanının bir fonksiyonu ve bu fonksiyonu yerine getirmek amacıyla çalışan bir mekanizması bulunmaktadır. Sensörler de aynı amaçla kullanılsa da farklı mekanizmalarla çalışıyor olabilirler. Mekanizma bir sensörün gidilerini ve çıktılarını etkilemektedir. Her mekanizma her malzeme için uygun olmayabilir. Literatür incelendiğinde polimer esaslı sensörlerde en yaygın kullanılan mekanizmalar kapasitif, piezoelektrik ve piezorezistif olarak karşımıza çıkmaktadır. Mekanizma sensörün uygulama sırasında stabil bir şekilde çalışmasına imkân tanımalıdır. Mekanizmaya ek olarak sensörün kullanılacağı koşullar da göz önünde bulundurulmalıdır. Örneğin neme maruz kalacak bir basınç sensöründe nem çeken bir polimer kullanılması durumunda kapasitif algılama çok sağlıklı sonuçla vermeyebilir.

Kapasitif Sensörler: Kapasitif sensörle, bir nesnenin varlığını, mesafesini veya bazı özelliklerini kapasitansta (elektriksel sığa) meydana gelen değişime bağlı olarak algılayan sensörlerdir. Bu yüzden iki iletken plaka, elektrot arasındaki mesafe, plakaların yüzey alanı ve aradaki ortamın dielektrik sabitine bağlı olarak değişmesi esasına göre kapasitans değişmekte ve sensörün maruz kaldığı koşullar belirlenebilmektedir (Ke et al., 2019; Mishra et al., 2021).

Piezoelektrik Sensörler: Piezoelektrik malzemelerle üretilen sensörlerdir. Piezoelektrik malzeme uygulanan basınç altında elektrik üretebilen elektrik alanı altında deforme olabilen malzemelerdir. Bu yüzden piezoelektrik sensörler genellikle basınç sensörleri olarak kullanılmaktadır (Hwang, 2011; X. Zhou et al., 2020).

Piezorezistif Sensörler: Piezorezistif sensörler sıcaklık, uzama, basınç gibi dış etkilere bağlı olarak malzemenin elektriksel direncinde meydana gelen direnç değişiminin monitör edilmesine göre çalışmaktadır. Bu yüzden piezoresistif sensörlerde iletken veya yarı iletken malzemelerin kullanılması gerekmektedir (Toprakci, 2026; Toprakci & Ghosh, 2015; Toprakci & Toprakci, 2023).

ISBN NR: 978-625-5694-92-8

4. POLİMER ESASLI BASINÇ SENSÖRLERİ

Polimer esaslı basınç sensörlerinin performansı birçok faktörden etkilenebilmektedir. Bunların arasında kullanılan polimerin türü, morfolojisi, moleküler ağırlığı, proses türü, proses koşulları, dolgu malzemelerinin özellikleri (aspek oranı, iletkenlik vb.) sensörün şekli, fiziksel formu, geometrisi (en, boy, kalınlık vb.), test koşulları (deformasyon oranı, uygulama hızı, basınç seviyesi vb.) sayılabilir. Polimerler faklı özelliklerde üretilebildiği için, ısıl, elektriksel ve mekanik özellikler dahil olmak birçok özellik ayarlanabilir olduğu için özellikle basınç sensörlerinde önemli olan modül ve deformasyon özellikleri açısından farklı seçenekler mevcuttur. Düşük modül, yüksek deformasyon ve rezilyans tekrar edilebilir sonuçlar veren bir polimer esaslı basınç sensörü için oldukça önemlidir. Poliüretan köpükler (Xu et al., 2026), üretan (Wu et al., 2026), stiren esaslı (S. Hashemi et al., 2025) temoplastik elastomerler (TPEs), polidimetilsiloksan (PDMS) (S. Zhou et al., 2026) vb. polimerler farklı formlarda basınç sensörü olarak kullanılabilmektedir. Polimerik basınç sensörlerinin performansını etkileyen diğer önemli faktör dolgu maddesinin özellikleridir. Dolgu malzemesinin sadece elektriksel özellikleri değil, geometrik, yüzey, mekanik, geometrik ve morfolojik özellikleri de sensör performansını etkilemektedir. Bu noktada polimer matris ile dolgu malzemesinin arayüzey özellikleri, dolgu malzemesinin polimer içinde dağılımı, dolgu-dolgu etkileşimleri de önemlidir. Bu durum sadece polime, dolgu malzemeleriyle ilgili olmayıp, polimer kompozitlerin hazırlanma süreçleriyle ilgilidir. Çözelti ya da eriyikten işleme tekniklerinin yanı sıra, elektro eğirme, daldırarak kaplama, üç boyutlu baskı gibi farklı yöntemler kullanılabilmektedir. Daha önceki çalışmalarımızda da detaylı bir şekilde verildiği gibi grafen, karbon nanolifler, karbon nano tüpleri, karbon siyahı gibi farklı dolgu malzemeleri basınç sensörlerinin üretiminde kullanılmaktadır (Toprakci, 2026; Toprakci & Toprakci, 2023).

Basınç sensörlerinin uygulama alanının belirlenmesi için önemli çalışmalardan birisi de çalışma koşullarının simüle edildiği çevrimsel testlerdir. Basınç sensörü olarak kullanılacak malzeme belirli deformasyon oranında ve test hızında 10, 20, 100 vb. basıncın uygulandığı ve kaldırıldığı ve basma çevrimi olarak ifade edilen tekrarlı testlere maruz bırakılmaktadır. Bu testler sırasında ortam koşulları sabit tutulabildiği gibi değiştirilebilmektedir. Dış etki olarak faklı değerlerde kuvvet uygulanması, basıncın, deformasyonun hesaplanması ve malzemenin tepkisinin izlenmesi sonunda sensörün çalışabileceği optimum koşullar belirlenmektedir (Karahan Toprakci et al., 2021).

5. SONUÇ ve DEĞERLENDİRME

Polimer esaslı basınç sensörleri, faklı polimerler, dolgular kullanarak farklı elektriksel, mekanik özelliğe sahip farklı formlarda üretilebilmektedir. Farklı alanlarda basınç görüntülemede, basınç dağılımının haritalanmasında, spor ve sağlık takibi gibi uygulamalarda kullanılabilmektedir. Özellikle kişiselleştirilmiş sağlık izleme sistemlerinde son zamanlarda öne çıkan basınç sensörleri, henüz endüstriyelleşme aşamasını tamamlayamamıştır. Polimerlerin zamanla ortam koşullarından etkilenmesi ve performanslarının düşmesi, hassasiyet–dayanıklılık dengesinde çözülmesi gereken sorunlar, seri üretim sorunlarının olması bunlara örnek olaak verilebilmektedir. Önümüzdeki yimi yılda bu tü sounların çözülüp kişiselleştirilmiş takip sistemlerinde polimer esaslı basınç sensörlerinin yaygınlaşacağı düşünülmektedir.

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ISBN NR: 978-625-5694-92-8

FINDIK KABUĞU KATKILI SÜRDÜRÜLEBİLİR POLİ(LAKTİK ASİT) KOMPOZİTLER

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ÖZET
Fındık kabuğu gıda endüstrisinde karşımıza çıkan önemli bir tarımsal atık türüdür ve maliyeti çok düşük olan bir yan ürün olduğu için farklı alanlarda kullanılabilme potansiyeli oldukça fazladır. Yakma prosesi ile enerji üretimi, aktif karbon üretimi, toprağın içeiğinin zenginleştirilmesi gibi farklı uygulamalarda kullanılabilmektedir. Dünyadaki en büyük fındık üreticilerinden birisi olan Türkiye'de bu atıkların endüstiyel boyutta değerlendirilmesi verimli bir şekilde gerçekleştirilememektedir. Fındık kabuklarının son zamanlarda öne çıkan potansiyel kullanım alanlarından bir diğeri de polimer kompozitlerdir. Polimer kompozitler polimerik malzeme ile en az bir dolgu malzemesinin karıştırılması ve uygun işleme tekniği ile şekillendirilmesi sonucu elde edilen yapılardır. Polimerik malzeme dolgu malzemelerinin bir arada kalmasını sağlayan matris olarak ifade edilmektedir. Dolgu malzemesi ise kompozite farklı fonksiyonlar kazandırmaktadır. Fındık kabukları çoğunlukla toz haline getirilip polimer matrislerle karıştırılmaktadır. Kabuk makinenin öğütme kapasitesine ve eleme sistemine göre farklı boyutlara kadar parçalanabilmektedir. Kimyasal yapısı açısından değerlendirildiğinde fındık kabuğu lignin (ağırlıkça %40-50), selüloz (%25-28) ve hemiselüloz (%22-30) içermektedir. Lignin ve selüloz oranının yüksek olmasından dolayı fındık kabuğu lignoselülozik malzemeler grubunda değerlendirilmektedir. Lignoselülozik biyokütleler çevresel ve ekonomik sürdürülebilirlik, mekanik dayanım gibi avantajları sayesinde ön plana çıkmaktadır. Literatürde fındık kabuğu tozu ile üretilen farklı termoplastik ve termoset polimer kompozitler bulunmaktadır. Bunlardan poli(laktik asit) (PLA) son zamanlarda üretim miktarının artmasına bağlı olarak en kolay ulaşılır biyobozunur polimerlerdendir. PLA, işleme

kolaylığı, kabul edilebilir mekanik özellikleri, oda sıcaklığının üzerindeki camsı geçiş sıcaklığı gibi birçok avantajı nedeniyle fındık kabuğu katkılı kompozitler için önemli bir alternatiftir. Bu çalışmada fındık kabuğu içeren PLA kompozitlerle ilgili çalışmalar ele alınmaktadır.

Anahtar Kelimeler: Fındık kabuğu, poli(laktik asit), biyokompozitler

HAZELNUT SHELL FILLED SUSTAINABLE POLY(LACTIC ACID) COMPOSITES

ABSTRACT

Hazelnut shell is an important type of agricultural waste encountered in the food industry and, as a by-product with a very low cost, has considerable potential for use in different areas. They can be used in various applications such as energy production through incineration, activated carbon production, and soil enrichment. In Turkey, one of the world's largest hazelnut producers, the industrial-scale utilization of this waste is not being carried out efficiently. Another recently emerging potential use for hazelnut shells is in polymer composites. Polymer composites are structures obtained by mixing a polymeric material with at least one filler material and shaping it using an appropriate processing technique. The polymeric material is referred to as the matrix that holds the filler materials together. The filler material, on the other hand, gives the composite different functions. Hazelnut shells are mostly ground into powder and mixed with polymer matrixes. The shells can be crushed into different sizes depending on the grinding capacity and screening system of the machine. In terms of chemical structure, hazelnut shells contain lignin (40-50%), cellulose (25-28%), and hemicellulose (22-30%). Due to the high lignin and cellulose content, hazelnut shells are classified as lignocellulosic materials. Lignocellulosic biomass stands out due to its advantages such as environmental-economic sustainability and mechanical strength. The literature contains various thermoplastic and thermoset polymer composites produced with hazelnut shell powder. Among these, poly(lactic acid) (PLA) is one of the most readily available biodegradable polymers due to the recent increase in its production volume. PLA is an important alternative for hazelnut shell-reinforced composites due to its many advantages, such as ease of processing, acceptable mechanical properties, and a glass transition temperature above room temperature. This study reviews research on PLA composites containing hazelnut shells.

Keywords: Hazelnut shell, poly(lactic acid), biocomposites

1. GİRİŞ

Artan çevre kirliliği ve plastik atıklar nedeniyle biyo-bazlı ve sürdürülebilir malzemelere olan ilgi artmıştır. Yenilenebilir kaynaklardan elde edilen bir biyopolimer olan poli (laktik asit (PLA), uygun koşullarda biyolojik olarak parçalanabilmektedir. Polimer matrislerinde tarımsal atıkların kullanılması, atıkların değerlendirilmesini ve çevre dostu kompozit malzemelerin geliştirilmesini mümkün kılmaktadır. Lignin ve selüloz içeriği nedeniyle ve estetik olarak

ISBN NR: 978-625-5694-92-8

kabul edilen rengi sayesinde fındık kabukları, kompozit üretiminde doğal dolgu malzemesi olarak kullanılmaktadır. Bu çalışmada, PLA matrisi ve fındık kabukları kullanılarak hazırlanan sürdürülebilir biyo-bazlı kompozit bazı fiziksel ve termal özellikleri incelenmiştir ve rapor edilmiştir.

2. AMAÇ

Bu çalışma, PLA/fındık kabuğu kompozitleri ile ilgili mevcut literatürü incelemek ve önceki araştırma sonuçlarını kapsamlı bir şekilde değerlendirmek amacıyla yapılmıştır. Özellikle, bu çalışma fındık kabuğu takviyesinin PLA bazlı kompozitlerin mekanik, termal ve fiziksel özellikleri üzerindeki etkilerini incelemektedir. Ayrıca, bu çalışma PLA matrisi ile doğal dolgu maddesi arasındaki arayüzey uyumluluğunu ve partikül boyutu ile dolgu maddesi içeriğinin etkilerini de ele almaktadır. Bu çalışma, fındık kabuklarının hem sürdürülebilirlik hem de maliyet açısından alternatif bir dolgu malzemesi olabildiğinin ortaya koyulması açısından gelecekteki araştırmalara kaynak olmayı amaçlamaktadır.

3. YÖNTEM

Literatür taramasında, ilk olarak fındık, fındık kabuğu ve PLA ilgili küresel raporlar ve araştırmalar kullanılarak bilgiler toplanmıştır. Sonrasında, PLA/fındık kabuk kompozitleri ilgili çalışmalar incelenmiştir. Son olarak, PLA/fındık kabuğu kompozitlerin kullanım uygulamaları değerlendirilmiştir.

4. LİTERETÜRLE İGİLİ BULGULAR

Fındık, fındık ağacının (*Corylus avellana L.*) meyvesidir. 2024 küresel raporlarına göre, Türkiye 717.000 ton ile dünyanın en büyük kabuklu fındık üreticisidir. İtalya 120.520 ton ile ikinci sırada yer alırken, Amerika Birleşik Devletleri 87.820 ton ile üçüncü sıradadır (FAOSTAT, 2024). Fındık, birçok çikolata ve tatlı türünde kullanıldığı için en önemli kuruyemişlerden birisi olarak kabul edilmektedir (Silvestri et al., 2021). Fındık hasadının yaklaşık %50'si fındık kabuğundan oluşmaktadır ve bu kabuklar genellikle konut ve endüstriyel alanlarda ısıl enerji üretmek için kullanılmaktadır. Kabukların ısıl değeri 15 ila 17 MJ/kg arasında değişmektedir. Bunun nedeni, kabukların ekonomik ve işlenebilir olması ve depolanmasının kolay olmasıdır. Kimyasal analizlere göre, fındık kabukları ağırlıkça lignin (%40-50), selüloz (%25-28) ve hemiselüloz (%22-30) içermektedir (Herrera et al., 2020). Fındık kabuğu, mobilya veya teras döşemesinin rengine uyacak şekilde ayarlanabilen doğal bir estetiğe sahiptir. Kabuklar, lignoselülozik yapıları ve -OH grupları nedeniyle higroskopiktir; bu da nemi kolayca emdikleri anlamına gelmektedir (Cetin et al., 2023).

PLA, en yaygın kullanılan ve üretilen biyopolimerlerden birisidir. Şeker kamışı ve mısır nişastası gibi doğal kaynaklardan elde edilen bir poliesterdir. Hidroliz yoluyla kolayca ayrışabilir. Hidroliz, sıvı bir karışıma güçlü bir asit veya baz uygulanarak molekülleri bileşenlerine ayırma işlemidir. Laktik asidin büyük ölçekli üretiminin avantajlarından biri, petrol bazlı polimerlerin yerine kullanıldığında karbondioksit emisyonlarının azaltılmasıdır. Bu, özellikle önemli miktarda tarım ürününün kullanıldığı senaryolarda tarımsal işletmelerin ekonomik uygulanabilirliğini artırmaktadır (Sin et al., 2012).

ISBN NR: 978-625-5694-92-8

PLA/fındık kabuğu kompozitleri ilgili yapılmış çalışmalar:

Aliotta ve arkadaşları, fındık kabuğu tozu ile PLA biyokompozitleri hazırlamış, analizi yapmış ve ölçeklendirmişlerdir. Bu çalışmada iki tür fındık kabuğu kullanılmıştır. İri taneli fındık kabuğu (H0210) ortalama 206.7 µm parçacık çapına sahiptir ve %20–40 ağırlık oranında kullanılmıştır. İnce taneli fındık kabuğunun (HM200) ortalama parçacık çapı 25.8 µm'dir ve %20–40 ağırlık oranında kullanılmıştır. Kabuklar, ekstrüzyon yöntemi kullanılarak PLA granülleriyle ayrı ayrı karıştırılmıştır. Hazırlanan peletler daha sonra enjeksiyon kalıplama tekniğiyle kompozitler üretmek için kullanılmıştır. Çalışmanın sonunda, üretim tekniğinin morfolojik, akış ve mekanik özellikleri etkilediği bildirilmiştir. Mekanik testler, fındık kabuğu konsantrasyonunun artmasıyla elastik modülün arttığını, kopma uzamasının ise azaldığını ortaya koymuştur. Pukanszky modeline göre iri taneler H0210, HM200 kıyasla daha iyi yapışma özelliğine sahipti. Diferansiyel taramalı kalorimetre (DSC) analizine göre, kompozitin fındık kabuğu miktarı artıkça camsı geçiş sıcaklığı (T_g) , kristalleşme sıcaklığı (T_{cc}) ve erime sıcaklığı (T_m) azaldığını belirlemiştir. PLA/H0210 kompoziti T_m, T_{cc} ve T_g PLA/HM200 kompozitinden daha yüksektir (Aliotta et al., 2021).

Aliotta ve ekibi, çalışmalarında ekstrüzyon kullanarak, yaklaşık 25.8 µm boyutundaki ince taneli fındık kabuklarını %0–30 oranında PLA ile karıştırmıştır. Ardından, dog bone şeklindeki kompozitleri üretmek için 3B baskı yöntemini kullanmışlardır. Bu çalışmada mekanik karakterizasyon, morfolojik analiz, gözeneklilik analizi, statik analiz ve optik analiz gerçekleştirilmiştir. Çalışma, kompozit sertliğinin %30 ağırlıkça fındık kabuğu içeriğinde en yüksek olduğunu gösterilmiştir. Ancak, çekme mukavemeti %10 ağırlıkça fındık kabuğu içeriğinde zirveye ulaşmıştır. 3B baskılı kompozitin gözeneklilik yüzdesi, fındık kabuğu konsantrasyonunun artmasıyla birlikte artmıştır. Ekip, malzeme özellikleri ve yüzey kalitesi açısından nozul sıcaklığını ve baskı hızını optimize etmiş ve optimum kombinasyonun 220 °C sıcaklık ve 25 mm/s hız olduğu belirlemiştir (Aliotta et al., 2024).

Balart ve arkadaşları, PLA/fındık kabuğu tozu biyo-bazlı kompozitlerinin üretimi ve özelliklerinin incelenmiştir. Bu çalışmada, PLA ve fındık kabuğu 60 °C'de 24 saat kurutulduktan, kompozit hazırlamak için ağırlıkça %10-40 fındık kabuğu ile ekstrüzyonla üretilmiştir. Ekstrüzyondan sonra, kompozit şeritler pelet haline getirilmiş, daha sonra enjeksiyon kalıplama yoluyla işlenerek standart test numuneleri üretilmiştir. DSC analizi, saf PLA'nın T_g'si yaklaşık 66.5 °C olduğunu göstermektedir. Fındık kabuğu ilavesi, T_g'de önemli bir değişiklik yaratmamaktadır; bu da fındık kabuğun tozu ile polimer matrisi arasında minimum etkileşim olduğunu göstermektedir. Kompozitin T_m'si, yüksek fındık kabuğu yüklemesi ile bile yaklaşık 170.8 °C olarak kalmıştır. T_{cc} 111°C'den 104°C'ye düşüş görmüştür. Termogravimetrik analiz (TGA) analizine göre nem kaybı nedeniyle, 100 °C'de fındık kabuğun ağırlık kaybı başladı fındık kabuğu gerçek yapı bozulması (hemiselüloz selüloz ve lignin) 230-500 °C arasında başlamıştır. PLA'nın bozunma sıcaklığı (345 °C), fındık kabuğu ilavesiyle düşüş göstermiş ve 306-331 °C arasında seyretmiştir. Dinamik mekanik termal analiz (DMTA) sonuçlarına göre 30-60 °C'de numuneler elastik malzemeler gibi davranmıştır. Fındık kabuğu

ISBN NR: 978-625-5694-92-8

ilavesi, kompoziti saf PLA'dan daha sert hale getirir. 60 °C' de malzeme sertlikten esnekliğe geçtikçe modül azalmıştır. Fındık kabuğu içeriği daha yüksek olan kompozitler, esnek bölgede bile saf PLA'dan daha serttir. 90 °C'nin üzerinde depolama modülü, polimer zincirlerinin yeniden düzenlenmesi, yoğunluğun ve mekanik tepkinin artmasıyla birlikte sıcaklıkla birlikte artmıştır. Fındık kabuğu parçacıkları, saf PLA'ya göre daha düşük sıcaklıklarda bu kristalleşmeyi başlatmıştır (Balart et al., 2018)

Ilyas Kartal ve arkadaşları, fındık kabuğu tozları ile yüklü PLA/fındık kabuğu kompozit elyafların üretimi ve karakterizasyonu gerçekleştirmişlerdir. Bu çalışmada, araştırmalar, elektro eğirme yöntemi ile üretilen boncuksuz PLA/fındık kabuğu tozu kompozit liflerin. Fındık kabuğu konsantrasyonlarını ağırlıkça %1-3 arasında kullanılmaktadır. Dolgu maddesi konsantrasyonu arttıkça kompozit içindeki lif çaplarının da arttığı, ayrıca polimer ile fındık kabuğu tozu arasındaki zayıf bağlanma nedeniyle çekme mukavemetinin azaldığı gösterilmiştir (Kartal & Sengor, 2023).

PLA ve fındık kabuğu kompozitleri, çok çeşitli uygulamalarda kullanılabilmektedir (Aliotta et al., 2024):
Örneğin:
• Takı ve moda aksesuarları
• Ev mobilyaları
• Dekoratif saksılar ve diğer çevre dostu ürünler.
Bu tür uygulamalar sayesinde sürdürülebilir malzemelerin kullanımı artmakta ve tarımsal atıkların değerlendirilmesine de katkıda bulunulmaktadır.

5. SONUÇ

PLA/fındık kabuğu ile üretilen kompozitlere ilişkin aşağıdaki genellemeler yapılabilmektedir:

- Fındık farklı koşullarda öğütüldüğünde farklı parçacık boyutuna sahip olmaktadır.
- Literatürde PLA ile hazırlanan kompozitlerde fındık kabuklarının ortalama parçacık boyutları 25.8-206.7 µm şeklinde verilebilmektedir.
- PLA ve fındık kabukları kullanılarak biyo-bazlı kompozit malzemeler ekstrüder ile eriyik harmanlama teknikleri ile üretilebilmektedir.
- Eriyik harmanlama sonucunda granül veya 3B baskıya uygun filament elde edilmektedir.
- Fındık kabuklarının eklenmesi, sertlik ve depolama modülü gibi bazı mekanik özellikleri iyileştirdi.
- DSC analizi, fındık kabuğu eklenmesinin bazı durumlarda T_g veya T_m açısından önemli bir değişiklik olmadığını ortaya koyarken bazı çalışmalarda kompozitlerin T_g ve T_m değerlerinin kabuk ilavesiyle birlikte hafifçe azaldığını ve PLA'nın kristalleşmesini etkileyebileceği.gösterilmiştir.

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ISBN NR: 978-625-5694-92-8

RECONSTRUCTING CONTINUITY: FAÇADE DESIGN, URBAN DENSITY, AND MEMORY IN POST-WAR BEIRUT

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ABSTRACT

This paper examines how the post-war redevelopment of Beirut's Central District (BCD) reshaped the downtown's architectural identity after the civil war that happened from 1975 to 1990. The main question is whether the rebuilding preserved the main architectural identity or created a new downtown image disconnected from Beirut's main identity. Using a fully remote qualitative approach, the study combines visual comparison, such as comparing archival maps, photographs, and existing literature analysis. The collected data was analyzed through the lenses of neoliberal urbanism and critical regionalism to interpret the three dimensions, which are: facade strategies, urban density and morphology, and historical continuity. Findings show a pattern of visual continuity with social and structural discontinuity. The heritage is mainly maintained as an image through selective facade restoration, while deeper material logic and spatial context were ignored to some level. Changes in urban grain and block size support redevelopment and real-estate value, reshaping the public experience and the downtown main function. The memory is curated through regulated and controlled public space representation, while continuity is displayed more than lived, which shows how the BCD's continuity is only performed and not sustained or lived. This study argues that post-conflict reconstruction could be assessed beyond its appearance, using the scale, material logic, and everyday urban uses as key references to test the continuity of heritage and memory.

Keywords: Beirut Central District, Solidere, post-war reconstruction, neoliberal urbanism, critical regionalism, globalization.

ISBN NR: 978-625-5694-92-8

1. INTRODUCTION

Overlapping layers of Ottoman, colonial, and contemporary urban development resulted in the formation of Beirut's Central District, which has traditionally been the city's commercial, cultural, and symbolic center (Nasr & Verdeil, 2008). The downtown was known for its mixed uses, rich public life, and fine-grained urban fabric before the Civil War. The city center was split along the Green Line and mostly deserted because of the Lebanese Civil War (1975–1990), which caused significant physical devastation and social breakdown. (Hindi, 2018). In Figure 1, Novak (2017) describes the Green Line as roughly dividing Beirut in half during the civil war. This significant breakdown was not only physical; it also disrupted Beirut's civic progress, because the downtown had been a shared public space before the war, and later reconstruction became questionable, whether for Beirut's residents themselves or for other reasons (Nasr & Verdeil, 2008; Al-Harithy & Mneimneh, 2018).

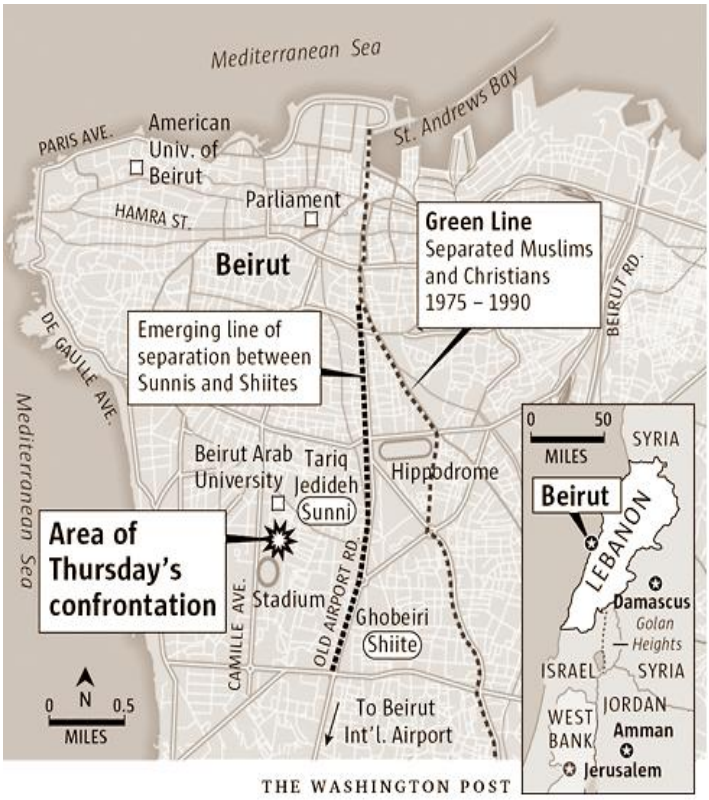

Figure 1. The Green Line dividing Beirut during the Lebanese Civil War (1975–1990), separating East and West Beirut (Novak, 2017)

Under Solidere, BCD reconstruction began in the 1990s, turning the war-affected region into a major redevelopment project. This renovation redefined the meaning and purpose of Beirut's downtown by reorganizing property ownership, planning authority, and urban shape rather than concentrating only on physical repair (Martinez-Garrido, 2008; Biscevic, 2014). Since then, academics have questioned whether this strategy created a regulated, privatized urban image consistent with international investment patterns or restored Beirut's historical character (Al-

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Harithy & Mneimneh, 2018; Karam, 2018). This change further shows how globalization affected post-war reconstruction, where cities were redesigned to compete in global economic networks and draw in transnational investment (Zoghi Hoseini et al., 2018). In this regard, Beirut's Central District was renovated to conform to international norms for real estate development, tourism, and finance, strengthening an urban image that appeals to foreign markets rather than regional customs. This globalization pressure does not entirely erase the local history of Beirut, but it helps to explain why the architectural image-making was affected by the global "world-class" branding and how it became prominent in how the center was redeveloped (Zoghi Hoseini et al., 2018; Peck et al., 2009).

The study aims to determine whether the restoration of Beirut's central area kept its architectural identity and urban fabric or developed a new, different urban image. The main research question is "How did post-war reconstruction in Beirut's Central District affect façades, urban density, and historical continuity, and shape its architectural identity?

The scope of this study is limited to investigating how the reconstruction affected façade design, urban density, and historical continuity in the downtown area that was damaged and divided along the green line. The analysis will include 3 dimensions, which are: Facade Strategy, to investigate whether the reconstruction went towards facadism or authentic restoration, Urban Density and Morphology, to compare the new taller, larger blocks to the traditional scale, and lastly, the Historical Continuity, to examine the extent to which the new BCD preserves or selectively erases the historical memory of the place. The research relied on a fully remote, archive-based approach; therefore, it only included online-accessible materials such as archival maps, photos, planning documents, and existing literature. The research only examines the reconstruction period led by Solidere in the early 2000s, when rebuilding became crucial for the whole city, not just for restoring physical structures. The scope does not extend beyond this period because the purpose is to understand how this specific moment established BCD's architectural identity as Lebanon was recovering from war.

2. LITERATURE REVIEW

This chapter examines Beirut's reconstruction through a historical lens, situates post-conflict rebuilding within broader urban strategies, explores the role of façades and heritage in shaping representation, and analyzes the implications of urban morphology and density in the evolving cityscape.

2.1 Beirut's Reconstruction in Historical Perspective

Beirut's reconstruction is part of a long list of planning interruptions, where Nasr and Verdil (2008) claim that modernization and redevelopment have reshaped the urban core many times. In Figure 2, Mazraani (2024) demonstrates that Solidere's reconstruction of BCD was

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established to revitalize Beirut's downtown after the civil war. Hindi (2018) further explains that the influence of colonial planning on Beirut's urban form was clear before the war, providing an important baseline for understanding historical continuity in this context.

After the war, the reconstruction of BCD intensified these processes. Martinez-Garrido (2008) describes the Solidere Project as a missed opportunity to resolve the conflict, as many public spaces, like Martyr Square, were lost. Biscevic in 2014 argued that Solidere is a kind of capital-driven urban reconstruction, as it served economic interests more than social recovery. Nasr and Verdeil's historical timeline framing shows that Beirut's post-war reconstruction isn't a single reset moment, but rather part of a long series of repeated planning, and how that reshapes the centre and redefines the city's core identity (Nasr & Verdeil, 2008).

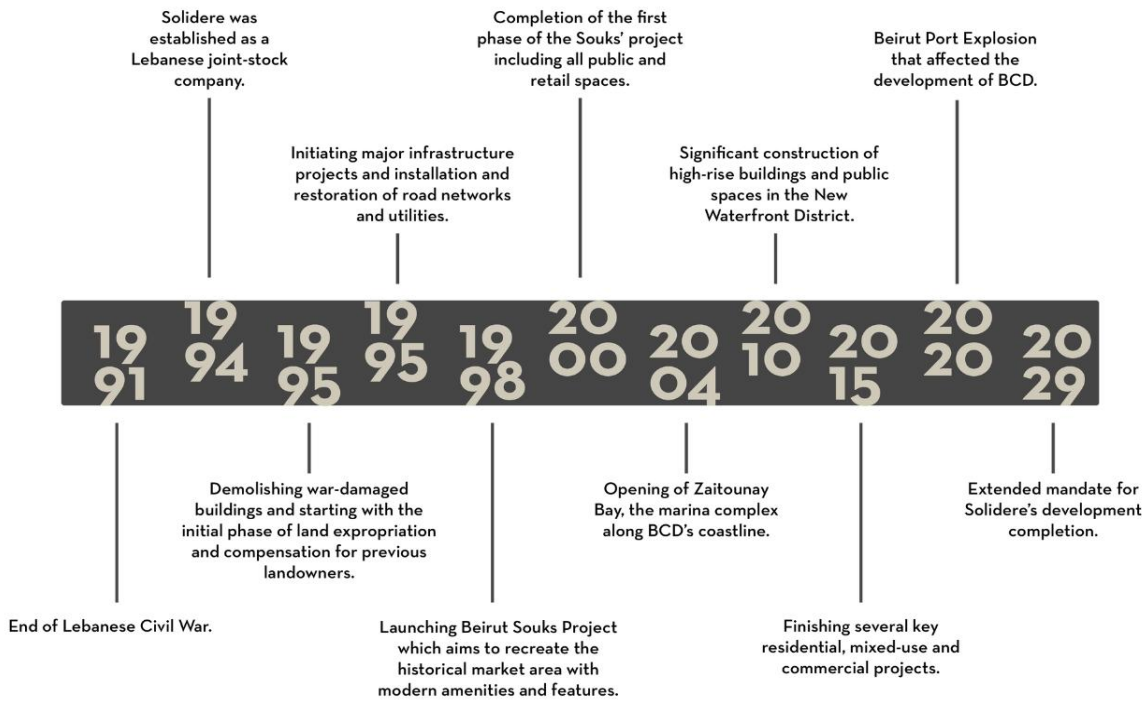

Figure 2. Solidere's reconstruction plan for the Beirut Central District following the Lebanese Civil War (Mazraani, 2024).

2.2 Post-Conflict Reconstruction and Urban Strategy

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In post-war urban reconstruction, Beirut is frequently used as a case study. Al-Harithy and Mneimneh (2018) criticize the national recovery for being reduced to a symbolic downtown project while ignoring deeper social and cultural repairing. In the same way, Verdeil (2010) and Leclair-Paquet et al. (2010) state that Beirut's post-war reconstruction prioritized image and control over public urban life. This repositions reconstruction not only as building replacement and repair, but also as a political project that defines access and the meaning of public space recovery (al-Harithy & Mneimneh, 2018; Leclair-Paquet et al., 2010). Figure 3 is an example of Solidere's restoration works: Restored quarter in Beirut's Central District. (Martínez-Garrido, L., 2008). Those critiques support studying the BCD through the historical continuity aspect and the public space change, because the successful reconstruction is not only measured by the looks of the building, but also whether the reconstruction functions as a shared space after division (Verdeil, 2010; Martinez-Garrido, 2008).

Figure 3. Restored urban quarter in Beirut's Central District as part of the Solidere Redevelopment Project (Martinez-Garrido, 2008).

2.3 Façades, Heritage, and Representation

Beirut's post-war heritage restoration has gone under severe criticism for putting appearance before authenticity. Saliba (2013) offers a clear analysis of conservation techniques that rely on facadism, creating structures that appear old but are detached from their original material logic and social context. This method hides discontinuities while showing superficial continuity. Figure 4 is a sketch showing the early evolution of Beirut's residential architecture by Robert Saliba, 2013. By analyzing how Beirut's reconstruction refined memory and destruction and turned history into a consumable picture, Cooke (2002) and Bravo (2019) extend this criticism. In this situation, legacy is no longer lived but simply represented.

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In this debate, facades serve as a primary site for visually reflecting continuity, even as the urban fabric and everyday practices change significantly (Saliba, 2013; Bravo, 2019), which is why facade strategies are considered one of the main analytical dimensions in this research.

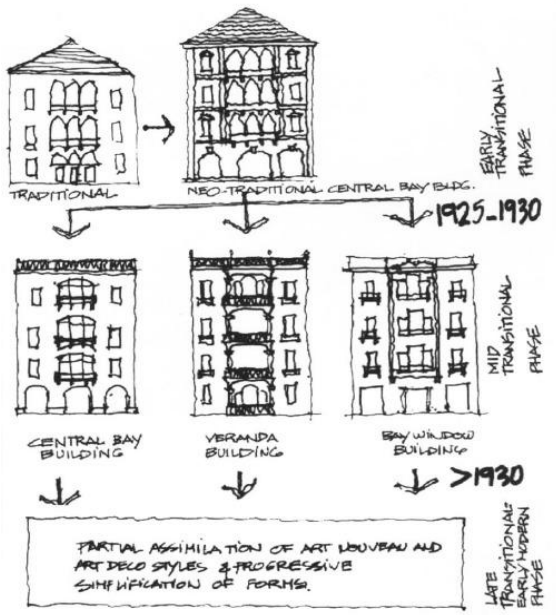

Figure 4. Evolution of Beirut's residential architecture illustrating traditional façade characteristics (Saliba, 2013).

2.4. Urban Morphology and Density

According to a study on urban morphology, identity is rooted in rhythm, scale, and block structure (Kristjánsdóttir, 2019). Larger blocks and new height regulations in line with global development models took the place of a fine-grained fabric in BCD restoration (Solidere, 2004; Karam, 2018). The spatial logic of daily living and the pedestrian experience were both impacted by these modifications (Zhang et al., 2023). Such morphological changes are characteristic of globalization-driven urban development, where local urban forms are adjusted to fit internationally recognizable models of density, scale, and land value (Zoghi Hoseini et al., 2018).

3. METHODOLOGY

This research was conducted through a purely qualitative methodology based on visual comparison and document analysis. This study applies to two interpreting frameworks, which are neoliberal urbanism and critical regionalism, when analyzing the facade strategies, urban morphology, urban density, and historical continuity. Data were collected through archival images, online documents, and maps (Solidere official files, UNESCO, and existing literature), and the before and after maps and images will be compared. The qualitative approach is suitable for this study because the research focuses on architectural identity, spatial transformation, and

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historical continuity, where interpretations require visual evidence and representational strategies rather than numerical data.

The comparative logic is built around the before-and-after pairings, where pre-war documents create a baseline condition, and the post-war documents show the outcome of this reconstruction, allowing changes to be traced across three dimensions of the study. The analytical steps involved in selecting key areas within the BCD, like Martyr Square and the waterfront, are based on their relevance to literature and their availability in archives. Next, compared the maps and the before-and-after documents considering facade strategies, which are openings, balconies, material expression, depth vs surface treatment (Saliba, 2013; Frampton, 1983). Urban density and morphology, which are block size and rhythm (Solidere, 2004; Kristjánsdóttir, 2019; Zhang et al., 2023), and Historical continuity, which is the transformation of the public spaces and representational vs lived identity (Martinez-Garrido, 2008; Cooke, 2002; Bravo, 2019; Al-Harithy & Mneimneh, 2018) and then interpret the results through two frameworks that are neoliberal urbanism and critical regionalism using the literature to support each analysis part.

3.1 Theoretical Framework:

This paper treats the theoretical framework as part of methodology, because the two frameworks below are used as interpretive tools that guide how the visual and document-based material is read and compared in the analysis. And it is explained below:

According to Peck et al. (2009), neoliberal urbanism describes how privatization, market-led planning, and centralized governance transform cities. This framework, when applied to Beirut, explains how Solidere turned the downtown into a controlled investment landscape where public space, density, and heritage are all managed to promote economic value (Biscevic, 2014; Martinez-Garrido, 2008). In this study, neoliberal urbanism is used specifically to interpret the redevelopment decisions and mechanisms as a part of the investment reconstruction model, where the results of it are shaped by the priorities of the market and private sector rather than actual public recovery (Peck et al., 2009; Biscevic, 2014).

Critical regionalism, instead of just reproducing surface-level regional imagery, offers a lens through which to evaluate whether architecture meaningfully responds to local climate, materials, and cultural conditions (Frampton, 1983). Studies stated that the importance of that regional identity must come from tectonic logic and lived practice, not aesthetic purpose (Zoghi Hoseini et al., 2018). This framework is used to assess the authenticity of BCD's reconstructed environment. In this research, critical regionalism is applied as a tool to evaluate facade reconstruction beyond appearance and to ensure that architectural elements are integrated as meaningful materials rather than just symbols (Frampton, 1983; Saliba, 2013).

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4. ANALYSIS

This study applies two interpreting frameworks, Neoliberal Urbanism and Critical Regionalism, to examine Facade Strategies, Urban Density and Morphology, and Historical Continuity. Through the application of these frameworks, the research enables a comparative analysis of Beirut's Central District before the civil war and the post- civil war reconstruction period.

4.1 Neoliberal Urbanism

Neoliberal Urbanism refers to an urban planning change driven by market trends, privatization, and profit maximization (Verdeil, 2011; Bravo, 2019). In Beirut, the post-war reconstruction of the Central District was handed to the private company Solidere, which did not just expand the urban footprint but also transformed the downtown into an exclusive zone of high-end businesses and a consumption hub oriented toward global capital. This method prioritized luxury development over public needs, reshaping the urban fabric of the post-war BCD.

<u>Façade Strategies:</u>

The historic facades in the BCD were often treated as superficial ornaments rather than a living heritage. Many historical and old buildings were demolished, and their mere appearances were later replicated. As Figure 5 shows, the reconstruction practice focused on "Facadism", preserving or recreating building front images without their context. Cooke (2002) notes that Solidere's new housing blocks were designed with "generic Arab Mediterranean Facades," styled to appear Levantine but lacking authentic detail. The reconstructed façades were designed for an elite audience. Solidere imposed strict and often costly design regulations, which compelled the original local owners to sell their holdings. As a result, residents were pushed, and the rebuild downtown became an elite-oriented environment created for investors,

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tourists, and high-income users. Together, these practices show how neoliberal façade policies create a socio-economic barrier (Bravo, 2019, Cooke 2002).

Figure 5. The focus of the reconstruction process is on "Facadism" (Martinez-Garrido, 2008).

The reconstruction of post-war Beirut Central District has significantly changed urban morphology by prioritizing large-scale development and vehicular accessibility over historic spatial patterns. The fine-grained historic street network made of small plots and narrow alleys was replaced with unified blocks as many individual parcels were converted into large development sites (Verdeil, 2011; Bravo, 2019). The Beirut Souks, which were known for a dense network of commercial passes, were reconstructed as a single, expensive retail complex framed by pedestrian corridors and open plazas, creating a different urban fabric. At the same time, as shown in Figure 6, new widened roads were introduced to facilitate vehicular access to the new business district. Although some historic elements were superficially preserved, many sub-roads were removed or realigned, creating a downtown characterized by orthogonal blocks and grand boulevards. This shift shows a broader replacement of traditional urban typologies with market-oriented spatial configurations that focus on ease of vehicular access and real estate value over pedestrian-oriented movement and the rhythm of everyday life.

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Figure 6. Showing the new road system in the BCD (Solidere, 2012)

Historical Continuity:

Heritage in the Beirut Central District was transformed into a branding campaign rather than meaningful preservation. Solidere promoted the image of Beirut as an "ancient city of the future", emphasizing archaeological remains such as Roman baths and Phoenician relics in the new downtown, while marginalizing more recent layers of urban memory, where only one third of traditional buildings were preserved, while the rest were demolished. (Makdisi, 1997; Saliba, 2013). This approach resulted in the loss of historical and symbolic heritage sites to be removed or replaced, as seen in Figure 7, with the Martyr Square (Martinez-Garrido, 2008).

Figure 7. Martyr's Square before the Lebanese Civil War (1960s) (left), compared with the reconstructed square in 2005 (right) (Martinez-Garrido, 2008).

4.2 Critical Regionalism

Critical Regionalism is an architectural approach that focuses on contemporary construction in local culture and environment. Frampton (1983) argues that architecture should be based on regional traditions, local materials, climate adaptation, and cultural symbols to resist the homogenizing effects of global modernism.

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Façade Strategies:

The façade strategies of Beirut's Central District reconstruction focused on making the design "Contemporary yet Lebanese" identity by using traditional architectural features. However, the outcomes were inconsistent and criticized. Many of the reconstructed facades superficially included these features and elements, resulting in repetitive and idealized compositions that Cooke describes as a "restored Levantine vernacular" and lacking depth (Cooke e, 2002). In the reconstruction, Saliba (2013) talks about how the exterior and design of the building are more important than connecting the facade to the interior, as they adopted regional motifs without considering the material authenticity considering the material authenticity. Figures 8 and 9 show a comparison of pre-war Beirut façades (Figure 8) and post-war reconstructed façades in the Beirut Central District (Figure 9). Pre-war façades rely on local materials and climate-responsive elements such as deep balconies and stone articulation. In contrast, the reconstructed façades reuse historic motifs but apply them as surface treatments with new materials and detailing. While these façades visually reference the past, they lack the tectonic clarity and climatic logic present in the pre-war buildings. This reflects Saliba's critique of postwar conservation in Beirut as producing "stage-set" façades that prioritize image over material and spatial authenticity, conflicting with the principles of critical regionalism.

Figure 8. Pre-war Beirut facades [26]

Figure 9. Post-war Beirut facades [28]

Urban Density and Morphology:

The pre-war urban fabric follows a consistent, human-scale density shaped by local growth patterns. The post-war reconstruction introduces larger blocks and increased building heights that reflect global development models rather than Beirut's historic scale. When read through critical regionalism criteria, this shift weakens the relationship between urban form and local identity, prioritizing image and investment over contextual scale (Zoghi Hoseini et al., 2018).

Historical Continuity:

ISBN NR: 978-625-5694-92-8

Figures 10 and 11 compare curated representations of heritage in the Beirut Central District with everyday urban practices elsewhere in the city. While Solidere's reconstructed spaces present heritage as a controlled visual image, lived identity emerges through informal use, social interaction, and everyday appropriation of space. This comparison reveals how regional identity in the BCD is displayed rather than embedded in daily urban life, supporting Bravo's reading of Beirut as a city where meaning is produced through lived experience rather than formal representation (Bravo, 2018).

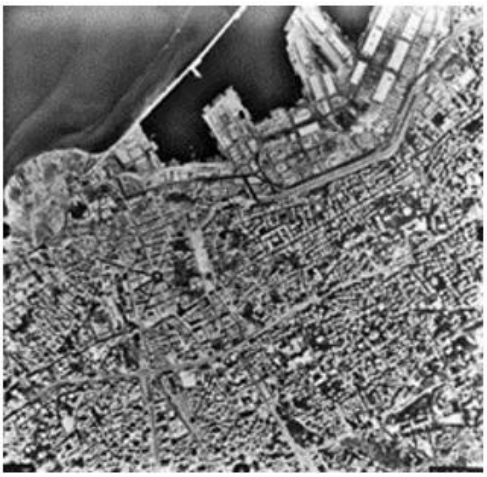

Figure 10. Pre-war Beirut [10]

Figure 11. Post-war Beirut [27]

Representative/curated identity (Solidere): Figure 12 shows a clean, empty, overly organized BCD image, and Figure 13 shows Star-architect developments in the new waterfront area.

Figure 12. The BCD [28]

Figure 13. Mina el Hosn [29]

Lived / everyday urban identity: Figure 14 and Figure 15 show El Hamra Street, a bustling downtown Beirut neighborhood known for its streetscape, where people coexist and appropriate the street and its sidewalks.

ISBN NR: 978-625-5694-92-8

Figure 14. El Hamra Street [30]

Figure 15. El Hamra Street [30]

5. FINDINGS

The reconstructed Beirut Central District is characterized by newly built structures that deliberately feature traditional facades; however, critics often characterize these as cosmetic. As Cooke (2002) notes, while the reconstruction aimed to represent heritage, it lacks heritage embodied.

Reconstruction also altered urban density and social composition by replacing low- to mid-rise fabric with high-rise buildings and luxury developments, thereby transforming the area to serve elites and foreign investors (Bravo, 2019). The public spaces, as well, were privatized, and mixed-use urban life allowed consumption-oriented environments to change the area's identity.

Although an attempt to replicate heritage and memory, historic continuity was selectively preserved. Archaeological sites and a limited number of surviving buildings, such as Saifi Village, were incorporated into the new plan (Bravo, 2019). In conclusion, the reconstruction project maintained a symbolic facade of continuity while diminishing the material and social fabric of the historic city.

6. DISCUSSION AND CONCLUSION

These findings showcase the tensions of reconstructing a post-war city. Solidere's post-war strategy focused on both continuity and transformation. On one side, it selectively preserved historical landmarks, offering a visual reference to Beirut's past. On the other hand, however, critics argue that this continuity is only symbolic.

These outcomes reflect a larger political-economic logic. Solidere prioritized efficiency, investment, and market attraction at the expense of memory and inclusivity. Supporters regard the project as restoring Beirut's regional image through the upgraded infrastructure and the tailored public spaces, while critics see it as class segregation. Urban form of the area was often determined by the real estate value; traditional features such as alleys were selectively referenced but not fully sustained.

Overall, the evidence of the reconstruction shows mixed results. The downtown shows a stylistic design and selective historical references, yet most of the city's social memory was removed. Scholars note this approach as exemplifying neoliberal urbanism, where Beirut was thought of as a marketable product and heritage became part of a branded identity instead of lived continuity (Cooke, 2002; Bravo, 2019)

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ISBN NR: 978-625-5694-92-8

HİBRİT KAMUSAL MEKÂNLAR: GENÇLERİN DİJİTAL KÜLTÜRLE ŞEKİLLENEN KENTSEL MEKÂN DENEYİMİ

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ÖZET

Kentsel kamusal mekânlar, kentlerin sosyal, kültürel ve ekonomik yaşamının temel bileşenlerinden biridir. Bu alanlar, bireylerin bir araya gelerek etkileşim kurduğu, dinlendiği ve kentsel yaşamın gündelik ritmine katıldığı ortak mekânsal platformlar olarak işlev görür. Özellikle gençler için kamusal mekânlar; sosyalleşme, etkileşim, kimlik gelişimi ve kolektif deneyim üretimi açısından kritik bir rol üstlenmektedir. Ancak günümüz kentlerinde gençlerin kamusal mekân kullanım biçimleri yalnızca fiziksel çevre koşullarıyla değil, aynı zamanda dijital teknolojiler, sosyal medya kültürü ve değişen yaşam pratikleriyle de giderek daha fazla şekillenmektedir. Mobil teknolojiler, konum tabanlı uygulamalar ve dijital iletişim ağları, gençlerin hangi mekânları tercih ettiğini, bu mekânlarda ne tür sosyal deneyimler aradığını ve kamusal alanı nasıl anlamlandırdığını yeniden tanımlamaktadır.

Bu bağlamda gençlerin kentsel kamusal alanlara yönelik alışkanlıkları; sosyal normlar, çevresel koşullar ve toplumsal algıların yanı sıra dijital kültürün yönlendirdiği yeni tercih kalıplarıyla biçimlenmektedir. Parklar, meydanlar, kıyı alanları ve canlı kent caddeleri gibi mekânlar hâlâ gençler için karşılaşma, deneyim ve sosyal bağ kurma alanları olmayı sürdürse de, bu mekânların kullanım biçimleri giderek daha hibrit ve teknolojiyle etkileşimli bir karakter kazanmaktadır. Hızlı kentleşme, dijitalleşme ve toplumsal dönüşümler, gençlerin kamusal mekân deneyimini yeniden şekillendirirken, geleceğin kentlerinde kamusal alanların nasıl tasarlanması gerektiğine dair yeni sorular ortaya çıkarmaktadır.

Bu çalışma, gençlerin kentsel kamusal mekânları nasıl kullandığını, bu mekânlardan beklentilerini ve sosyal tercihlerini inceleyerek teknoloji çağında değişen kamusal mekân deneyimini ortaya koymayı amaçlamaktadır. Elde edilen bulgular, gençlerin yöneldiği yeni mekânsal pratikleri anlamaya katkı sunarken, aynı zamanda geleceğin kentlerinde daha kapsayıcı, esnek ve genç odaklı kamusal mekân senaryolarının geliştirilmesine yönelik önemli bir tartışma zemini sunmaktadır.

Anahtar Kelimeler : Kamusal Mekan, Sosyalleşme, Gençler, Kentsel Mekân Deneyimi, Dijital Kültür

1.GİRİŞ

1.1. Dijital Dönüşüm ve Kentsel Sosyal Yaşam

20. yüzyılın sonlarında gerçekleşen dijital devrim, modern toplumun yapısını önemli ölçüde dönüştürmüş; toplumsal normlar, insan etkileşimi, kendini ifade etme biçimleri, medya kullanımı ve tüketim alışkanlıkları üzerinde derin etkiler yaratmıştır. Bu dönüşümün en görünür etkileri ise kentsel ortamlarda ortaya çıkmaktadır (Gutiérrez-Ujaque et al., 2025). Dijital teknolojilerin gündelik yaşamın ayrılmaz bir parçası haline gelmesiyle birlikte bireylerin iletişim kurma, bilgiye erişme ve sosyal ilişkilerini sürdürme biçimleri de yeniden şekillenmiştir.

Son yıllarda bilgi ve iletişim teknolojilerinin hızla gelişmesi, toplumsal yapının giderek daha fazla bilgi odaklı bir karakter kazanmasına yol açmıştır. Bu süreçte sosyal medya platformları bireylerin iletişim kurabileceği, etkileşimde bulunabileceği ve iş birliği geliştirebileceği katılımcı dijital ortamlar olarak önem kazanmıştır (Lampropoulos et al., 2022). Sosyal ağlar; kullanıcıların profil oluşturmasına, fotoğraf ve video paylaşmasına, durum güncellemeleri yapmasına ve arkadaşlarıyla iletişim kurmasına olanak tanıyan çok yönlü iletişim araçlarıdır (Horzum, 2016). Bu özellikleri sayesinde sosyal medya yalnızca bireyler arası iletişimi kolaylaştıran bir araç değil, aynı zamanda sosyal ilişkilerin kurulması ve sürdürülmesinde etkili bir sosyal platform haline gelmiştir (Reyes et al., 2026; Lampropoulos et al., 2022).

Dijital iletişim teknolojilerinin yaygınlaşmasıyla birlikte bireylerin sosyalleşme biçimlerinde de önemli değişimler ortaya çıkmıştır. Sosyalleşme, insan yaşamının temel ihtiyaçlarından biri olup geleneksel olarak yüz yüze etkileşimler aracılığıyla gerçekleşmiştir. Ancak çevrimiçi iletişim platformlarının erişilebilirliği ve kullanım kolaylığı, dijital etkileşim biçimlerini birçok birey için önemli bir alternatif haline getirmiştir (Reyes et al., 2026). Bu bağlamda günümüz toplumlarında sosyal ilişkilerin hem fiziksel hem de dijital mekânlar üzerinden kurulduğu hibrit bir sosyal yapıdan söz etmek mümkündür.

1.2. Çevrimiçi ve Çevrimdışı Sosyal Etkileşim

İnternetin sosyal etkileşim üzerindeki etkileri literatürde farklı yaklaşımlar çerçevesinde ele alınmaktadır. Bir görüşe göre çevrimiçi iletişim araçları yüz yüze etkileşimi destekleyici bir rol üstlenmekte ve bireylerin sosyal ilişkilerini güçlendirmektedir (Giddens, 2008; Lieberman & Schroeder, 2020). Buna karşılık bazı araştırmalar, bireylerin çevrimiçi ortamlarda daha fazla zaman geçirmesinin yüz yüze iletişim fırsatlarını azaltabileceğini ileri sürmektedir (Tosuntaş et al., 2024). Dolayısıyla literatürde dijital iletişim teknolojilerinin sosyal yaşam üzerindeki etkilerinin hem destekleyici hem de sınırlayıcı yönlerinin bulunduğu görülmektedir.

Bazı araştırmalar ise çevrimiçi etkileşimin çevrimdışı ilişkileri de güçlendirebileceğini göstermektedir. İnternet yeni sosyal ilişkiler geliştirmek için fırsatlar sunmakta, yüz yüze iletişimin mümkün olmadığı durumlarda sosyal destek sağlayabilmekte ve bireylerin ortak ilgi alanları etrafında sosyal gruplar ya da hareketler oluşturmasına olanak tanımaktadır (Lieberman & Schroeder, 2020). Aynı zamanda çevrimiçi iletişim araçları coğrafi mesafenin yarattığı engelleri azaltarak bireylerin sosyal ağlarını genişletmesine katkı sağlamaktadır (Reyes et al., 2026; Lieberman & Schroeder, 2020).

Bu bağlamda dijital sosyal etkileşimlerin bireylerin iyi oluşu üzerindeki etkileri de literatürde tartışılan önemli konular arasındadır. Araştırmalar dijital etkileşimlerin bireylerin psikolojik iyi oluşu üzerinde hem olumlu hem de olumsuz etkiler yaratabildiğini göstermektedir (Tibbetts et al., 2021). İnsanların sosyal ilişkiler kurma ve etkileşim içinde olma ihtiyacı doğuştan gelen bir gereksinimdir ve sosyal ilişkiler bireylerin refah düzeyinin en güçlü belirleyicilerinden biri olarak kabul edilmektedir (Tibbetts et al., 2021).

1.3. Dijital Sosyal Etkileşim Tercihleri ve Yeni Sosyalleşme Biçimleri

Çevrimiçi sosyal etkileşim tercihleri bireyler arasında farklılık gösterebilmektedir. Song ve Jiang (2015), bireylerin çevrimiçi sosyal etkileşimi tercih etme eğilimlerinin çeşitli bireysel ve sosyal faktörlerle ilişkili olduğunu ortaya koymuştur. Buna göre, yüz yüze iletişimde kendini daha rahat ifade edemeyen bireylerin çevrimiçi etkileşimi daha fazla tercih edebildiği görülmektedir. Ayrıca bireyin bulunduğu sosyal çevrede çevrimiçi etkileşimin yaygın olması, bu tercihi güçlendirebilmektedir.

Bununla birlikte, çevrimiçi ortamlarda daha aktif olan bireylerin bu iletişim biçimini daha güçlü biçimde benimsediği; mevcut yüz yüze ilişkilerinden daha az memnun olan bireylerin ise çevrimiçi etkileşime yönelme olasılığının daha yüksek olduğu belirtilmektedir.

Dijital iletişim teknolojilerinin yaygınlaşmasıyla birlikte yeni sosyalleşme biçimleri de ortaya çıkmıştır. Bu bağlamda literatürde “sofalizing” yani “sofalizasyon” kavramı dikkat

ISBN NR: 978-625-5694-92-8

çekmektedir. “Kanepe” ve “sosyalleşme” kelimelerinin birleşiminden türetilen bu kavram, bireylerin fiziksel olarak dışarı çıkmadan ev ortamında çevrimiçi platformlar aracılığıyla sosyalleşmesini ifade etmektedir (Tosuntaş et al., 2024). Bu eğilim özellikle genç kuşaklar arasında giderek daha görünür hale gelmektedir.

Günümüzde gençlerin büyük bir kısmı dijital teknolojilerle yoğun biçimde etkileşim içerisindedir. Araştırmalar gençlerin yaklaşık %95’inin akıllı telefon kullandığını ve %45’inin neredeyse sürekli çevrimiçi olduğunu göstermektedir (Lieberman & Schroeder, 2020). Dijital ortamlar gençler tarafından arkadaşlarıyla iletişim kurmak, eğlenceye erişmek, destek bulmak ve yeni bilgiler öğrenmek amacıyla yaygın biçimde kullanılmaktadır (Dodge et al., 2026). Bununla birlikte sosyal medya kullanımı yalnızca iletişim kurma aracı değil, aynı zamanda kendini ifade etme, popülerlik kazanma ve yeni sosyal ilişkiler kurma gibi motivasyonlarla da ilişkilendirilmektedir (Horzum, 2016).

1.4. Dijital Çağda Kentsel Kamusal Mekân, Gençler ve Sosyal Etkileşim

Dijital iletişim araçlarının yaygınlaşmasına rağmen kamusal mekânlar gençlerin sosyalleşme ve deneyim üretme süreçlerinde önemli bir rol oynamaya devam etmektedir. Kentsel kamusal alanlar bireylerin karşılaşma, etkileşim kurma ve sosyal bağlar geliştirme süreçlerinin gerçekleştiği temel sosyal mekânlardır.

Araştırmalar gençlerin özellikle hareketlilik deneyimini zenginleştiren, kamusal alanlarda doğal gözetim sağlayan ve farklı kullanıcı gruplarının bir arada bulunmasını teşvik eden yapılı çevre özelliklerini tercih ettiğini göstermektedir (Waintrub et al., 2024). Bununla birlikte çalışmalar kamusal alanların çoğunlukla yetişkin kullanıcıların ihtiyaçlarına göre düzenlendiğini ve gençlere yönelik mekânsal olanakların sınırlı kaldığını ortaya koymaktadır (Eriksen & Houborg, 2025). Bu durum gençlerin kamusal alan kullanımının ve bu alanlardan beklentilerinin daha fazla araştırılması gerektiğini göstermektedir.

Dijital teknolojilerin gelişmesi kentsel kamusal mekânların kullanım biçimlerini de dönüştürmektedir. Günümüzde kamusal alanlar yalnızca fiziksel karşılaşma mekânları değil, aynı zamanda dijital iletişim ağlarıyla etkileşim içinde olan hibrit sosyal ortamlar haline gelmektedir. Bu nedenle kentsel mekânların tasarımında yalnızca fiziksel özelliklerin değil, aynı zamanda kullanıcıların sosyal ve duygusal deneyimlerinin de dikkate alınması gerekmektedir.

Dijital çağda kentler dönüşmeye devam ederken, kentsel yaşamın duyusal ve duygusal boyutlarını önceliklendiren metodolojilerin benimsenmesi sürdürülebilir ve insan odaklı kentsel gelişim için önemli bir gereklilik olarak görülmektedir (Gutiérrez-Ujaque et al., 2025). Bu yaklaşım, kamusal mekânların yalnızca fiziksel kullanım alanları değil, aynı zamanda sosyal deneyim üretim alanları olarak ele alınmasını gerektirmektedir.

2. YÖNTEM

Bu araştırma, gençlerin kentsel kamusal mekân kullanım alışkanlıklarını, kamusal mekân tercihlerini, bu mekânlara yönelik sosyal algılarını ve dijital çağda değişen mekânsal yönelimlerini ortaya koymayı amaçlayan nicel bir araştırma olarak planlanmıştır. Araştırmada

ISBN NR: 978-625-5694-92-8

veri toplama yöntemi olarak anket tekniği kullanılmıştır. Anket yöntemi, kullanıcıların mekânsal davranışlarını, tercihlerini ve algılarını sistematik biçimde ölçebilmesi nedeniyle kentsel tasarım ve peyzaj mimarlığı araştırmalarında yaygın olarak kullanılan bir veri toplama aracıdır (Khalifa et all.,2022).

Peyzaj mimarlığı disiplini yalnızca fiziksel çevrenin estetik düzenlenmesiyle sınırlı olmayıp, aynı zamanda kentsel mekânların sosyal kullanım biçimlerini, sosyal etkileşim örüntülerini , kullanıcı davranışlarını ve gündelik yaşam pratiklerini anlamaya dayalı planlama ve tasarım stratejileri geliştirmeyi hedefleyen bir disiplindir. Bu nedenle genç kullanıcıların beklenti, alışkanlık ve tercihlerini anlamaya yönelik anket çalışmaları; geleceğin kentlerinde daha esnek, erişilebilir, sosyal olarak canlı ve dijital çağın davranış kalıplarına duyarlı kamusal alanların planlanmasında önemli bir araç olarak değerlendirilebilir.

Bu araştırma Trabzon kentinde yaşayan üniversite öğrencileri üzerinde yürütülmüştür. Genç katılımcılar, kamusal mekânları aktif biçimde kullanan ve kentsel sosyal yaşamın dinamiklerini belirleyen önemli bir kullanıcı grubu olarak kabul edilmektedir. Bu nedenle araştırmada, kentsel mekânları aktif biçimde deneyimleyen ve geleceğin kamusal alanlarına ilişkin planlama ve tasarım süreçlerinde rol alabilecek potansiyele sahip genç kullanıcıların kamusal mekân kullanım pratiklerini anlamaya yönelik bir örneklem tercih edilmiştir.

Anket formu dört ana bölümden oluşmaktadır. İlk bölümde katılımcıların sınıf düzeyi, cinsiyeti, ikamet biçimi, ulaşım tercihleri ve günlük olarak dış mekânda geçirdikleri süre gibi demografik ve gündelik yaşam verileri belirlenmiştir. Ayrıca kamusal mekânların kullanım sıklığı, kullanım zamanları ve amaçları da ankette yer alan sorularla belirlenmiştir.

İkinci bölümde kamusal mekân kullanım alışkanlıkları analiz edilmiştir. Bu bölümde katılımcıların serbest zamanlarında tercih ettikleri mekân türleri ve kentte en sık kullandıkları kamusal mekânlar sorgulanmıştır. Katılımcılardan sahil, park/yeşil alan, meydan, sokak, alışveriş merkezi çevresi, kafe-restoran, kültür-sanat mekânları ve kampüs alanları gibi farklı kamusal mekân türlerini tercih sırasına göre değerlendirmeleri istenmiştir.

Üçüncü bölümde katılımcıların kamusal mekân tercihlerini etkileyen mekânsal ve sosyo-kültürel faktörler değerlendirilmiştir. Anketin bu bölümünde katılımcıların bir kamusal mekânı tercih etmelerinde etkili olan faktörler incelenmiştir. Güvenlik, ulaşılabilirlik, konfor, estetik, temizlik, ekonomik uygunluk, etkinlik çeşitliliği ve dijital altyapı gibi mekânsal özelliklerin tercih üzerindeki etkileri değerlendirilmiştir.

Son bölümde ise 5'li Likert tutum ölçeği kullanılarak kamusal mekânların sosyal işlevselliğine ilişkin algılar ölçülmüştür. Bu kapsamda kamusal mekânların sosyal bağ kurma, gençlerin kent yaşamında görünürlüğünü artırma, kültür-sanat etkinlikleriyle ilişkilendirilmesi, sosyal medya etkisi, dijital altyapı olanakları ve mekânsal kapsayıcılık gibi konular 5'li Likert ölçeği kullanılarak değerlendirilmiştir.

3.BULGULAR

Anket verileri tanımlayıcı istatistiksel analiz yöntemleri kullanılarak değerlendirilmiştir. Katılımcıların demografik özellikleri ile kamusal mekân kullanım alışkanlıkları frekans ve

ISBN NR: 978-625-5694-92-8

yüzde dağılımları üzerinden analiz edilmiştir. Mekân tercihleri ve kamusal mekân algısına ilişkin Likert ölçeği verileri ise ortalama değerler üzerinden değerlendirilmiş; ölçeğin yapısal geçerliliğini ortaya koymak amacıyla faktör analizi uygulanarak faktör yükleri incelenmiştir.

Bu analizler sayesinde gençlerin kentte hangi kamusal mekân türlerini tercih ettiği, bu mekânları hangi amaçlarla kullandığı ve kamusal mekânların sosyal işlevselliğine ilişkin algılarının nasıl şekillendiği ortaya konulmuştur.

3.1.Katılımcı Profili ve Gündelik Yaşam Verileri

Araştırma kapsamında uygulanan ankete toplam 84 öğrenci katılmıştır. Katılımcıların sınıf düzeyi, cinsiyeti, barınma durumu, ulaşım türü, serbest zamanlarda tercih ettikleri kamusal alanlar ve günlük dış mekânda bulunma sürelerine ilişkin veriler, Çizelge 1'de yüzde (%) dağılımları ile sunulmuştur.

Çizelge 1. Katılımcıların profili ve günlük yaşam verilerinin % dağılımı

Değişken	Kategori	Oran (%)	Değişken	Kategori	Oran (%)
Sınıf Düzeyi	1. sınıf	25.3	**Günlük Dış Mekân Kullanımı**	6 saatten fazla	32.5
	2. sınıf	28.9		3–6 saat	37.3
	3. sınıf	21.7		2–3 saat	25.3
	4. sınıf	24.1		1 saatten az	4.8
Cinsiyet	Kadın	85.5	**Serbest Zaman Tercihi**	Açık alanlar	61.4
	Erkek	14.5		Kapalı mekânlar	38.6
Barınma Durumu	Ailemle	33.7	**Ulaşım Türü**	Toplu taşıma	83.1
	Tek başıma	9.6		Özel araç	7.2
	Yurtta	50.6		Yaya	9.6
	Arkadaşlarla	6			

Bulgular, örneklemin ağırlıklı olarak kadın öğrencilerden ve farklı sınıf düzeylerinden öğrencileri kapsayacak şekilde dengeli bir dağılım gösterdiğini ortaya koymaktadır. Bu durum, araştırmada elde edilen verilerin yalnızca belirli bir sınıf grubunun görüşlerini yansıtmakla sınırlı kalmayıp, üniversite öğrencilerinin farklı eğitim aşamalarındaki deneyimlerini kapsayan daha geniş bir kullanıcı perspektifi sunduğunu göstermektedir. Bu dağılım, genç kullanıcıların kamusal mekân deneyimlerinin farklı eğitim ve yaş evrelerini temsil eden bir örneklem üzerinden değerlendirilmesine olanak sağlamaktadır. Kadın katılımcıların yüksek oranı, akademik araştırmalara katılım konusunda daha istekli olmalarıyla ilişkilendirilebilir.

Araştırmaya katılan öğrencilerin önemli bir bölümünün ailelerinden uzakta ve geçici konaklama biçimlerinde yaşadığını göstermektedir. Bu durum, öğrencilerin gündelik yaşam pratiklerinde kamusal mekânlara yönelimini etkileyebilecek önemli bir sosyo-mekânsal değişken olarak değerlendirilebilir. Özellikle yurtta kalan öğrenciler için parklar, sahil alanları, kampüs çevresi ve kafe gibi kamusal mekânlar sosyal etkileşim ve gündelik yaşamın önemli parçalarından biri haline gelebilmektedir.

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Bu bulgular, üniversite öğrencilerinin kent içindeki hareketliliklerinin büyük ölçüde toplu taşıma sistemine bağlı olduğunu göstermektedir. Bu durum aynı zamanda genç kullanıcıların kamusal mekânlara erişiminde toplu taşıma bağlantılarının ve ulaşılabilirliğin önemli bir belirleyici faktör olduğunu ortaya koymaktadır.

Araştırma bulguları, gençlerin zorunlu kullanımlar dışında serbest zamanlarında açık kamusal alanları (%61,4) kapalı mekânlara (%38,6) kıyasla daha fazla tercih ettiğini göstermektedir. Bu durum gençlerin faaliyetlerini kamusal açık mekânlarda gerçekleştirme eğiliminde olduğunu ve kıyı alanları, parklar ve meydanlar gibi açık kamusal alanların genç kullanıcıların sosyal yaşamında önemli bir yer tuttuğunu göstermektedir.

Katılımcıların günlük olarak dış mekânda geçirdikleri süre incelendiğinde ise , öğrencilerin önemli bir bölümünün gün içerisinde uzun süre kamusal alanlarla ilişki içinde olduğu görülmektedir. Bu bulgular, üniversite öğrencilerinin gündelik yaşamlarının önemli bir kısmının kampüs çevresi, kafe, park, sahil ve benzeri kamusal mekânlarda geçtiğini göstermektedir. Genç kullanıcıların gün içerisinde uzun süre kamusal alanlarla etkileşim halinde olması, bu mekânların yalnızca rekreasyon alanları değil, aynı zamanda sosyalleşme, dinlenme, öğrenme ve gündelik yaşamın sürdürüldüğü önemli sosyal mekânlar olduğunu ortaya koymaktadır.

3.2. Kamusal Mekân Kullanım Alışkanlıklarına İlişkin Veriler

Katılımcıların kamusal mekân kullanım tercihleri incelendiğinde, birinci tercih düzeyinde en yüksek oranın sahil/kıyı alanlarına (%26,5) ait olduğu görülmektedir. Bunu kafe-restoran (%16,9) ve kampüs alanları (%14,5) izlemektedir. İkinci ve üçüncü tercihlerde ise alışveriş merkezi çevresi ve meydanların öne çıktığı dikkat çekmektedir. Buna karşılık sokak ve kapalı spor alanlarının oldukça düşük oranlarda tercih edildiği görülmektedir. Bu bulgular, genç kullanıcıların kamusal mekân tercihinde hem açık alanlara hem de sosyal etkileşim odaklı yarı kamusal mekânlara yöneldiğini göstermektedir. Bu durum gençlerin mekânsal tercihlerinin yalnızca doğa temelli açık alanlar ile sınırlı olmadığını, aynı zamanda sosyal etkileşim ve buluşma odaklı yarı kamusal mekânlara da güçlü bir yönelim bulunduğunu göstermektedir (Çizelge 2).

Genç kullanıcıların kamusal mekân tercihinde sosyal etkileşim ve hareketliliğin yoğun olduğu mekânlara yöneldiklerini göstermektedir. Özellikle sahil ve kıyı alanları, yürüyüş, buluşma ve sosyal etkinlikler açısından gençler için çekici kamusal alanlar olarak öne çıkmaktadır. Bununla birlikte kafe ve restoran gibi yarı kamusal mekânlar ise sosyal buluşma ve etkileşim açısından tercih edilmektedir.

Dolayısıyla genç kullanıcıların kentsel kamusal mekân deneyimi, açık kamusal alanlar ile sosyal buluşma mekânlarının birlikte var olduğu çok katmanlı bir kullanım biçimi ortaya koymaktadır. Bu durum, gençlerin kentte hem doğa ile ilişki kurabilecekleri hem de sosyal etkileşimlerini sürdürebilecekleri mekânlara ihtiyaç duyduklarını göstermektedir.

Çizelge 2. Katılımcıların kentte en çok kullandıkları kamusal mekân türleri

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Tercih Düzeyi	Sahil/Kıyı	AVM ve çevresi	Park/Yeşil Alan	Sokak	Meydan	Kafe-Restoran	Kapalı Spor	Kültür-Sanat	KTÜ Kampüs
1. Tercih	**26,5**	13,3	4,8	1,2	12,0	**16,9**	1,2	2,4	**14,5**
2. Tercih	10,8	**20,5**	12,0	1,2	**18,1**	8,4	3,6	7,2	7,2
3. Tercih	13,3	**16,9**	7,2	3,6	**16,9**	13,3	1,2	2,4	**13,3**

Öte yandan park ve yeşil alanların daha düşük tercih edilmesi, bu alanların genç kullanıcıların beklentilerine yeterince cevap vermediğini veya sosyal etkinlik açısından daha sınırlı kaldığını düşündürmektedir. Bu durum, kamusal açık alanların yalnızca yeşil alan olarak değil, aynı zamanda sosyal etkinlikleri destekleyen ve genç kullanıcıları çekebilecek programlar içeren mekânlar olarak tasarlanması gerektiğini göstermektedir.

Çizelge 3. Gençlerin en çok tercih ettikleri mekânları kullanımına ilişkin değerler

Değişken	Kategori	Oran (%)	
Mekânları kullanma sıklığı	Her gün	10,8	
	Haftada 1–2 gün	36,1	
	Haftada 3–4 gün	42,2	
	Ayda 1-2 gün	10,8	
Mekânların kullanılma zamanı	Sabah	2,4	
	Öğle	36,1	
	Akşam	59,0	
	Gece	2,4	
Mekânları kullanma amacı	**1. Amaç**	**2.Amaç**	**3. Amaç**
Arkadaşlarla buluşma	88,0	1,2	3,7
Yalnız zaman geçirme/rahatlama	8,4	25,3	--
Yürüyüş/gezinti	--	12,0	8,5
Spor yapma	--	6,0	2,4
Etkinlik/konser/sergi katılımı	--	7,2	2,4
Yeme–içme	--	34,9	12,2
Alışveriş	--	9,6	28,0
Ders Çalışma	--	--	30,5
Fotoğraf	--	--	4,9

Bu sonuçlar, genç kullanıcıların kamusal mekânları günlük yaşamlarının düzenli bir parçası olarak kullandığını göstermektedir. Kamusal alanların haftalık kullanım sıklığının yüksek olması, bu mekânların yalnızca rekreasyon amaçlı değil, aynı zamanda sosyalleşme, buluşma ve gündelik yaşamın sürdürülmesi açısından önemli mekânsal ortamlar olduğunu ortaya koymaktadır.

Katılımcıların kamusal mekânları günün hangi zaman dilimlerinde kullandıkları incelendiğinde, kullanımın büyük ölçüde akşam saatlerinde yoğunlaştığı görülmektedir. Bu durum, üniversite öğrencilerinin gündelik programlarının kamusal mekân kullanım zamanlarını belirleyen önemli bir faktör olduğunu göstermektedir. Ders saatleri ve eğitsel faaliyetler nedeniyle sabah saatlerinde kamusal mekân kullanımı sınırlı kalırken, sosyal buluşmalar ve rekreasyonel aktiviteler çoğunlukla akşam saatlerinde gerçekleşmektedir.

Katılımcıların kamusal mekânları hangi amaçlarla kullandıkları incelendiğinde, en yüksek oranın arkadaşlarla buluşma (%91,6) olduğu görülmektedir. Bu sonucu sırasıyla yeme-içme

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(%48,2)**,** alışveriş (%37,3), yalnız zaman geçirme/rahatlama (%33,7) ve ders çalışma (%30,1) izlemektedir. Bu bulgular, gençlerin kamusal mekânları öncelikle sosyal etkileşim ve buluşma mekânı olarak deneyimlediğini göstermektedir. Kamusal alanların genç kullanıcılar için yalnızca fiziksel bir rekreasyon ortamı değil, aynı zamanda sosyal ilişkilerin kurulduğu ve sürdürüldüğü bir buluşma platformu olduğu anlaşılmaktadır. Özellikle arkadaşlarla buluşma oranının oldukça yüksek olması, gençlerin kamusal mekânları gündelik sosyal yaşamın önemli bir parçası olarak kullandığını ortaya koymaktadır.

Çizelge 4. Genç Katılımcıların mekân tercihinde etkili olan faktörler

Bir mekânı tercih etmenizde en etkili faktörlerden üçü			
Değişkenler	**1.sıra**	**2.sıra**	**3.sıra**
Güvenlik	**39,8**		
Ulaşılabilirlik	**32,5**	**24,1**	
Konfor	**16,9**	**18,1**	9,6
Kalite	7,2	18,1	7,2
Wifi/elektrik		4,8	4,8
Estetik/kimlik		13,3	12,0
Temizlik	1,2	9,6	15,7
Sessizlik		2,4	3,6
Arkadaşlarımın tercih etmesi	1,2	4,8	4,8
Etkinlik çeşitliliği		2,4	14,5
Ekonomi		1,2	21,7

Katılımcıların bir kamusal mekânı tercih ederken dikkate aldıkları faktörler incelendiğinde, en önemli kriterin ulaşılabilirlik (%56,6) olduğu görülmektedir. Bunu sırasıyla konfor (%44,6) ve güvenlik (%39,8), mekân kalitesi (%32,5), temizlik (%26,5) ve estetik/kimlik (%25,3) gibi faktörler izlemektedir. Buna karşılık Wi-Fi veya elektrik erişimi (%9,6)**,** sessizlik (%7,2) ve arkadaşların tercih etmesi (%10,8) gibi faktörlerin daha düşük oranlarda tercih kriteri olarak belirtilmesi dikkat çekicidir. Bu durum, genç kullanıcıların kamusal mekân tercihlerinde teknolojik olanaklardan ziyade erişilebilirlik, konfor ve güvenlik gibi temel mekânsal özelliklere daha fazla önem verdiğini göstermektedir.

Peyzaj mimarlığı ve kentsel tasarım açısından değerlendirildiğinde bu bulgular, kamusal alanların genç kullanıcılar için çekici hale gelmesinde erişilebilir konum, mekânsal konfor ve güvenli kullanım koşullarının belirleyici olduğunu ortaya koymaktadır. Özellikle üniversite öğrencileri gibi genç kullanıcı grupları için kamusal mekânların kent içi ulaşım ağlarına yakın olması, konforlu oturma alanları ve güvenli kullanım ortamı sunması önemli bir planlama kriteri olarak değerlendirilebilir.

Araştırma bulguları, gençlerin kamusal mekânları öncelikle sosyal buluşma ve etkileşim alanları olarak deneyimlediğini ve mekân seçiminde erişilebilirlik, konfor ve güvenlik gibi temel mekânsal özelliklerin belirleyici olduğunu göstermektedir.

Çizelge 5 . Katılımcıların kamusal mekânlarda tercih ettiği sosyal ortam türleri

Kamusal mekânda en çok hangi sosyal ortamı tercih edersiniz?	
Sessiz ortamlar	**36,1**
Kalabalık ortamlar	1,2

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Trend/Popüler mekanları	14,5
Tavsiye edilen ortamlar	**22,9**
Eğlenceli ve renkli ortamlar	21,7
Doğal ve rahat ortamlar	1,2
Kendi standartlarıma uygun olması	1,2
Sessiz ortamlar	1,2

Genç kullanıcıların kamusal mekân deneyiminde yalnızca hareketli ve kalabalık ortamları değil, aynı zamanda rahat, sakin ve bireysel deneyime olanak tanıyan mekânsal atmosferleri de önemsediklerini göstermektedir. Özellikle sessiz ortamların yüksek oranda tercih edilmesi, gençlerin kamusal alanlarda sosyal buluşmaların yanı sıra dinlenme, düşünme ve bireysel zaman geçirme gibi ihtiyaçlarını da karşılamak istediğini ortaya koymaktadır.

3.3. Kamusal Mekân Algısı ve Sosyal İşlevselliğe İlişkin Değerlendirme

3.3.1.Tanımlı Buluşma Noktalarının Önemine İlişkin Değerlendirme

Katılımcıların büyük çoğunluğu bu unsuru önemli bir faktör olarak gördüğü anlaşılmaktadır. Gençler bu ifadeye 4 ve 5 düzeyinde yüksek katılım göstermiştir**.** Bu durum genç kullanıcıların kamusal mekânlarda buluşmayı kolaylaştıran belirgin referans noktalarına ihtiyaç duyduğunu göstermektedir. Tanımlı buluşma noktaları; meydanlar, anıtlar, kamusal sanat elemanları, simgesel yapılar veya belirli mekânsal odaklar gibi kent içinde yön bulmayı ve buluşmayı kolaylaştıran mekânsal referanslar olarak değerlendirilebilir. Bu tür mekânsal odakların varlığı, kamusal alanların sosyal etkileşimi destekleyen birer buluşma platformu olarak kullanılmasını kolaylaştırmaktadır.

3.1.2.Kentte Gençlere Uygun Kamusal Mekânların Yeterliliğine İlişkin Değerlendirme

Katılımcıların "Kentte gençlere uygun kamusal mekânlar yeterlidir" ifadesine verdikleri yanıtlar incelendiğinde, genel olarak bu görüşe düşük düzeyde katılım gösterildiği görülmektedir. Bulgulara göre katılımcıların %27,7'si en düşük düzey olan 1, %39,8'i ise 2 düzeyinde değerlendirme yapmıştır. Buna karşılık orta düzey katılım oranı %26,5, yüksek katılım düzeyleri ise oldukça sınırlı kalmıştır (%6 oranında 4, %0 oranında 5).

Bu sonuçlar, araştırmaya katılan gençlerin önemli bir bölümünün kentte genç kullanıcıların ihtiyaçlarına cevap verebilecek kamusal mekânların yeterli olmadığı yönünde bir algıya sahip olduğunu göstermektedir. Başka bir ifadeyle mevcut kamusal alanların gençlerin beklenti ve kullanım alışkanlıklarıyla tam olarak örtüşmediği söylenebilir.

3.1.3. Mekân Kimliği ve Estetiğinin Önemine İlişkin Değerlendirme

Katılımcıların "Mekânın kimliği ve estetiği (tasarım dili, özgünlük) benim için önemlidir" ifadesine verdikleri yanıtlar incelendiğinde, katılımcıların %42,2'si en yüksek katılım düzeyi olan 5**,** %37,3'ü ise 4 düzeyinde değerlendirme yapmıştır. Bu sonuçlar, genç kullanıcıların kamusal mekân tercihinde yalnızca işlevsel özellikleri değil, aynı zamanda mekânsal kimlik, estetik kalite ve tasarım özgünlüğü gibi nitelikleri de önemli bir kriter olarak değerlendirdiğini göstermektedir. Kamusal mekânların karakteristik ve özgün bir tasarım diline sahip olması, genç kullanıcıların bu alanlarla kurduğu ilişkiyi güçlendiren önemli bir unsur olarak öne çıkmaktadır.

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3.1.4. Güvenlik Kaygısı Nedeniyle Bazı Mekânlardan Kaçınma Durumuna İlişkin Değerlendirme

Katılımcıların "Güvenlik kaygısı nedeniyle bazı mekânlardan kaçınırım" ifadesine verdikleri yanıtlar incelendiğinde, %30,1'i bu ifadeye katılmadığını (1) belirtirken, %14,5'i düşük düzeyde katılım (2) göstermiştir. Bu dağılım, genç kullanıcıların bir kısmının kamusal mekânlarda güvenlik kaygısı yaşamadığını gösterirken, önemli bir bölümünün ise belirli mekânlardan güvenlik gerekçesiyle kaçınabildiğini ortaya koymaktadır. Özellikle yüksek katılım düzeylerinin toplamda dikkate değer bir oran oluşturması, güvenlik algısının kamusal mekân kullanımını etkileyen önemli faktörlerden biri olduğunu göstermektedir.

Faktör yükleri incelendiğinde, tüm ifadelerin kabul edilebilir düzeyde (≥.467) olduğu ve özellikle ekonomik uygunluk (.760) ve kapsayıcılık (.738) değişkenlerinin ölçeğin en güçlü bileşenleri arasında yer aldığı görülmektedir. Bu durum, kamusal mekân deneyiminin yalnızca fiziksel değil, aynı zamanda sosyo-ekonomik ve kapsayıcı boyutlarla şekillendiğini ortaya koymaktadır. Bulgular, gençlerin kamusal mekân tercihinde önceliğin ekonomik erişilebilirlik, güvenlik ve kapsayıcılık gibi temel niteliklere dayandığını göstermektedir. Buna karşılık, mekânın "popüler" ya da "sosyal medyada görünür" olmasının daha düşük düzeyde etkili olduğu anlaşılmaktadır. Bu durum, dijital çağın etkilerine rağmen genç kullanıcıların hâlâ fiziksel mekân deneyimini ve doğrudan sosyal etkileşimi önceliklendirdiğine işaret etmektedir.

3.1.5. Kamusal Mekânlara İlişkin Tutumların Değerlendirilmesi

Katılımcıların kamusal mekânlara ilişkin tutumları incelendiğinde, özellikle bazı ifadelerde yüksek düzeyde katılımın (4 ve 5) belirgin biçimde öne çıktığı görülmektedir. Özellikle kamusal mekânların ekonomik olarak erişilebilir olması (%54,2)**,** kapsayıcı olması (%43,4) ve güvenli kullanım koşulları sunması (%43,4) gibi unsurların genç kullanıcılar açısından en önemli kriterler arasında yer aldığı anlaşılmaktadır. Benzer şekilde kamusal mekânların kültür-sanat etkinlikleriyle desteklenmesi ve programlı etkinliklerle zenginleştirilmesi de yüksek düzeyde önemsenmektedir.

Buna karşılık, kamusal mekân tercihinde sosyal medya etkisi ve içerik üretimi gibi dijital odaklı unsurların görece daha düşük düzeyde önemsendiği görülmektedir. Ayrıca mekânın popüler olmasının sosyal işlevselliği artırdığı yönündeki görüşün düşük katılım düzeyinde kalması, genç kullanıcıların mekân tercihinde popülerlikten ziyade işlevsellik ve deneyim kalitesini önemsediklerini göstermektedir.

Çizelge 6. Kamusal mekânlara ilişkin tutum ifadeleri (Likert ölçeği, %)

İfade	1	2	3	4	5	mean
Kamusal mekânlar kentte "sosyal bağ" kurmamı sağlar	10.8	—	—	24.1	19.3	3.3
Kamusal mekânlar gençlerin kent yaşamında görünür olmasını destekler.	3.6	—	—	28.9	20.5	3.49
Kamusal mekânlar kültür-sanat etkinlikleriyle anlam kazanır	3.6	—	—	34.9	24.1	3.72
Kamusal mekânlar ekonomik olarak uygun olmalıdır	3.6	—	—	20.5	**54.2**	**4.18**
Mekânın sosyal işlevselliğini en iyi artıran şey "programlı etkinliklerdir".	7.2	—	—	22.9	24.1	3.49

ISBN NR: 978-625-5694-92-8

İfade	**1**	**2**	**3**	**4**	**5**	**mean**
Kamusal mekânı seçmemde sosyal medya etkili olur.	9.6	—	—	16.9	18.1	3.23
Kapalı mekânda internet/Wi-Fi/şarj noktası olması kullanımımı artırır.	12.0	—	—	21.7	33.7	3.54
Kamusal mekânda içerik üretimini önemsiyorum (foto/video)	16.9	—	—	14.5	13.3	2.87
Mekânın sosyal işlevselliğini en iyi artıran şey "popüler olmasıdır"	18.1	—	—	16.9	**4.8**	**2.66**
Mekânda rahatsız edilme riski kullanımımı azaltır	4.8	—	—	28.9	**43.4**	**4.02**
Kentsel alanlarda wifi ve internet imkanı, gençlerin sosyalleşme imkanını artırır	6.0	—	—	26.5	27.7	3.54
Kamusal mekânlar farklı kimlik ve yaşam tarzlarına kapsayıcı olmalıdır.	4.8	—	—	25.3	**43.4**	**3.98**

Bu bulgular genel olarak değerlendirildiğinde, gençlerin kamusal mekânlara ilişkin beklentilerinin sosyal etkileşim, güvenlik, kapsayıcılık ve erişilebilirlik ekseninde şekillendiği; dijital unsurların ise bu deneyimi destekleyen ancak belirleyici olmayan ikincil faktörler olarak kaldığı söylenebilir. Ayrıca, ortalama değerlerin genel olarak orta ve yüksek düzey arasında yoğunlaştığı görülmektedir. En yüksek ortalama değerin "kamusal mekânların ekonomik olarak uygun olması" (Mean=4.18) ifadesine ait olması, genç kullanıcılar açısından ekonomik erişilebilirliğin temel belirleyici olduğunu ortaya koymaktadır. Benzer şekilde güvenlik (Mean=4.02) ve kapsayıcılık (Mean=3.98) gibi unsurların da yüksek ortalamalara sahip olması, kamusal mekânların tercihinde sosyal ve mekânsal güvenliğin önemli bir rol oynadığını göstermektedir.

Buna karşılık, "mekânın popüler olması" (Mean=2.66) ve "içerik üretimi" (Mean=2.87) ifadelerinin düşük ortalama değerler alması, genç kullanıcıların kamusal mekân tercihlerinde popülerlik ve dijital görünürlükten ziyade işlevsellik, güvenlik ve deneyim kalitesini öncelikli olsuğunu ortaya koymaktadır. Sosyal medya etkisinin orta düzeyde kalması (Mean=3.23) ise dijital faktörlerin belirleyici değil, destekleyici bir rol oynadığını düşündürmektedir.

4. TARTIŞMA

Bu araştırmanın bulguları, gençlerin kentsel kamusal mekânlarla kurduğu ilişkinin tek boyutlu bir kullanım biçiminden ziyade, çok katmanlı ve dönüşen bir deneyim yapısı sergilediğini ortaya koymaktadır. Kuramsal çerçevede vurgulanan dijitalleşme, sosyal medya ve değişen sosyalleşme pratiklerinin kamusal mekân kullanımını dönüştürdüğüne ilişkin yaklaşımlar (Gutiérrez-Ujaque et al., 2025; Reyes et al., 2026), bu çalışmanın bulgularıyla birlikte değerlendirildiğinde daha bütüncül bir anlam kazanmaktadır.

Araştırma sonuçları, gençlerin kamusal mekânları öncelikle sosyal etkileşim ve buluşma alanı olarak kullandığını açıkça göstermektedir. Arkadaşlarla buluşma oranının yüksekliği, kamusal mekânların genç kullanıcılar için hâlâ temel bir sosyalleşme platformu olduğunu ortaya koymaktadır. Bu durum, literatürde çevrimiçi etkileşimlerin yüz yüze ilişkileri destekleyebileceğine yönelik görüşlerle (Lieberman & Schroeder, 2020) örtüşmektedir. Nitekim dijital iletişim araçlarının yaygınlaşmasına rağmen, fiziksel kamusal mekânlar gençler için sosyal ilişkilerin sürdürüldüğü vazgeçilmez ortamlar olmaya devam etmektedir.

Bununla birlikte çalışmanın önemli bulgularından biri, gençlerin kamusal mekân tercihlerinde açık alanlara yönelimin devam etmesi, ancak bu alanların sosyal mekânlarla birlikte

ISBN NR: 978-625-5694-92-8

kullanılmasıdır. Bu durum, kamusal mekân kullanımında "doğa–sosyal mekân" ikiliğinden ziyade, bu iki yapının birlikte var olduğu hibrit bir kullanım biçimine işaret etmektedir. Özellikle kıyı alanları, meydanlar ve kafe çevrelerinin birlikte kullanılması, gençlerin hem açık alan deneyimine hem de sosyal etkileşime eş zamanlı ihtiyaç duyduğunu göstermektedir.

Araştırma bulguları erişilebilirlik, konfor ve güvenlik gibi temel mekânsal özelliklerin yanı sıra estetik ve mekânsal kimliğin önemli bulunması, kamusal alanların yalnızca işlevsel değil, aynı zamanda deneyimsel ve algısal boyutlarıyla değerlendirildiğini göstermektedir. Bu bulgu, çağdaş kentsel tasarım yaklaşımlarında vurgulanan kullanıcı deneyimi ve mekânsal kalite kavramlarıyla örtüşmektedir.

Öte yandan çalışmada elde edilen önemli bir sonuç, gençlerin kamusal mekânlara ilişkin değerlendirmelerinde dijital etkenlerin ikincil bir rol oynadığını göstermesidir. Sosyal medya ve içerik üretimi gibi unsurların mekân tercihinde sınırlı etkisinin olması, literatürde tartışılan "dijital sosyalleşmenin fiziksel mekânın yerini alacağı" yönündeki yaklaşımları sorgular niteliktedir. Bunun yerine, dijital araçların kamusal mekân deneyimini destekleyen ancak belirleyici olmayan unsurlar olduğunu göstermiştir.

Bununla birlikte güvenlik algısının kamusal mekân kullanımını etkileyen önemli bir faktör olduğu görülmektedir. Katılımcıların bir bölümünün güvenlik kaygısı nedeniyle bazı mekânlardan kaçınması, kamusal alanların tasarımında güvenlik ve algılanan güvenlik kavramlarının önemini ortaya koymaktadır. Bu durum, Khalifa et all.,(2022)'in de ifade ettiği gibi özellikle genç kullanıcılar için kamusal mekânların yalnızca erişilebilir değil, aynı zamanda güvenli ve konforlu hissedilen ortamlar olması gerektiğini göstermektedir.

Tüm bu bulgular birlikte değerlendirildiğinde, gençlerin kamusal mekân deneyiminin sosyal etkileşim, mekânsal kalite, güvenlik ve kapsayıcılık ekseninde şekillenen çok katmanlı bir yapı sergilediği söylenebilir. Bu yapı, dijitalleşmenin etkisiyle dönüşmekte ancak fiziksel kamusal mekânların önemini ortadan kaldırmak yerine, bu mekânların daha esnek, deneyim odaklı ve kullanıcı merkezli biçimde yeniden düşünülmesini gerekli kılmaktadır.

Peyzaj mimarlığı ve kentsel tasarım açısından bu sonuçlar, kamusal mekânların yalnızca fiziksel düzenlemeler olarak değil; sosyal, kültürel ve deneyimsel süreçleri destekleyen bütüncül mekânsal sistemler olarak ele alınması gerektiğini ortaya koymaktadır.

5. SONUÇ VE ÖNERİLER

Bu çalışma, gençlerin kentsel kamusal mekân kullanım alışkanlıklarını, mekânsal tercihlerini ve bu mekânlara ilişkin algılarını ortaya koyarak, dijital çağda dönüşen kamusal mekân deneyimini değerlendirmeyi amaçlamıştır. Elde edilen bulgular, gençlerin kamusal mekânlarla kurduğu ilişkinin çok boyutlu ve dinamik bir yapı sergilediğini göstermektedir.

Araştırma sonuçları, genç kullanıcıların kamusal mekânları öncelikle sosyal etkileşim ve buluşma alanı olarak kullandığını ortaya koymaktadır. Bununla birlikte açık kamusal alanlara yönelik güçlü bir eğilim bulunmasına rağmen, bu alanların tek başına yeterli olmadığı; gençlerin kafe, restoran ve yarı kamusal mekânlarla birlikte hibrit bir kullanım pratiği geliştirdiği görülmektedir. Bu durum, gençlerin kamusal mekân deneyiminin doğa ve sosyal mekân arasında kurulan çok katmanlı bir ilişki üzerinden şekillendiğini göstermektedir.

Bunun yanı sıra genç kullanıcıların mekân tercihinde ulaşılabilirlik, konfor, güvenlik ve estetik kalite gibi mekânsal özellikleri ön planda tuttuğu belirlenmiştir. Özellikle mekânsal kimlik ve tasarım kalitesine verilen önem, kamusal alanların yalnızca işlevsel değil, aynı zamanda deneyimsel ve algısal boyutlarıyla da değerlendirilmesi gerektiğini ortaya koymaktadır. Öte yandan dijital olanakların kamusal mekân kullanımını destekleyici bir rol oynadığı, ancak belirleyici bir faktör olmadığı görülmektedir.

Araştırmanın dikkat çekici bulgularından biri, gençlerin mevcut kamusal mekânları yeterli bulmamasına rağmen bu mekânlara yönelik beklentilerinin yüksek olmasıdır. Bu durum, mevcut kamusal alanların genç kullanıcıların ihtiyaçlarına tam olarak cevap veremediğini, ancak bu kullanıcı grubunun kamusal mekânlara güçlü bir talep ve bağlılık geliştirdiğini göstermektedir.

Elde edilen bulgular doğrultusunda peyzaj mimarlığı ve kentsel planlama açısından aşağıdaki öneriler geliştirilebilir:

- Kamusal mekânlar, yalnızca rekreasyon alanları olarak değil; sosyal etkileşim, buluşma ve gündelik yaşamı destekleyen çok işlevli alanlar olarak tasarlanmalıdır.
- Açık kamusal alanlar, kafe, etkinlik alanı ve sosyal buluşma noktalarıyla desteklenerek hibrit kullanım senaryoları geliştirilmelidir.
- Kamusal mekân tasarımında erişilebilirlik, konfor ve güvenlik temel öncelikler arasında ele alınmalıdır.
- Genç kullanıcıların mekânla kurduğu ilişkiyi güçlendirmek için mekânsal kimlik, estetik kalite ve özgün tasarım dili ön planda tutulmalıdır.
- Kamusal alanlarda tanımlı buluşma noktaları ve mekânsal odaklar oluşturularak sosyal etkileşim desteklenmelidir.
- Farklı kullanıcı gruplarının ihtiyaçlarını karşılayacak şekilde kapsayıcı ve esnek mekânsal kurgular geliştirilmelidir.
- Kamusal alanlarda gündüz–akşam kullanımını destekleyen tasarım stratejileri (aydınlatma, güvenlik, etkinlik programları vb.) uygulanmalıdır.

Dijitalleşmenin etkisiyle dönüşen kent yaşamında kamusal mekânlar önemini kaybetmemekte; aksine genç kullanıcılar için daha esnek, daha deneyim odaklı ve daha kapsayıcı biçimde yeniden tanımlanmaktadır. Çalışmamız, gençlerin kamusal mekân deneyiminin fiziksel mekânın ötesine geçerek sosyal, kültürel ve deneyimsel katmanların kesişiminde yeniden üretildiğini ortaya koymaktadır. Bu bağlamda peyzaj mimarlığı disiplini, gençlerin değişen mekânsal beklentilerini okuyarak, geleceğin kentlerinde çok katmanlı, kullanıcı odaklı ve sürdürülebilir kamusal mekânların tasarlanmasında kritik bir rol üstlenmektedir.

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ISBN NR: 978-625-5694-92-8

YENİ DÖNEMDE İSLAM BAHÇELERİ: GELENEKSEL ESTETİĞİN MODERN ŞEKİLLERİ VE KULLANIM YÖNTEMLERİ

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ÖZET

İslam bahçeleri, tarih boyunca sadece doğa ile iç içe olma değil, aynı zamanda kültürel, dini ve estetik bir anlam taşıyan mekanlar olarak tasarlanmıştır. Geleneksel İslam bahçeleri, genellikle cennet tasavvurunu simgeleyen düzenlemeler, su öğeleri, geometrik desenler ve doğal bitki örtüsü ile şekillenmiştir. Bu unsurlar, hem estetik hem de manevi anlam taşıyan peyzajları oluşturur. Ancak 20. yüzyılın sonlarından itibaren, İslam bahçelerinin tasarımında önemli değişiklikler yaşanmış, geleneksel estetik anlayışları, modern peyzaj tasarımı ve mimariyle birleşerek yeni bir biçim almıştır.

Bu yazı, çağdaş İslam bahçelerinin tasarımında görülen geleneksel estetik ilkelerinin, modern malzemeler ve işlevsel unsurlarla nasıl bir araya geldiğini incelemektedir. Geometrik düzen, su öğeleri ve bitkisel desenler gibi geleneksel unsurlar, çağdaş tasarımlarda, özellikle kamusal

ISBN NR: 978-625-5694-92-8

alanlarda meditasyon, sosyalleşme ve doğa ile etkileşimi teşvik etmek amacıyla kullanılmıştır. Bu bağlamda, çağdaş İslam bahçeleri, geleneksel estetiği modern zamanların ihtiyaçlarına ve fonksiyonel taleplerine göre uyarlamaktadır.

Aga Khan Bahçesi (Kanada), Al-Azhar Park (Mısır), Doha İslam Sanatları Müzesi Bahçesi (Katar) gibi örnekler, bu dönüşümün somut örneklerini sunmaktadır. Her bir bahçe, geleneksel öğeleri modern biçimler ve malzemelerle harmanlayarak, yeni anlamlar ve işlevler yaratmaktadır. Bu tasarımlar, sadece görsel estetik değil, aynı zamanda insan-doğa ilişkisini yeniden inşa etme amacı gütmektedir.

Sonuç olarak, çağdaş İslam bahçeleri, geleneksel estetikle modern tasarım anlayışlarını birleştirerek hem kültürel mirası yaşatmakta hem de doğa ile insan arasındaki bağlantıyı yeniden şekillendirmektedir. Bu yazı, çağdaş İslam bahçelerinin tasarımındaki bu evrimi ve gelecekteki tasarımlar için ilham verici potansiyelini tartışmayı amaçlamaktadır.

Anahtar Kelimeler: Çağdaş İslam bahçeleri, Peyzaj tasarımı, Geometrik düzen

1. GİRİŞ

Kültürel çeşitlilik ve farklılık İslam dünyasının belirleyici özelliğidir (Ruggles, 2017). Kur'an'da cennet, altından nehirler akan, gölgeli ve bereketli bahçeler olarak tanımlanır. Bu tasvir, İslam coğrafyasında gelişen bahçe tasarımlarının mekânsal kurgusunu büyük ölçüde etkilemiştir. İslam bahçelerinde genel olarak, cennet tahayyülünü yansıtan dört kollu su sistemi (çahar bağ), simetrik eksenler, içe dönüklük, duvarla çevrili yapı ve bitkisel kompozisyonun kutsal metinlerle ilişkilendirilmesi gibi ortak unsurlar gözlemlenir. Özellikle İran ve Hindistan'daki Şah Abbas'ın İsfahan'daki çahar bağ ya da Babür dönemine ait Şalimar Bahçesi gibi örneklerde, bu temsiliyet çok belirgindir. Bahçeler çoğunlukla göğe dönük bir armoniyi ve sonsuzluk duygusunu verir; bu bağlamda "ideal" bir düzenin dünya üzerindeki izdüşümüdür (Turgut, 2026). İslam coğrafyasının büyük bölümünü kaplayan sıcak ve kurak iklim koşulları, bahçe tasarımında su yönetimini işlevsel olduğu kadar sembolik bir unsur hâline getirmiştir. Bu bağlamda geliştirilen kanal sistemleri yalnızca iklimi yumuşatmakla kalmamış; dört yönde kesişen su eksenlerinden oluşan çahar bağ düzeni, İslam bahçe geleneğinin temel mekânsal örüntüsü olarak yerleşmiştir.

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Bu temel örüntünün çağdaş İslam bahçelerinde nasıl ve hangi biçimlerde sürdürüldüğü, günümüz peyzaj mimarlığının önemli sorularından birini oluşturmaktadır.

Geçmişte İslam bahçeleri daha çok saray çevresinde, yönetici elitin mahremiyetine hizmet ederken (Ruggles, 2008; Moustafa, 2009); artık geniş kitlelere hitap eden kamusal peyzaj alanlarına dönüşmektedir. Bu dönüşümde, modern kent yaşamının beraberinde getirdiği yoğun yapılaşma, iklim krizi, sosyal yabancılaşma ve kamusal alan eksikliği gibi faktörlerin etkisi büyüktür. Modern İslam bahçeleri, geleneğin formunu değil anlamını taşır ancak bu anlam sabit değil, her seferinde iklimle, kültürle, kullanıcıyla, bağlamla yeniden yorumlanır.

2. YÖNTEM

Bu çalışma, günümüz İslam bahçelerinin çeşitli örnekler üzerinden incelenmesini hedeflemektedir. Bu çalışma nitel araştırma yaklaşımı kapsamında gerçekleştirilmiştir. Çalışmada, İslam bahçesi geleneğinin çağdaş yorumlarını analiz etmek amacıyla örnek olay incelemesi yöntemi kullanılmıştır. Farklı coğrafi ve kültürel bağlamları temsil eden Al-Azhar Park (Mısır), Aga Khan Garden (Kanada), Aga Khan Park (Toronto), Doha İslam Sanatları Müzesi Bahçesi (Katar) ve Mughal Garden (Hindistan) örnekleri seçilmiştir. Bu örnekler; mekânsal kurgu, su kullanımı, bitkisel tasarım ve kamusal kullanım açısından karşılaştırmalı olarak değerlendirilmiştir.

3. ÇAĞDAŞ İSLAM BAHÇELERİNİN DEĞERLENDİRİLMESİ

Bu bölümde, seçilen örnekler üzerinden çağdaş İslam bahçeleri mekânsal kurgu, su kullanımı, bitkisel tasarım ve kamusal kullanım açısından değerlendirilmiştir. Farklı coğrafi ve kültürel bağlamlarda geliştirilen bu bahçeler, geleneksel İslam bahçesi ilkelerinin çağdaş tasarım yaklaşımlarıyla nasıl yeniden yorumlandığını ortaya koymaktadır.

3.1. Al-Azhar Park'ın Değerlendirilmesi

Mısır – Al Darb al Ahmar bölgesinde atık çöp depolama alnının kaldırılması ile yapılmış alan, yaklaşık 30 ha büyüklüğündedir (Abdel Rahman & Yassin, 2016). Alan 2005 yılında açılmıştır (Görsel 1). Parkın tasarımında geleneksel İslam bahçesi öğeleri üç temel unsur aracılığıyla yansıtılmıştır.

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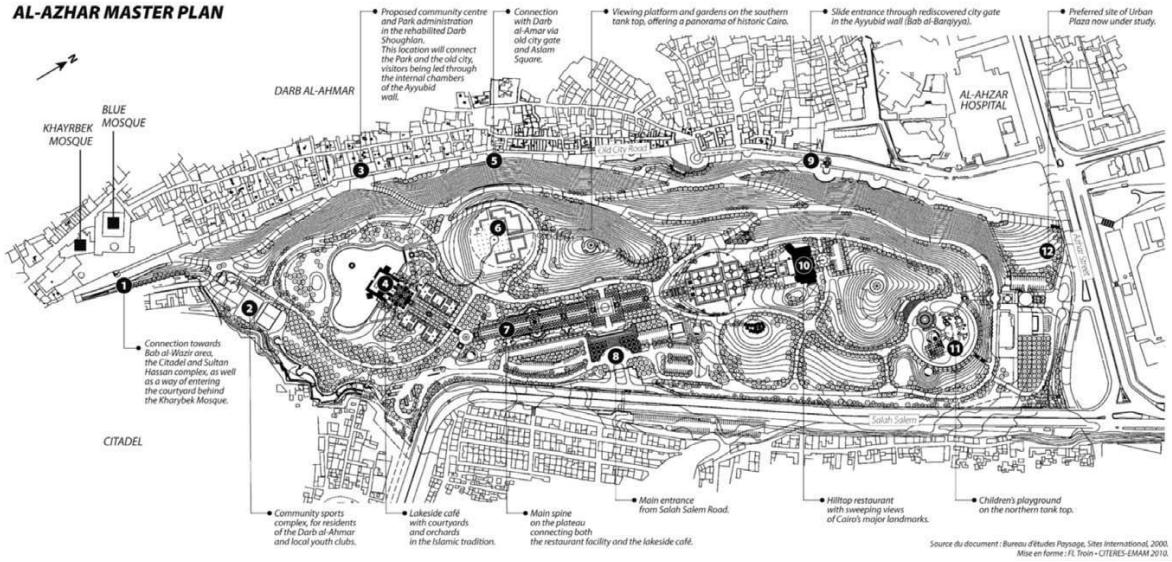

Görsel 1. Al-Azhar Park planı (URL 1)

Park, Fatimid ve Mameluk dönemlerine ait tarihi yapılarla çevrilidir. Kamusal park olarak tasarlanmış alanda (Aga Khan Historic Cities Programme, 2004); yürüyüş yolları, dinlenme alanları, çocuk oyun alanları, kafeler ve amfi tiyatro gibi yoğun sosyal kullanım alanları yer almaktadır (Ismail and Babatunde, 2009). Fatimid kemerleri, Timuri tarzı su kanalları, Mamluk taş işçiliği gibi tarihî peyzaj öğeleri çağdaş düzenle iç içe yerleştirilmiştir (Görsel 2).

Görsel 2. Al-Azhar Parkı'nda su öğelerinin kullanımı (URL 2)

3.1.1. Tasarım Özellikleri

Çahar bağ Düzeni: Parkın ana ekseni boyunca geometrik, simetrik bir dört bölmeli düzen hakimdir. Bu, klasik İslam bahçe planlamasının modern bir yorumu olarak irdelenir (Görsel 3).

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Görsel 3. Al-Azhar Parkı'nda çahar bağ sisteminin mekânsal kurgusu a) (URL 3) b) (URL 4) c) (URL 3)

Su Öğesi ve Aksiyel Su Kanalları: Yürüyüş eksenine paralel uzanan su kanalları, havuzlar ve çeşmeler İslam bahçesi estetiğini modern kamusal peyzajla buluşturur (Görsel 3).

Mamluk ve Fatimid Süslemeleri: Ayyubid duvarı, Fatimid kemerler ve Mamluk taş işçiliği, parkın hem anıtsal kimliğini hem de estetik referanslarını pekiştirir (URL 3)

Bitki Seçimi: Yerel iklime uygun ağaç ve çalılar kullanılmıştır; nemli batıya eğilimli alanlardaki yeşil zonlar, kuru bölümleri tanımlamak için steplerde sukulentler tercih edilmiştir. Özellikle hurma, turunç gibi meyve ağaçlarına yer verilmiştir.

Bitkilendirmede simetrinin ön planda tutulduğu görülmektedir. Geometrik olarak yerleştirilmiş meyve ağaçları hem İslam bahçesi geleneğinde hem de genel olarak tarihsel bahçecilik pratiklerinde önemli bir yer tutar. Bu düzenleme hem gözle takip edilebilir güzellik yaratır hem de cennet bahçesi idealini yansıtır (Ruggles, 2008).

3.2. Aga Khan Garden'ın Değerlendirilmesi

Geleneksel anlayışın çağdaş yorumlarına ışık tutan Aga Khan Garden, günümüz İslam bahçesi anlayışını farklı coğrafyalardaki örnekler üzerinden değerlendirme imkânı sunan; geleneksel estetiğin modern tasarım ilkeleriyle harmanlandığı önemli bir örnektir.

Aga Khan Garden, Kanada'nın Alberta eyaletinde, Edmonton kenti yakınlarındaki University of Alberta Botanik Bahçesi (eski adıyla *Devonian Botanic Garden*) içinde yer almaktadır. Kuzey yarıküredeki en kuzey İslami bahçe olarak tanımlanan 4.8ha'lık bu bahçe, Aga Khan IV tarafından University of Alberta Botanik Bahçesi'ne bağışlanmıştır. Bahçe, kuzey iklimine uygun bir Mughal/İslam peyzaj mimarisi yorumu olarak tasarlanmıştır; su, ışık, gölge, geometri ve yerel bitkilerle kültürel diyalog amacı güder (Görsel 4). Planlama aşaması 10 yıl sürmüş,

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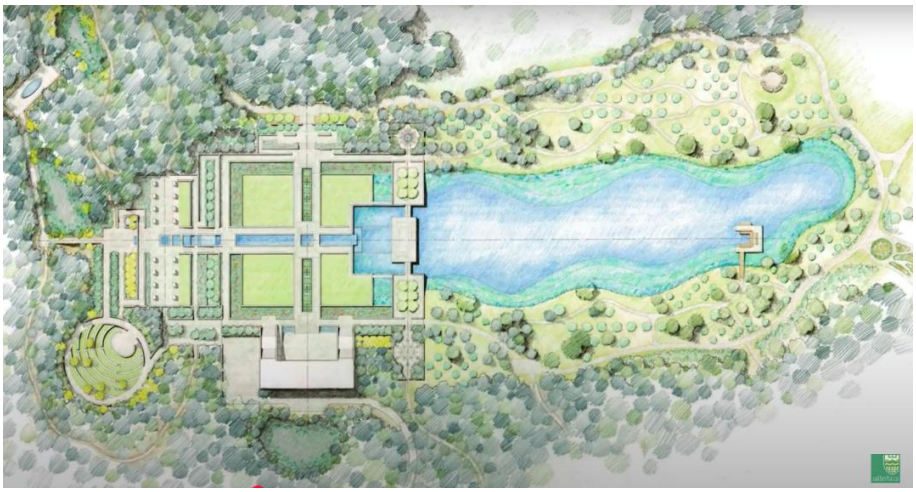
inşaat 18 ayda tamamlanmıştır. Park; 2018 yılında açılmıştır (Aga Khan Trust for Culture, 2018).

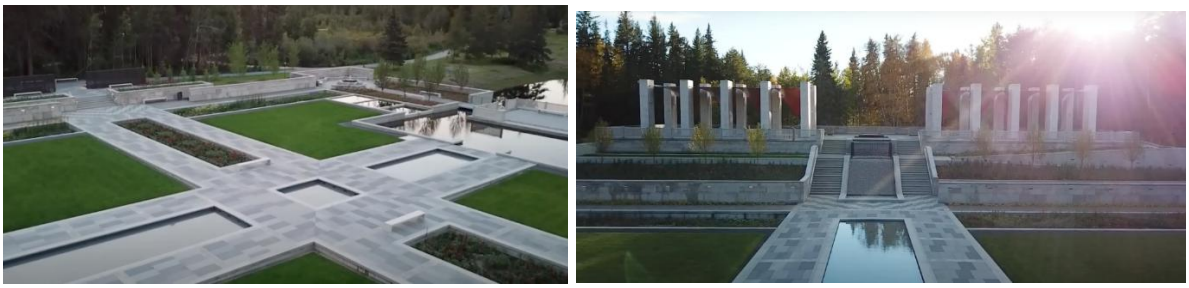
Bahçe, dinlenme, eğitim, bilimsel araştırma, kültürel etkinlikler ve toplumsal buluşma alanı olarak tasarlanmıştır. İçinde bir amfi tiyatro ve kültürel etkinliklere uygun Diwan Pavilion bulunmaktadır (Aga Khan Trust for Culture, 2018).



Görsel 4. Aga Khan Garden'ın plan görünüşü (URL 4)

3.2.1.Tasarım Özellikleri

Çahar bağ Plan Şeması: Bahçe, dört ana aksın birleştiği klasik çahar bağ (dört bahçe) plan düzenine sahiptir. Bu plan, cennet bahçesi anlayışının modern yansıtılmasıdır (University of Alberta, 2025) (Görsel 5).



Görsel 5. Aga Khan Garden plan şeması (URL 5)

Su Unsurunun Kullanımı: Basamaklı teraslardan süzülen su akışları, yansımalı havuzlar, doğal bir çağlayanla entegre edilmiş çukur havuzlara yer verilmiştir. Akan su, havuzlar ve su kanalları geleneksel İslam bahçelerinde olduğu gibi merkezi bir öğedir. Su, hem estetik hem de sembolik anlam taşır (Görsel 6).

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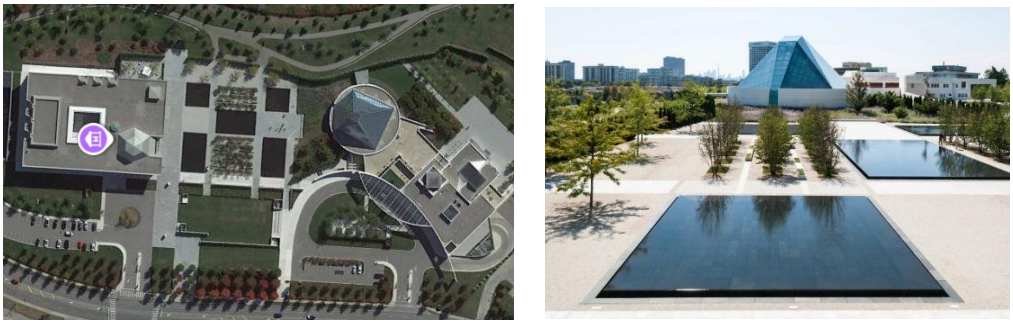
Bahçede kullanılan dört bölmeli tasarım, İslam'da cennet tasvirlerine ve Kur'an'daki dört cennet ırmağına gönderme yapar.

Bitki Seçimi: 25.000'den fazla bitki (ağaç, çalılık, sulak alan türleri)'nin yer aldığı bahçede; gül, lavanta gibi İslam bahçelerinde sık rastlanan bitkiler, geleneksel estetiği çağrıştıracak biçimde kullanılmıştır. Bitkisel düzenleme ve yol aksları simetri ve geometri ilkelerine göre tasarlanmıştır. Bahçe tasarımında çağdaş yorumlara da rastlanmaktadır. Kanada'nın soğuk iklimine uygun dayanıklı bitki türleri seçilerek, geleneksel türler yerel türlerle ekolojik açıdan dengelenmiştir. Modern erişilebilirlik standartlarına uygun yollar, rampalar ve oturma alanları dikkat çekmektedir. Malzeme seçiminde, geleneksel malzeme dokusunu çağrıştırsa da dayanıklı modern malzemeler kullanılmıştır. Aydınlatma, suyun akışı ve ses gibi unsurlar çağdaş tekniklerle kontrol edilmekte, böylece duyusal deneyim zenginleştirilmektedir (URL 6).

3.3. Aga Khan Parkı'nın Değerlendirmesi

Toronto, Kanada'da yer alan Aga Khan Parkı, Aga Khan Müzesi ve İsmaili Merkezi'nin çevresini kaplayan yaklaşık 6,8 hektarlık bir alandır. Lübnanlı peyzaj mimarı Vladimir Djurovic tarafından tasarlanan park 2015 yılında açılmıştır (URL 7) (Görsel 6).



Görsel 6. Aga Khan Parkı plan ve su öğesi görünüş (URL 7)

3.3.1.Tasarım Özellikleri

Çaharbagh Düzeni: Park; Babür ve Fars bahçe geleneklerinden ilham alan formel bir düzene sahiptir. Tasarımda çarhar bağ ilkesi temel alınmış, geometrik servis ağacı plantasyonları ve taş döşemeli yürüyüş eksenleri bu düzeni destekler biçimde kurgulanmıştır. Yeni Delhi'deki Hümayun Türbesi ve Granada'daki Elhamra avlu bahçeleri tasarımın başlıca referansları arasında yer almaktadır. Lübnanlı peyzaj mimarı Vladimir Djurovic tasarımında tarihi islam bahçelerinin uyandırdığı duygu, koku ve sesi aktarmaya karar verdi (URL 7).

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Su Unsurunun Kullanımı: Parkın merkezinde çarhar bağ düzeninde konumlandırılmış, siyah granit kaplama beş yansıtma havuzu yer almaktadır. Bu havuzlar, eksenel kanallar ve yürüyüş yollarıyla bölünmüş geleneksel dört bölümlü Fars su bahçesi anlayışını çağdaş bir yorumla yansıtmaktadır.

Tasarımda iklim koşulları belirleyici bir etken olmuştur. Toronto'nun sert kış koşulları nedeniyle su öğelerinin tasarımı özel bir mühendislik gerektirmiştir. Bu tercih, geleneksel İslam bahçelerinde işlevsel ve sembolik bir unsur olan suyun, farklı iklim bağlamlarında nasıl yeniden yorumlandığını somut biçimde ortaya koymaktadır.

Bitki Seçimi: Geleneksel Pers ve Babür dönemi çahar bağ tasarımından esinlenen bahçeler, yaban eriği ağaçlarının düzenli dikimleriyle doğal bir geometriye kavuşturulmuştur. Hem tefekkür için huzurlu bir alan hem de kamusal etkinlikler veya özel organizasyonlar için esnek alanlar sunmaktadır. Sedir çitlerle çevrili bir alanın ötesinde, bahçeler bir parka dönüştürülmüştür. Parktaki ağaçlar –*Magnolia stellata* (Yıldız Manolya), *Betula nigra* (Nehir Huş Ağacı), *Populus tremuloides* (Titrek Kavak) ve *Prunus serrulata* (Salkım Kiraz) gibi– çeşitli renkleri, Görselleri ve Kanada iklimine dayanıklılıklarıyla seçilmiş. Parkın her yerine kuşları ve kelebekleri cezbetmek için en uygun olan çalı ve bitkiler de dikilmiştir; bunlar arasında *Rose Glow Barberry, Chinese Wis*teria ve F*orsythia* sp. çalıları yer almaktadır (URL 7).

3.4.Doha İslam Sanatları Müzesi Bahçesi Değerlendirmesi

“Corniche”,Basra Körfezi kıyısında, başkent Doha’nın merkezinden geçerek kıyı boyunca kıvrılan yaklaşık 7 km uzunluğunda bir sahil promenadı olan Museum of Islamic Art binasının kıyı parkı, Corniche kenarında 4–5 hektarlık yapay bir yarımada üzerinde kurulmuş olup, Atlas Okyanusu'na uzanan manzaralı bir park alanıdır. 2012 yılında kurulmuştur (Al Fadala et all., 2023) (Görsel 7).

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Görsel 7. Doha İslam Sanatları Müzesi Bahçesi genel görünümü (URL 8), (URL 9)

Peyzaj Tasarımını Hiroshi Okamoto'ya aittir. Alan çöp sahasının kente kazandırılması projesidir. 23 metrelik bir heykelin yer aldığı alanda; yürüme yolları, oturma alanları, yeme içme alanları, çocuk oyun alanları yer almaktadır. Alan kültürel etkinliklere ev sahipliği yapmaktadır (Furlan & Sinclair, 2021).

3.4.1.Tasarım Özellikleri

Sahil boyunca yansıtıcı su yüzeyleri kullanılmıştır. Doğaya uygun organik rampalarla tasarlanmış yamaçlar; panoramik manzaraların izlenmesini sağlamaktadır. Deniz kenarında; yerel iklime uygun bitkilendirme, doğal rüzgar ve gölgeleme stratejisiyle çevresel sıfır-kaynak yaklaşımına paralel bir düzen kurulmuştur (Al Fadala et all., 2023).

Çahar bagh Düzeni: Doha İslam Sanatları Müzesi Bahçesi'nde klasik çahar bağ düzeni doğrudan uygulanmamış; ancak aksiyal kurgu ve geometrik organizasyon aracılığıyla bu sistemin çağdaş ve soyut bir yorumu geliştirilmiştir. Mekânsal düzen, İslam bahçesi geleneğinde görülen simetri ve düzen anlayışını yansıtmaktadır (Al Fadala et all., 2023).

Su Unsurunun Kullanımı: Projede su öğesi, geleneksel bahçelerdeki merkezi ve sembolik rolünden ziyade, estetik ve mekânsal sürekliliği destekleyen bir unsur olarak ele alınmıştır. Kıyı boyunca yer alan yansıtıcı su yüzeyleri, hem görsel etki yaratmakta hem de mikroklimatik katkı sağlamaktadır (Al Fadala et all., 2023).

Bitki Seçimi: Bitkilendirme tasarımında yerel iklim koşullarına uyumlu, düşük su tüketimine sahip bitki türleri tercih edilmiştir. Bu yaklaşım, sürdürülebilir peyzaj tasarımı ilkeleri ile örtüşmekte olup, İslam bahçesi geleneğinin çağdaş çevresel yaklaşımlar ile yeniden yorumlandığını göstermektedir (Al Fadala et all., 2023).

3.5.The Mughal Garden Değerlendirmesi

Hindistan'ın Yeni Delhi kentinde yer alan Rashtrapati Bhavan (Cumhurbaşkanlığı Sarayı)'ın hemen arkasında 6 ha lık alanda konumlandırılmıştır 1917 yılında Sir Edwin Lutyens tarafından planlanmaya başlanan alanın bitkisel düzenlemeleri 1928–1929 yıllarında William Robert Mustoe başkanlığında tamamlanmıştır. Bahçe 2023'te "Amrit Udyan" adını almıştır (URL 10).

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Görsel 8. Mughal Garden çahar bağ sisteminin mekânsal kurgusu (URL 11)

Rashtrapati Bhavan Mughal Bahçesi, geleneksel Babür bahçeciliği estetiğini modern peyzaj ilkeleriyle harmanlayan üç ana bölümden oluşmaktadır. İlk bölüm olan Dikdörtgen Bahçe, dört eşit parçaya ayrılmış klasik bir yerleşim düzenine sahiptir; ortada yer alan havuz ve çevresinde uzanan simetrik su kanalları, geleneksel cennet bahçesi anlayışını yansıtır. İkinci bölüm olan Gül Bahçesi (veya Uzun Bahçe), 16 kare gül yatağı, pergolalar ve tırmanıcı bitkilerle donatılmış özel bir alandır; bu düzenleme, hem bitkisel çeşitliliğe hem de kokusal deneyime önem verilen geleneksel bahçecilik geleneğini çağdaş bir formda sürdürmektedir (Görsel 9). Üçüncü bölüm olan Dairesel Bahçe (İnci Bahçesi), merkezde konumlandırılmış küçük bir güneşlenme havuzu ve çevresindeki dairesel bitki dizilimi ile dikkat çeker; aynı zamanda kelebek bahçesi olarak da işlev gören bu alan, doğa ile duyusal etkileşimi teşvik eden modern bir yorum sunmaktadır. Bu üç bölüm, geleneksel Babür bahçesi motiflerinin çağdaş ihtiyaçlara göre yeniden işlenmiş biçimlerini ortaya koymaktadır. Bahçe dönemsel olarak farklı özellikler ile geliştirilerek sürdürülebilir nitelik kazandırıldı. 1998'de yağmur suyu toplama, 2002'de tıbbi bitkiler eklendi; 2008'de "Roshni" ekolojik proje başlatıldı; 2015'te atık su muamelesi ve yeraltı sularına destek sistemi uygulandı (URL 12).

3.5.1.Tasarım Özellikleri

Çahar bağ Sistemi: Ana bahçe dört kola bölünmüş simetrik "çahar bağ" düzenine sahiptir. Bu alanın ortasında lotus tasarımlı fıskiyeler konumlandırılmıştır.

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Görsel 9. Mughal Garden'da çahar bağ sisteminin mekânsal kurgusu (URL 13)

Bitkisel Tasarım: *Rododendron* sp.ve mevsimlik çiçeklerin yer aldığı, 150'den fazla gül çeşidinin bulunduğu oldukça renkli bir tasarım dikkat çekmektedir.

Su Öğesi: Bahçe, yapay su kanalları ve havuzlarla desteklenmiştir. Su farklı formlarda dikkat çekmektedir (Görsel 10).

Görsel 10. Mughal Garden su öğesinin kullanımı (URL 13), (URL 14)

3.6. Sunder Nursery Değerlendirmesi

UNESCO Dünya Mirası alanı içinde yer alan Humayun Türbesi yakınındaki alandır. 2018 yılında açılan park geleneksel "çahar bağ" yapısı ile çağdaş çizgilerin bir araya geldiği tasarım özelliklerini gösterir. Park eski bir mezarlık alanına kurulmuştur. Simetrik su kanalları ve havuzları, dört bölmeli geometrik bahçe şeması ile tasarlanmış olan park alanı 36 ha alan üzerinde kurulmuştur (Görsel 11). 300'den fazla ağaç türünün kullanıldığı alanda, bitki tanıtım

ISBN NR: 978-625-5694-92-8

panelleri, çocuk oyun alanları ve amfitiyatro bulunur(Balasubramaniam, 2010, Adhiya, 2014, Nanda & Shaheer, 2015).

Görsel 11. Sunder Nursery'de su öğesinin kullanımı (URL 15)

Çalışma kapsamında incelenen örnekler, İslam bahçesi geleneğinin çağdaş peyzaj tasarımındaki yansımalarını ortaya koymak amacıyla belirli tasarım kriterleri çerçevesinde değerlendirilmiştir. Bu doğrultuda, geleneksel ve çağdaş İslam bahçeleri; mekânsal kurgu, su kullanımı, bitkisel tasarım ve kullanım biçimleri açısından karşılaştırmalı olarak analiz edilmiştir (Çizelge 1).

Çizelge 1. Geleneksel ve Çağdaş İslam Bahçelerinin Karşılaştırılması

Kriter	Geleneksel	Çağdaş
Plan	Çahar bağ	Esnek yorum
Su	Sembolik	Sürdürülebilir
Kullanım	Özel	Kamusal
Bitki	Fonksiyonel	Ekolojik
Anlam	Cennet metaforu	Sosyal + kültürel

4. SONUÇ

Çağdaş İslam bahçeleri, geleneksel sembollerini korurken daha esnek, erişilebilir ve çok katmanlı kullanıma açık tasarım dillerine yönelmiştir. Çalışmada ele alınan örneklerden de görüldüğü gibi geleneksel dört bahçe (çahar bağ) planı hâlâ birçok çağdaş tasarımda görülmekte; ancak artık bu planlar modern peyzaj unsurlarıyla yeniden yorumlanmaktadır.

Modern kullanıcı, bahçeyi sadece estetik bir unsur olarak değil; aynı zamanda dinlenme, sosyalleşme, yürüyüş, kültürel etkinlik ve doğayla temas kurma gibi çoklu işlevler üzerinden deneyimlemektedir. Su unsurunun kullanımı, geçmişteki gibi görsel ve sembolik önemini korurken; artık suyun verimli kullanımı, yağmur suyu hasadı ve doğal sulama sistemleri gibi sürdürülebilirlik ilkeleri ön plana çıkmaktadır. Bitkilendirme tercihleri de bölgesel iklim koşullarına ve ekosistem korumasına duyarlı biçimde seçilmektedir.

İslam estetiğinin zamansız unsurları geometri, tekrar, simetri, su ve gölge kullanımı çağdaş malzemeler, yapısal teknolojiler ve kentsel planlama anlayışlarıyla bir araya getirilmektedir. Bu da bahçeyi, geçmişle gelecek arasında bir köprü haline getirmektedir.

Sonuç olarak, modern İslam bahçesi anlayışı; gelenekten kopmadan, çağın ihtiyaçlarına yanıt veren, sosyal bütünleşmeyi ve çevresel sorumluluğu gözeten bir tasarım alanına dönüşmüştür. Bu bağlamda, geleneksel bahçe estetiğinin yalnızca yeniden üretimi değil, aynı zamanda güncellenerek yeniden yorumlanması söz konusudur.

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ISBN NR: 978-625-5694-92-8

THE SOCIAL GENDER OF SPACE: AN ANALYSIS OF THE FEMALE EXPERIENCE IN PEARL S. BUCK'S NOVEL THE MOTHER WITHIN THE CONTEXT OF FEMINIST SPACE THEORY

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ABSTRACT

Pearl S. Buck's novel The Mother tells the story of a woman's struggle for survival in rural China. The novel also presents a narrative that aims to make women's spatial experiences visible. This study aims to examine how space is constructed in the context of gender from the perspective of feminist spatial theory in the aforementioned novel. Feminist theory does not evaluate space merely as a physical environment; according to the theory, space is an area where social relations and power structures are produced. In this context, the limitation of women's movement, the separation of public and private space, and the invisibility of women in space constitute the fundamental issues of feminist spatial theory.

In the novel, places such as the village, the field and the home appear as spaces that determine the woman's life. The village functions as a space of social control. The home represents the space where the role of motherhood is produced. The field, on the other hand, is noteworthy as the space where the woman's productivity is displayed but is often rendered invisible. These spatial contexts significantly influence the woman's social position.

This study aims to read a literary novel within a feminist theoretical framework and to discuss the role of space in the production of gender within this context. It thus argues that the novel presents women's experience of space not as an individual experience, but as a representation of the patriarchal spatial order.

Anahtar Kelimeler: Feminist spatial theory, Gender, The Mother

1.INTRODUCTION

Space is not merely a neutral element that refers solely to the physical environment. It is a space where social relations are lived out and cultural norms are reproduced. In this context, the concept of space is a dynamic structure that shapes individuals' everyday experiences and facilitates the establishment and maintenance of social relations (Lefebvre, 1991). One of the major determinants in the formation of space is gender relations. Feminist theory argues that spaces designated as 'public' are not neutral spaces; rather, they are constituted in different ways for women and men within a patriarchal order. Feminist spatial researchers highlight that the public-private sphere distinction constitutes a fundamental social arrangement that restricts women's mobility (Massey, 1994; McDowell, 1999). From a feminist perspective, space is evaluated not merely as a structure with physical boundaries, but also as a social order in which

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social roles and power relations are produced (Rose, 1993). In a patriarchal social order, space is generally associated with women's domestic duties, whilst men are regarded as active participants in the public sphere. This situation results in women's mobility being confined within certain boundaries and their social roles being defined through these spaces. Feminist theory examines how women's spatial experiences and everyday practices are shaped within the social order, whilst also aiming to make visible the role of space in the production of gender (Spain, 1992).

In this respect, social space represents spheres of production not only in an architectural context but also in a cultural one. Literature emerges as one of the most significant representatives of this cultural context. Literary texts facilitate an understanding of social relations by making visible individuals' social positions and the ways in which these positions are shaped. In this context, the novel enables an analysis of the social dimension of space by bringing together the everyday life practices of its characters with spatial narratives. The spatial approaches developed through such studies present novels not merely as individual stories, but as narratives that reveal how space is constructed and experienced. For this reason, literary texts constitute a significant field of analysis for examining the relationship between space and gender.The novel we will examine in this study, Pearl S. Buck's *The Mother* (Figure 1), centres on the life struggles of a woman living in rural China, whilst also presenting a powerful narrative that brings to light women's social and spatial experiences. The novel recounts the life of a mother who, after being abandoned by her husband, is forced to take on both domestic responsibilities and agricultural work in order to raise her children and sustain her livelihood (Buck, 1933). Throughout this process, the woman's daily life largely unfolds within confined spaces such as the village, the home and the fields. In this context, these spaces function not merely as physical environments but also as social spaces where social roles are constructed.

The novel "The Mother" is a significant narrative that highlights the spatial constraints faced by women in a patriarchal social order. The novel's spatial structure reveals how a woman's restricted range of movement is defined by her social role through specific locations. The village, the field and the home constitute the settings of the female character's daily experiences, whilst also emerging as elements that determine her position within society. This study aims to examine how space shapes the experience of women as users by analysing Pearl S. Buck's novel *The Mother* from the perspective of feminist spatial theory. Accordingly, the spatial contexts that feature prominently in the novel's narrative will be analysed within the framework of feminist spatial theory, and the ways in which the female character's life is constrained within spaces such as the village, the home and the fields will be discussed. In line with this theoretical framework, the novel's spatial structure will be evaluated within the context of feminist spatial theory.

ISBN NR: 978-625-5694-92-8

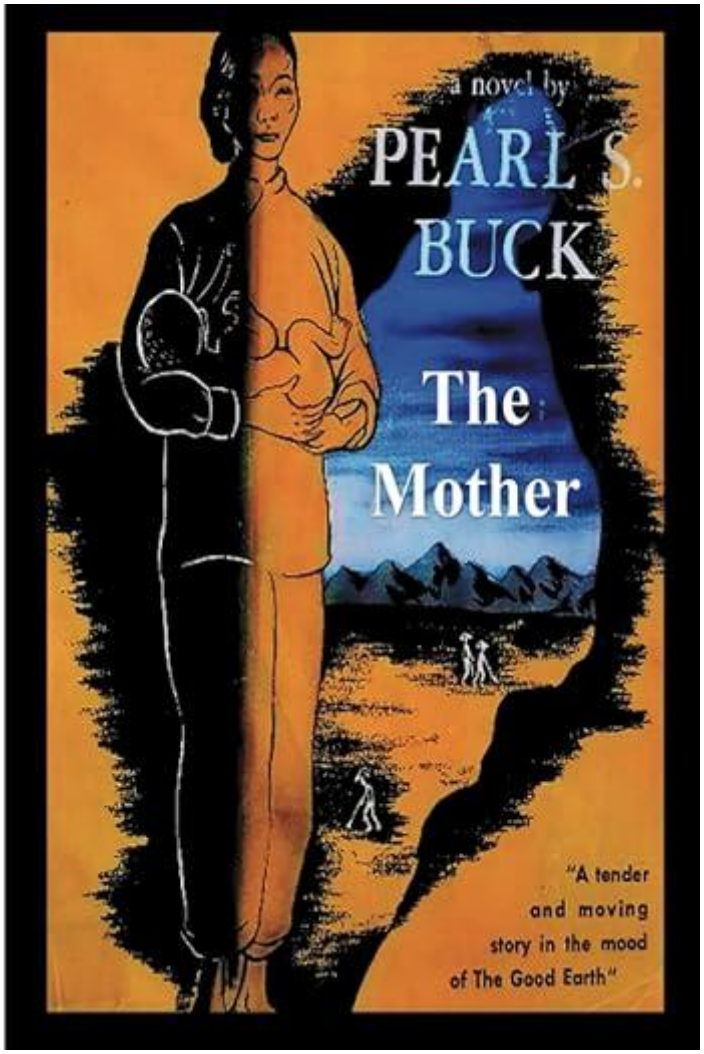

Figure 1. Pearl S. Buck's novel "The Mother"

2.AN ANALYSİS OF THE SPATIAL STRUCTURE OF THE NOVEL FROM THE PERSPECTIVE OF FEMINIST SPATIAL THEORY

It presents a narrative demonstrating how the life of the female character in the novel is shaped within specific spatial contexts. The spatial structure depicted in the novel will be examined in terms of the woman's visibility in public spaces, the significance of the land as a space of production, the limitations on the woman's range of movement, and the function of the private sphere. Within the scope of the analysis, the following topics will be discussed: the spatial confinement of the village, the function of the home as a private sphere, the meaning of the land as a space of production, the boundaries of the woman's sphere of movement, and the relationship between woman and space in terms of her spatial representation.

2.1.The Village's Spatial Enclosure

In Pearl S. Buck's novel *The Mother*, the village is portrayed as a spatial context in which the patriarchal social order is distinctly felt. In the village, the public sphere is largely under male domination, and social decisions are made by men. The mother character at the centre of

ISBN NR: 978-625-5694-92-8

the novel has very limited participation in public life; she is positioned more as a supporting or secondary figure within the village's male-centred order. This situation demonstrates that women's visibility in the public sphere is very low. When viewed through the lens of feminist spatial theory, the village functions not merely as a physical settlement but also as a space of surveillance where patriarchal social control operates. A woman's behaviour, motherhood, fidelity and diligence are constantly evaluated within the narrow social circle of village society, and this situation confines her social role within certain boundaries. Thus, the spatial boundaries of the village transform into a social framework that narrows the mother's life horizons, linking her destiny to biological reproduction and agricultural labour.

2.2.Home: A Haven or a Prison?

In feminist theory, the home is regarded as a contradictory space that embodies both security and oppression. On the one hand, the home is seen as the centre of family life and a sense of security; on the other, it is regarded as a private sphere where women's social roles are restricted and reproduced (Spain, 1992). In the novel *The Mother*, the home becomes a space where, in the husband's absence, the mother is forced to take on all responsibilities. Life within the home creates a context that renders the mother's loneliness and heavy responsibilities visible. The woman becomes responsible for both the care of the children and the continuity of the family. In this respect, whilst the home emerges as a space that reinforces the mother's maternal identity, it simultaneously becomes a confining space that limits her potential to develop other social identities. Thus, the home functions as a spatial arrangement where women's identities are reproduced and social roles are fixed.

2.3.Land: Freedom or Necessity?

The field, one of the novel's key settings, is a place of production where the mother is forced to work in order to sustain her life. Whilst the field is a space where the woman demonstrates her physical strength and resilience, this labour is often rendered socially invisible. Although the woman expends intense labour to ensure the family's economic survival, this labour is largely accepted as a natural duty and is not recognised as a social value. The symbolic relationship established between nature and fertility in Buck's narrative is also noteworthy. The parallel drawn between the mother's body and the earth's productivity points to the naturalisation of women's productive and reproductive capacities. Feminist theory, however, argues that such naturalisations constitute a discourse that ideologically legitimises women's labour and social roles. In this context, the field can be regarded both as a productive space where life is sustained and as a spatial context in which women's labour is rendered invisible.

2.4.Limitations of the Range of Motion

According to feminist spatial theory, an individual's social position is directly linked to their opportunities for spatial movement. The fact that women's scope of movement is limited leads to a narrowing of their social freedoms (Massey, 1994). In the novel *The Mother*, the mother's life is largely shaped within the triangle of the village, the home and the fields. The

ISBN NR: 978-625-5694-92-8

absence of the city or alternative living spaces within the narrative demonstrates that the woman's life horizon is confined within specific spatial boundaries.

This situation reveals that the woman's social destiny is spatially constrained. The mother character is surrounded both by the walls of the house and the social boundaries of the village. The absence of any possibility of escape clearly demonstrates that the space functions as a patriarchal prison.

2.5.The Spatial Representation of Women

The mother figure at the heart of the novel can be seen not merely as an individual character, but also as a symbolic figure representing the experiences of women in patriarchal societies. Buck's narrative brings to light the invisibility of women's labour and the limitations women face in social spaces.
However, the novel does not present women solely as passive figures of victimhood. The resilience, labour and continuity practices developed by the mother within her daily life can also be interpreted as a form of silent resistance emerging within the patriarchal spatial order. In this respect, the novel demonstrates that women not only live within restrictive spatial conditions but also develop strategies for survival and resistance within these conditions.

3.RESULTS AND DISCUSSION

This study aims to examine Pearl S. Buck's novel *The Mother* within the framework of feminist spatial theory, with a view to revealing how it shapes women's spatial experience. The analysis reveals that the spaces featured in the novel—such as the field, the village and the home—are not merely physical environments, but also spaces where gender roles are constructed. In the novel's narrative, the village is portrayed as a space of patriarchal order and social control, whilst the home is represented as a space where the woman assumes the role of motherhood. The field, meanwhile, is regarded as a space that reveals the woman's productivity yet remains largely unseen. When these three spaces are considered together, it becomes apparent that the female character's life is constrained and her scope of movement is confined within specific spatial frameworks.

When examined from the perspective of feminist spatial theory, it becomes evident that space plays a significant role in the establishment and maintenance of social relations. It highlights the constraints to which the female character is subjected within the patriarchal order, as well as her struggle for existence as a mother, as manifested through the practices of daily life.

Consequently, the novel provides a significant example for understanding space within a gender context. By highlighting the invisibility of women's labour, the limitations on their movement, and the impact of the patriarchal spatial order on women's lives, it offers a powerful narrative that can be evaluated within a feminist spatial framework. Furthermore, the evaluation of literary texts within a spatial perspective constitutes an important area of research for interdisciplinary studies aimed at understanding the relationship between gender and space.

ISBN NR: 978-625-5694-92-8

Such analyses enable a more comprehensive assessment of the relationships between space, gender and cultural studies.

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ISBN NR: 978-625-5694-92-8

THE PRODUCTION OF SPATIAL MEANING: AN EXAMINATION THROUGH BASIC DESIGN ELEMENTS AND DESIGN PRINCIPLES IN LANDSCAPE ARCHITECTURE

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ABSTRACT

In contemporary discourse, the concept of space is understood not merely as a physical environment, but as a phenomenon produced through social, cultural, and experiential processes. Public landscape areas, particularly those found in cities, play a significant role in the production of spatial meaning as key spaces where users engage in social interaction and experience the space. This study aims to examine the role of basic design elements and design principles used in landscape architecture in the production of spatial meaning. A qualitative research method was employed in the study, involving a literature review and case study analysis. The Central Park (New York), Trabzon EYOF Olympic Park (Trabzon) and High Line (New York) projects were analysed in terms of basic design elements and design principles. The research findings indicate that design principles used in landscape design-such as rhythm, balance, emphasis, hierarchy and unity-have a significant impact on spatial perception and user experience. The study demonstrates that landscape architecture is not merely an aesthetic arrangement, but also a key tool in fostering social interaction and shaping spatial identity.

Keywords: Spatial meaning, Landscape architecture, Basic design principles, Public space, Spatial perception

1. INTRODUCTION

Cities are not merely spaces composed of a collection of physical structures. They are also complex systems where social relationships are established, cultural values are produced, and individuals carry out their daily life experiences. Space is one of the fundamental research topics

ISBN NR: 978-625-5694-92-8

of disciplines such as architecture, urban planning, geography, and landscape architecture. In traditional approaches, space has mostly been considered as a physical and geometric arrangement, and the technical and aesthetic dimensions of spatial arrangements have been emphasized. However, especially since the second half of the 20th century, the view that space should be considered not only as a physical arrangement but also as a product of social and cultural processes has gained importance (Lefebvre, 1991).

The concept of spatial meaning has become an important research topic, particularly in urban studies. Spatial meaning is formed through how individuals perceive space, the emotional connection they establish with space, and their social experiences. Public landscape areas play an important role in this process. Parks, squares, and open spaces have a significant place in the production of spatial meaning as areas where people interact socially and experience urban life. In this context, landscape architecture is not merely an aesthetic arrangement process. Landscape design is a design process that directly influences how people perceive space and the relationship they establish with it. The fundamental design elements and principles used in this process shape spatial experience. Spaces are not only physical entities but also multi-layered areas that interact with individuals through senses, images, meanings, and experiences. Design elements lie at the heart of these experiences. Basic elements such as line, form, color, texture, direction, proportion, and rhythm not only determine the aesthetic character of a space but also directly influence the user's psychological, perceptual, and behavioral responses. The aim of this study is to examine the role of fundamental design elements and principles used in landscape architecture in the production of spatial meaning. In the research, the effects of landscape design on spatial perception and user experience were evaluated by analyzing examples such as Central Park, Trabzon EYOF Olympic Park, and High Line.

2. THEORETICAL FRAMEWORK

2.1. The Social Production of Space

One of the most important theorists addressing the social dimension of the concept of space is Lefebvre. According to Lefebvre, space is not only a physical entity but also a phenomenon produced by social relations (Lefebvre, 1991). Lefebvre explains the production of space with a three-dimensional model: spatial practices, spatial representations, and representational spaces. Spatial practices express how people use space in their daily lives, while spatial representations encompass planning and design processes. Representational spaces express how individuals experience space. The interaction of these three dimensions enables the formation of spatial meaning.

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According to this perspective, cities, parks, and public spaces are not merely composed of a collection of physical elements. These spaces are also shaped by economic systems, cultural values, and political processes. Therefore, space is considered an area where social order is reproduced. Harvey (2001) also examines spatial production within the context of capitalist production relations, emphasizing that space is shaped by economic systems. According to Harvey, urban spaces and landscape designs are often shaped by the needs of economic processes. When considered within the context of landscape architecture, parks and public open spaces are important components of social life. These areas play a significant role as places where social interactions take place, cultural events are organized, and urban identity is formed.

2.2. The Production of Spatial Meaning in Landscape Architecture

Landscape architecture is a discipline that addresses the natural and built environment with a holistic approach. Landscape design includes not only aesthetic and ecological arrangements but also social and cultural dimensions (Corner, 1999).

Landscape spaces gain meaning through the experiences and social interactions of users. Parks, gardens, and public open spaces play an important social role as places where people come together, relax, and socialize. In this context, landscape architecture plays a role in the production of spatial meaning in three fundamental ways:

- Ecological arrangement: Integration of natural elements into the space
- Social use: Public spaces enabling social interactions
- Cultural representation: Landscape design reflecting local identity and cultural values.

Spaces are not merely physical entities, but multifaceted entities that interact with individuals through senses, images, meanings, and experiences. At the heart of these experiences lie design elements. Fundamental elements/principles such as line, form, color, texture, direction, proportion, and rhythm not only determine the aesthetic character of a space but also directly influence its meaning. In landscape design, the basic design elements constitute the fundamental components of spatial organization. These elements are point, line, form, texture, color, and scale. A point creates a focal point in a space, while a line directs spatial movement. Form expresses three-dimensional spatial arrangements, while texture defines surface characteristics. Color creates the atmosphere of a space, while scale influences how users perceive the space. Basic design principles determine the arrangement of design elements. The most commonly used design principles in landscape design are rhythm, balance, emphasis, hierarchy, and unity. Rhythm refers to the regular repetition of spatial elements, while balance ensures an even distribution of visual weight in the space. Emphasis creates focal points that

ISBN NR: 978-625-5694-92-8

attract attention, while hierarchy determines the spatial organization. Unity ensures that design elements form a harmonious whole. Using basic design elements/principles, emotional meanings (comfort, joy, tranquility), symbolic meanings (power, belonging, community), and aesthetic meanings (beauty, balance, integrity) can be created in a space (Ching, 2007; Norberg-Schulz, 1980; Lynch, 1964). The impact of design elements and principles on spatial perception and the production of spatial meaning can be summarized as follows:

Table 1. The effect of design elements and principles on spatial perception and spatial meaning production.

Design Element/Principle	Use in Landscape Design	Impact on Spatial Perception	Contribution to the Production of Spatial Meaning.
Point	Focal elements such as sculptures, monuments, special trees, and water features	It directs the user's attention to a specific point.	It creates symbolic meaning and identity by establishing a focal point in the space.
Line	Walkways, axes, plant borders	It determines the direction of movement and creates spatial flow.	It shapes the way the space is experienced by directing user movement.
Form	Plant groups, topography, structural elements	It provides three-dimensional spatial organization.	It determines the character and atmosphere of the space.
Texture	Plant materials, stone pavements, water surfaces	It creates visual and tactile variety.	It strengthens spatial perception by enriching the user experience.
Color	Plant species, flowers, material choices	It affects the emotional atmosphere of the space.	It strengthens spatial identity with seasonal change and aesthetic diversity.
Scale/Proportion	Design appropriate to human scale	It facilitates the user's relationship with the space.	It creates user comfort and a sense of belonging.
Rhythm	Tree rows, plant repetitions, regular elements	It creates a sense of visual continuity and movement.	It provides spatial order and perceptual continuity.
Balance	Symmetrical or asymmetrical element distribution	It provides visual stability.	It strengthens the aesthetic integrity of the space.
Emphasis	Sculpture, water feature, special plant groups	It creates attention-grabbing areas.	It creates focal points that define spatial identity.
Hierarchy	Main roads, secondary roads, open space organization	It provides spatial order and orientation.	It determines user movement and spatial organization.
Unity	Harmony of plant species, materials, and design language	It creates a sense of unity in the space.	It strengthens the identity and aesthetic integrity of the space.

In this research, academic studies on spatial meaning, landscape architecture, and fundamental design principles were examined as part of the literature review. Within this scope, three important landscape projects were selected for the research:

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- High Line (New York)
- Central Park (New York)
- Trabzon EYOF Park (Trabzon)

These projects were analyzed in terms of their fundamental design elements and design principles.

3. FINDINGS

3.1. Analysis of High Line in Terms of Design Elements, Principles, and Spatial Meaning

The High Line is one of the most impactful adaptive reuse projects in contemporary landscape architecture. This former freight railway line, built in the 1930s, was transformed into a public park between 2009 and 2019. The design work was primarily undertaken by James Corner (Field Operations), Diller Scofidio + Renfro, and plant designer Piet Oudolf. (Sun, 2021; URL 1).

Figure 1. High Line (URL 1)

High Line is a significant example that clearly demonstrates the role of design elements and design principles in the production of spatial meaning. The project not only creates a recreational area but also produces a layered spatial narrative that brings together urban memory, ecological processes, industrial heritage, and user experience.

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Table 2. An analysis of High Line in terms of spatial meaning, in line with its design elements and principles.

Design Element/Principle	Use in Landscape Design	Impact on Spatial Perception	Contribution to the Production of Spatial Meaning.
Point	Artworks located in specific areas, seating terraces, viewing balconies and water features	It draws the user's attention to specific points along the walking route.	It enriches the spatial experience by creating focal points that relate to the city landscape.
Line	The basic design of the park is a linear walkway, a design following the railway tracks and plant bands	It directs the user's movement in a unidirectional flow.	It establishes continuity with urban history by tracing the old railway line.
Form	Waving seating elements, platforms, plant masses and raised topographic surfaces	It creates three-dimensional spatial variety.	It creates a combination of natural and industrial forms that define the character of the space.
Texture	Weed-like plants, plant textures emerging from between concrete slabs, wooden seating elements	It creates visual and tactile variety.	It produces an urban ecological identity through the fusion of industrial infrastructure and natural landscape.
Color	Seasonally changing plants, flowering periods and natural color palette	It changes the atmosphere of the space according to the season.	It creates a sense of time and season by reinforcing the idea of bringing nature back to the city.
Scale/Proportion	Walkways, seating areas and platforms suitable for pedestrian scale	It provides the user with a safe and comfortable experience.	It creates a human-scale escape space within the density of the city.
Rhythm	Repeating concrete slabs and plant strips along with railway tracks	It enhances the sense of movement and provides visual continuity.	It produces perceptual continuity and rhythmic spatial experience throughout linear movement.
Balance	Balance established between plant density and hard surfaces	It provides visual stability.	It creates urban ecological aesthetics with the balance of natural and artificial elements.
Emphasis	Viewing terraces, platforms opening to the city view, art installations	It directs the user's attention to specific spatial scenes.	It creates a spatial narrative by allowing the city to be experienced from different perspectives.
Hierarchy	Main walking axis, resting areas, viewing points and connecting stairs	It increases the readability of the space. It creates a holistic perception in the space.	It structures the spatial experience in stages by organizing user movement.
Unity	Plant palette, material language and design approach that preserves the railway tracks	It draws the user's attention to specific points along the walking route.	It creates a strong spatial identity unique to the High Line through the fusion of industrial history and natural landscape.

3.2. Analysis of Central Park in Terms of Design Elements and Principles, and Spatial Meaning

Central Park is one of the most important examples of the modern urban park concept. It was designed to meet the need for public green space in the rapidly growing city of New York in the 19th century. The park's design was realized within the framework of the Greensward Plan, developed in 1858 by landscape architect Frederick Law Olmsted and architect Calvert Vaux. Central Park represents a design approach that combines the romantic aesthetics of the natural landscape with urban planning. In this context, the park is not only a recreational area but also

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a spatial meaning-making space that shapes the social, cultural, and experiential dimensions of urban life (Rybczynski, 1999; URL 2).

Figure 2. Central Park (URL 2)

Table 3. Analysis of Central Park in terms of spatial meaning according to its design elements and principles.

Design Element/Principle	Use in Landscape Design	Impact on Spatial Perception	Contribution to the Production of Spatial Meaning.
Point	Bethesda Fountain, monuments, bridges, lakeside viewpoints	It directs the user's attention to specific spatial focal points.	It creates strong social and visual focal points within the park.
Line	Tree rows, walking paths, bike paths and park axes	It determines the direction of movement and organizes the circulation system.	It creates a fluid spatial experience within nature by guiding user movement.
Form	Wide meadows, lakes, undulating topography and vegetation	It provides three-dimensional spatial diversity.	It creates a pastoral atmosphere within the city by emphasizing the natural landscape character.
Texture	Grass areas, dense groups of trees, rocky areas and water surfaces	It provides visual and tactile diversity.	It enhances the feeling of contact with nature by strengthening the natural landscape experience.
Color	Seasonal vegetation, flower gardens and tree species	It changes the atmosphere of the space according to the seasons.	It strengthens the perception of time and the cycle of nature through seasonal changes.
Scale/Proportion	Wide meadows (Sheep Meadow), human-scale paths and open spaces	It offers the user both a broad landscape experience and individual use areas.	It creates a feeling of freshness and freedom within the density of the city.
Rhythm	Tree rows, repeating walkways and plant arrangements	It creates visual continuity and a sense of movement.	It provides perceptual continuity and a regular landscape experience throughout the space.
Balance	Balanced distribution of open meadows and dense woodlands	It creates visual and spatial balance.	It provides aesthetic integrity with the natural landscape composition.
Emphasis	Special areas such as Bethesda Terrace, Bow Bridge, lake views	It directs the user's attention to specific scenes.	It strengthens the urban identity by creating symbolic areas of the park.
Hierarchy	Main park paths, secondary walkways and recreation areas	It provides spatial order and circulation organization.	It increases the legibility of the park by guiding user movement. It creates a natural landscape integrity and a strong spatial identity within the city.
Unity	Natural landscape language, plant diversity and material harmony	It ensures that the park creates a holistic landscape character.	It creates strong social and visual focal points within the park.

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3.3. Analysis of Trabzon EYOF Park in Terms of Design Elements, Principles, and Spatial Meaning

Trabzon EYOF Park is one of the important recreational areas added to the city as part of the 2011 European Youth Olympic Summer Festival. The park serves as a public space offering open green areas to city dwellers in a densely built urban environment. Although developed for a sporting event, the park incorporates arrangements reflecting Japanese garden culture, and its current use is primarily as a landscape area for walking, resting, socializing, and recreation. In this context, when evaluated in terms of design elements and principles, EYOF Park can be interpreted as a public landscape where urban open space generates spatial meaning through user experience, circulation organization, and landscape arrangements.

Figure 3. Trabzon EYOF Park

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Table 4. Spatial analysis of Trabzon EYOF Park in accordance with its design elements and principles.

Design Element/Principle	Use in Landscape Design	Impact on Spatial Perception	Contribution to the Production of Spatial Meaning.
Point	Structures referencing Japanese garden art, seating areas, monumental entrance points and event areas	It directs user attention to specific areas.	It creates socio-cultural spatial focal points by establishing activity and meeting points within the park.
Line	Walking paths, walkways and bicycle paths	It determines the direction of movement and regulates user flow.	It creates a dynamic spatial experience by directing physical and recreational activities.
Form	Large lawns, plant groups and organically shaped water surfaces	It provides three-dimensional spatial organization.	It establishes a functional spatial character that supports free activity and recreation use.
Texture	Grass surfaces, hard surface walkways of different characteristics, gravel surfaces, stone arrangements	It creates visual, tactile, and cultural diversity.	It enriches the user experience through the combination of active use areas and the natural landscape, referencing Japanese gardens.
Color	Grass areas, rock textures and seasonal plants with colorful surfaces	It ensures that the space gains a lively and dynamic atmosphere. It allows the user to use the space comfortably.	It creates an energetic spatial identity by strengthening the recreation theme.
Scale/Proportion	Large open spaces and walkways appropriate to human scale	It creates visual continuity and a sense of movement.	It creates a spacious and accessible recreation area within the city.
Rhythm	Rows of trees, large water surfaces, repeating walkways	It creates visual stability and spatial order.	It provides a dynamic and continuous user experience within the park.
Balance	Balanced distribution of green areas with open sports areas	It draws the user's attention to specific activity areas.	It ensures a functional balance between active and passive recreation areas.
Emphasis	Event areas and large lawn areas, squares	It regulates spatial organization and circulation.	It emphasizes the park's identity in terms of activity diversity.
Hierarchy	Main walking axes, secondary paths and connections to various event areas	It ensures that the park creates a holistic landscape character.	It increases the legibility of the park by directing user movement.
Unity	Harmonious planning of planting, walkways and recreation areas	It directs user attention to specific areas.	It creates an urban recreation identity through the combination of recreation and green spaces.

4. RESULTS AND EVALUATION

In High Line, design elements function not merely as an aesthetic arrangement, but as a system that creates a spatial narrative.

The main layers of meaning are:

1. Preservation of industrial memory
   - Preserving railway traces and continuing the rail lines in the design, makes the historical identity of the space visible.
2. Integration of nature and the city

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- The combination of natural-looking vegetation and concrete-steel infrastructure with plant life creates a new ecological landscape narrative within the city.

3. Linear spatial experience
   - The continuous walking axis and rhythmic plant arrangement allow the space to be experienced as a discovery route.
4. Alternative urban perspective
   - Being an elevated park offers the user the opportunity to experience the city from a different angle.

In High Line, design elements (point, line, form, etc.) and design principles (rhythm, balance, hierarchy, etc.) work together to create a powerful spatial meaning production that transforms the historical infrastructure into a contemporary landscape experience. In this respect, the park is not only a recreational area but also a spatial narrative representing urban memory and ecological transformation.

In Central Park, design elements and principles aim to create a balance between urban life and nature by creating the illusion of a natural landscape.

1. Nature experience within the city
   - Wide meadows, natural-looking lakes, and dense groups of trees create a "pastoral landscape experience within the city."
2. Social public space
   - Large open spaces, walking paths, and recreation areas make the park a "center of social interaction and public life."
3. Spatial diversity
   - Open spaces, semi-enclosed wooded areas, and waterfronts offer "different spatial experiences to the user."
4. Urban identity
   - Iconic landmarks (Bethesda Terrace, Bow Bridge) and strong landscape compositions make Central Park one of New York's strongest spatial symbols.

The design elements and principles in Central Park create a holistic spatial system that offers a natural landscape experience within the city. Thanks to this system, the park is not only a recreation area; It becomes a powerful public space where nature, social life, and urban identity converge.

The design elements and principles of EYOF Park were conceived with the aim of creating an urban recreation space themed around sports and Japanese garden art.

1. Spatial identity focused on Japanese gardens and recreation
   - Walking paths, structures such as the Teahouse, and large activity areas ensure that the park is "a public space representing active life and Japanese culture."
2. Public social space
   - Open lawn areas, resting areas, and walking routes create "social interaction spaces where users come together."
3. Movement and dynamism
   - Linear walkways ensure that the park offers "a dynamic and active spatial experience."
4. Green recreation area within the city
   - Large green areas and groups of trees create "an ecological and recreational breathing space in the city of Trabzon."

The design elements and principles of EYOF Park determine the spatial identity of the park by creating a cultural and recreation-based landscape organization. In this respect, the park is not only a reference to Japanese garden art; It is becoming an important public landscape space where urban life, social interaction and active recreation converge.

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ISBN NR: 978-625-5694-92-8

NANO İLAVELİ POLİÜRETAN KÖPÜK KATMANININ AHŞAP KOMPOZİT SANDVİÇ PANELLERİN FİZİKSEL ÖZELLİKLERİ ÜZERİNE ETKİSİ

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ÖZET

Bu çalışmada, nano ilaveli rijit poliüretan köpük (RPÜK) çekirdek katmanının ahşap kompozit sandviç panellerin (AKSP) fiziksel özellikleri üzerine etkisinin araştırılması amaçlanmıştır. Çalışma kapsamında çok duvarlı karbon nanotüp (ÇDKNT) ve nano grafen olmak üzere iki farklı nano malzeme, üç farklı nano katılım oranı (%0,1, 0,3 ve 0,5) ve iki farklı yüzey katman kalınlığına sahip (4 ve 6 mm) kavak (I-77/51 Populus *deltoides* Bartr.) kontrplağı kullanılarak 20 mm kalınlığa sahip panel üretimi gerçekleştirilmiştir. Nano malzemenin RPÜK'ün hücre yapısına etkisi taramalı elektron mikroskobu (SEM) kullanılarak ayrıca incelenmiştir. Elde edilen sonuçlara bakıldığında, yoğunluk değerleri standart bir kavak kontrplağına göre 4 mm yüzey katmanına sahip RPÜK çekirdekli panellerde %59'a kadar ve 6 mm yüzey katmanına sahip RPÜK çekirdekli panellerde ise %40'a kadar azalmıştır. Nano malzemenin etkisi incelendiğinde, RPÜK içerisindeki nano katılım oranının artmasıyla köpük yoğunluğunun genel olarak yükseldiği ve en yüksek yoğunluk değerinin %0,5 oranında ÇDKNT ilavesiyle elde edildiği belirlenmiştir. ÇDKNT'ın aksine, ağırlıkça %0,1 oranında nano grafen ilavesi köpük yoğunluğunu kontrol grubuna kıyasla azaltmış; ayrıca su alma ve kütle artışı bakımından en düşük değerlerin elde edilmesine neden olmuştur. Bu sonuç, SEM görüntülerinde gözlemlenen hücre boyutundaki küçülmelerin birim alana düşen hücre yoğunluğunu arttırması ve hücre duvarlarını güçlendirmesiyle ilişkilendirilebilir. Daha kompakt ve güçlendirilmiş hücresel yapı, su emiliminin düşmesine katkı sağlamaktadır.

Anahtar Kelimeler: Ahşap Kompozit Sandviç Panel, Rijit Poliüretan Köpük, Nano Grafen, Karbon Nanotüp

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1. GİRİŞ

Endüstride sandviç kompozit yapıların kullanımı giderek artmakta olup inşaat, havacılık, otomotiv ve ulaşım sektörlerinde yaygın olarak tercih edilmektedir. Sandviç kompozit yapı iki ince sert yüzey katmanı, düşük yoğunluklu çekirdek katmanı ve çekirdek tipine bağlı olarak yapıştırıcıdan oluşmaktadır (Feng vd., 2020; Arıkan, 2019). Sandviç kompozit paneller (SKP) düşük yoğunluk ve yüksek mukavemete sahip olduğundan dolayı geleneksel panellere kıyasla ağırlıktan kazanç sağlanmaktadır (Soleimani-Javid ve Mourad, 2022). Örneğin uçak motorlarında sandviç yapının kullanımı sayesinde ağırlık azaltımı sağlanmaktadır; kompozit malzemelerle yapıların yaklaşık %25-30 oranında hafiflediği literatürde raporlanmıştır (Mallick, 2008). Otomobillerde ise sandviç yapı kullanımı ağırlıktan kazanç sağlanmanın yanı sıra kendilerine has yapılarıyla taşıyıcı gövdeyi güçlendirmekte ve çarpmalara karşı dayanım sağlamaktadır. Diğer yandan inşaat endüstrisinde sandviç kompozit panelin çekirdek katman yapısı son ürün ihtiyacına uygun olarak değiştirilerek ısı ve ses izolasyonları sağlamaktadır (Ramnath ve ark., 2019; Sönmez, 2017).

Sandviç yapı özellikleri çekirdek katman türüne göre değişiklik göstermektedir. Çekirdek türü değiştirilerek ahşap kompozit sandviç panel (AKSP) üzerindeki etkilerinin araştırıldığı birçok çalışma bulunmaktadır (Kaya ve Özgür İmirzi, 2024; Mohammadabadi vd., 2023; Smardzewski ve Wojciechowski, 2023 Hossain vd., 2023; Negro vd., 2022; Khojasteh-Khosro vd., 2021; Thongcharoen vd., 2021). Sandviç yapıların çekirdek katmanında kullanılan malzemelerden biri de rijit poliüretan köpüklerdir (RPÜK). RPÜK'ler, yüksek hidroksil fonksiyonelliğine sahip kısa zincirli polyollerin kullanımı sayesinde yüksek çapraz bağ yoğunluğuna sahip bir yapı oluşturmaktadır (Sae-Ueng, 2021). Çapraz bağlanma reaksiyonları RPÜK'ün mekanik özelliklerini etkileyen en önemli faktördür. Bu bağlamda polyol bileşiminde düzenlemeler yapılarak RPÜK sertliği ve mekanik özellikleri iyileştirilebilmektedir (Sternberg ve ark., 2024; Desai ve ark., 2023).

Fiziksel olarak malzemenin boyutu azaltıldığında; kimyasal olarak yeni bağlar oluşur (Malik ve ark., 2023). Malzemenin yaptığı kimyasal bağlar tüm yapının özelliklerini etkilemektedir. Böylece mikrometre boyutundaki bir yapı nanometre boyutuna düşürüldüğünde özellikleri tam tersi yönünde değişecektir. Köpüklere ilave edilen nano dolgu maddeleri köpüğün hücre homojenliğini ve hücre yoğunluğunu arttırır (Mehdipour-Ataei ve Mohammadi, 2022). Hücre yoğunluğunun artması nano katkının çekirdekleştirici ajan olarak görev aldığını göstermektedir. Bu durum köpüğün rijitliğini arttıran parametrelerden biridir. Dolayısıyla nano katkı maddeleri köpüğün rijitliğini sağlayarak mekanik değerlerini arttırmaktadır. Ayrıca karışım içerisine büyük hacimli bir dolgu maddesi eklemeden malzemenin hafifliği korunur ve hem mekanik hem de fiziksel özellikleri iyileştirilmiş olur.

Bu çalışmada üç farklı oranda nano grafen ve çok duvarlı karbon nanotüp (ÇDKNT) ilave edilen RPÜK çekirdek katmanına sahip AKSP'in fiziksel özellikleri incelenmiştir.

ISBN NR: 978-625-5694-92-8

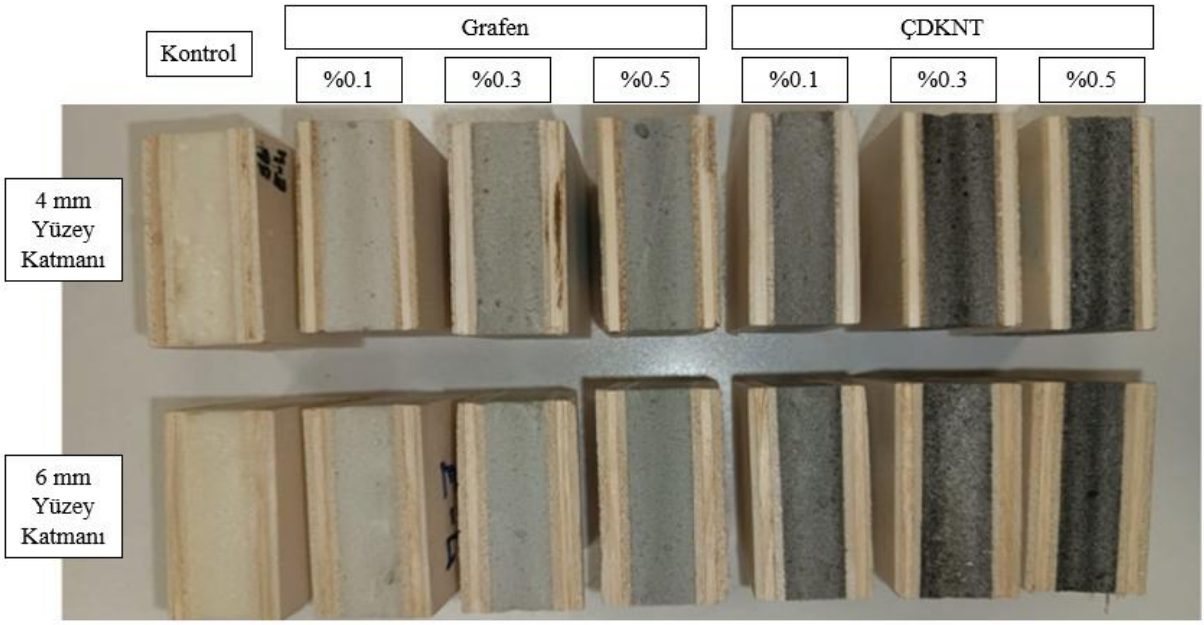
2. MATERYAL ve METOT

2.1. Materyal

Bu çalışmada RPÜK bileşenleri PURYAP Yapı Kimyasalları ve Makine Sanayi Tic.Ltd.Şti (İstanbul) firmasından temin edilmiştir. RPÜK üretimi için hacimce 1:1 oranında polyol ve izosiyanat kullanılmıştır. Polyol ve izosiyanatın 25 °C'deki viskoziteleri sırasıyla 250–300 mPa·s ve 220–250 mPa·s olup, yoğunlukları sırasıyla 1100 kg/m³ ve 1250 kg/m³'tür. Nano ilaveler (nano grafen ve ÇDKNT) Nanografi (Ankara) firmasından temin edilmiştir. Nano grafen %99,9+ saflığa, 5 nm kalınlığa, 18 µm çapa ve 135 m²/g spesifik yüzey alanına sahiptir. ÇDKNT'ler ise saflığı > %96, dış çapı 48-78 nm, iç çapı 5-15 nm, uzunluğu 10-25 µm, spesifik yüzey alanı 50 m²/g dır. AKSP'lerin yüzey katmanlarında 4 ve 6 mm olmak üzere kavak (Populus deltoides Bartr. I-77/51) kontrplağı kullanılmıştır. Kontrplaklar Metin SARIOĞLU Orman Ürünleri Sanayi ve Tic. Ltd. Şti. (İzmir) firmasından satın alınmıştır.

2.2. Sandviç Panel Üretimi

Çalışmada tek adımda üretim prensibi kullanılarak RPÜK'ün AKSP'in yüzey katmanına harici bir yapıştırıcı olmaksızın bağlanması sağlanmıştır. Çalışmanın ilk aşamasında RPÜK bileşenlerinde polyolun içerisine belirlenen oranlarda (%0,1, 0,3 ve 0,5) nano malzeme eklenmiş ve 5 dk el ile karıştırılmıştır. El ile karıştırma işleminden sonra her bir işlem 5 dk olacak şekilde 14000 r/min, 19000 r/min ve 23000 r/min devirde toplam 20 dk boyunca homojenizatör ile karıştırılmıştır. Karıştırma işlemi sırasında hem sıcaklığın nano malzemenin özelliklerini bozmasını engellemek hem de RPÜK içerisinde yığılmasını önlemek amacıyla karıştırma sıcaklığı 24°C'de sabit tutulabilmesi için soğutma uygulanmıştır (You ve ark., 2011). Karıştırma işlemi sonrasında polyol ve nano malzeme birleşiminin üzerine izosiyanat eklenerek karışım kalıp içerisine dökülerek 210×210×20 mm ölçülerinde AKSP ve nano ilaveli RPÜK'ler üretilmiştir.



Görsel 1. Üretilen Ahşap Kompozit Sandviç Panellerin Genel Görünümü

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2.3. Uygulanan Testler

Üretimi gerçekleştirilen AKSP ve RPÜK'ler 50 × 50 mm ölçülerinde boyutlandırılarak uygulanacak testler öncesi 20±2 °C'de %65±5 bağıl nemde 3 hafta süreyle iklimlendirme kabininde bekletilmişlerdir. RPÜK'lerin yoğunluklarının belirlenmesinde ASTM D1622M-14 ve su alma davranışlarının belirlenmesinde ASTM C272M-16 standardı takip edilmiştir. Nano ilaveli RPÜK çekirdek katmanına sahip AKSP'lerin yoğunluklarının belirlenmesinde TS EN 323 ve su alma davranışlarının belirlenmesinde TS EN 317 standardı kullanılmıştır. Diğer yandan RPÜK'lerin hücresel özelliklerini ve nano malzemeyle köpük birleşiminin etkilerini incelemek için taramalı elektron mikroskobu (SEM) analizi yapılmıştır.

2.4. İstatiksel Analizi

Bu çalışmada, nano ilaveli RPÜK çekirdek katmanının AKSP fiziksel özellikleri üzerine bir etkisinin olup olmadığı çoklu varyans analizi (ANOVA) ile %5 anlamlılık seviyesinde değerlendirilmiştir. İstatistiksel analizler SAS 9.4 istatistik yazılımı ile gerçekleştirilmiştir.

3. BULGULAR ve TARTIŞMALAR

Çalışma kapsamında üretilen AKSP'lere ait fiziksel özellikler Çizelge 1'de verilmiştir. Elde edilen verilere göre, genel olarak 6 mm kontrplak yüzey katmanı kullanılan örneklerin 4 mm kontrplak yüzey katmanına sahip örneklerden daha yüksek yoğunluk değerlerine sahip olduğu görülmüştür. En düşük yoğunluk değeri 4 mm'lik grup için ağırlıkça %0,5 nano grafen ilavesi yapılmış numunede (0.20 gr/cm^3), 6 mm'lik grup için ise ağırlıkça %0,3 nano grafen ilavesi yapılmış numunesinden (0.30 gr/cm^3) elde edilmiştir. 4 mm ve 6 mm kontrplak yüzey katmanına sahip grupların yoğunluk değerleri arasında istatisiki olarak anlamlı bir fark bulunmuştur. Çalışma kapsamında üretilen tüm panel grupları 20 mm kalınlığa sahip standart kontrplak ile karşılaştırıldığında yoğunluk değerinde %36 ile %60 oranında düşüş gerçekleşmiş ve tüm gruplar ile istatistiki olarak anlamlı bir fark bulunmuştur. Bu sonuç sandviç malzemeden beklenen hafiflik özelliğini yerine getirdiğini göstermektedir. İstatiksel analiz sonucunda kullanılan nano malzeme farketmeksizin 6 mm yüzey katman kalınlığına sahip gruplar içerisinde nano katılım oranının değiştirilmesi yoğunluk değerlerinde anlamlı bir fark oluşturmamıştır. 4 mm yüzey katman kalınlığına sahip gruplar incelendiğinde, nano grafen kullanımında nano katılım oranının artmasıyla yoğunluk değerleri düşmüş ve gruplar arasında istatistiki olarak anlamlı bir fark bulunmuştur.

AKSP'lerin su alma ve kalınlığına şişme değerleri incelendiğinde nano malzeme türü farketmeksizin nano ilavesiyle değerlerde artış gözlemlenmiştir. Genel olarak AKSP'lerde kullanılan yüzey katman kalınlığı arttıkça su alma ve kalınlığına şişme değerlerinde artış elde edilmiştir. İstatiksel analiz sonucunda kullanılan nano malzeme farketmeksizin 4 mm yüzey katman kalınlığına sahip gruplar içerisinde nano katılım oranının değiştirilmesi su alma değerlerinde anlamlı bir fark oluşturmamıştır. 6 mm yüzey katman kalınlığına sahip gruplar

ISBN NR: 978-625-5694-92-8

incelendiğinde, ÇDKNT kullanımında nano katılım oranının artmasıyla su alma değerleri düşmüş ve gruplar arasında istatistiki olarak anlamlı bir fark bulunmuştur. Kalınlığına şişme değerleri incelendiğinde, ağırlıkça %0.3 nano ilavesi ile en düşük değerler elde edilmiştir. Nano malzeme türü farketmeksizin 4 mm yüzey katman kalınlığına sahip AKSP gruplarında 20 mm standart kontrplak ile karşılaştırıldığında %54 oranına kadar düşüş elde edilmiştir. 4 mm yüzey katman kalınlığına sahip kontrol grubunda bile (nano ilavesiz) standart kontrplaka göre %29 oranında düşüş gözlemlenmiştir. Diğer yandan 6 mm yüzey katman kalınlığına sahip gruplarda su alma ve kalınlığına şişme değerlerinde 4mm yüzey katman kalınlığına sahip gruplara göre artış görülmüştür, bu artış yüzey katmanları üzerinde su itici bir uygulama yapılmadığından kaynaklanmaktadır. Al ve arkadaşları (2024) nano ilavesiz RPÜK çekirdek katmanına sahip AKSP'e uygulanan su alma özelliklerinde de benzer sonuçlar elde etmiştir.

Çizelge 1. Nano İlaveli RPÜK Çekirdek Katmanına Sahip AKSP'lerin Fiziksel Özellikleri

Parametreler			Yoğunluk (g/cm^3)	Su Alma (%)	Kalınlığına Şişme (%)
Nano Malzeme	Katman Kalınlığı (mm)	Nano Oranı (%)			
Kontrol	4	0	0.23 (0.023) f	42.69 (5.13) g	2.68 (0.70) cdef
	6		0.32 (0.008) bc	61.99 (3.10) abcd	4.64 (0.96) b
Grafen	4	0.1	0.24 (0.010) ef	43.07 (2.91) g	2.04 (0.32) ef
		0.3	0.23 (0.012) f	48.35 (8.80) fg	1.73 (0.32) f
		0.5	0.20 (0.003) g	46.05 (2.73) fg	3.31 (0.33) bcde
	6	0.1	0.32 (0.008) bc	57.89 (7.83) cde	4.68 (0.74) b
		0.3	0.30 (0.014) c	64.57 (6.06) abc	4.19 (0.79) bc
		0.5	0.31 (0.006) bc	61.36 (1.30) bcd	7.42 (1.87) a
ÇDKNT	4	0.1	0.25 (0.013) de	45.84 (4.30) fg	3.20 (0.44) bcdef
		0.3	0.26 (0.013) d	45.86 (2.04) fg	2.55 (0.28) def
		0.5	0.25 (0.009) de	51.39 (2.27) ef	3.32 (0.50) bcde
	6	0.1	0.32 (0.008) bc	68.77 (3.28) a	6.65 (1.68) a
		0.3	0.31 (0.004) bc	67.37 (4.67) ab	4.40 (1.05) b
		0.5	0.32 (0.009) b	56.57 (3.73) de	6.15 (1.48) a
20 mm Standart Kontrplak			0,50 (0,004) a	42.63 (2.06) g	3.77 (0.53) bcd

*Aynı harf olan gruplar arasında istatistiki olarak fark yoktur.

Nano ilaveli RPÜK'e ait fiziksel özellikler Çizelge 2'de verilmiştir. Nano ilaveli RPÜK'lerin yoğunluk değerlerine bakıldığında genel olarak nano ilave yüzdesi arttıkça yoğunluk değerlerinde artış gözlemlenmiştir. En yüksek yoğunluk değerinin 0.091 g/cm³ ile ağırlıkça %0.5 oranında ÇDKNT içeren numune olduğu görülmekte ve istatistiki olarak diğer gruplarla anlamlı bir fark olduğu tespit edilmiştir. Zhou ve arkadaşları (2023) yapmış olduğu çalışmada da benzer sonuçlar bulmuştur.

Nano ilaveli RPÜK'lerin 24 saat suda bekletme sonucunda hacimsel su alma ve kütle artışı değerlerindeki değişimler ayrıca incelenmiştir. Her bir grup için kütle artışı değerleri kontrol grubu ile karşılaştırıldığında ağırlıkça %0.1 nano grafen ve ağırlıkça %0.5 ÇDKNT ilaveli RPÜK en az kütle artışına sahiptir, fakat istatistiki açıdan anlamlı bir fark bulunmamıştır. Gruplar özelinde bakıldığında ise hacimsel su alma yüzdeleri ağırlıkça %0.3 nano ilavesinde

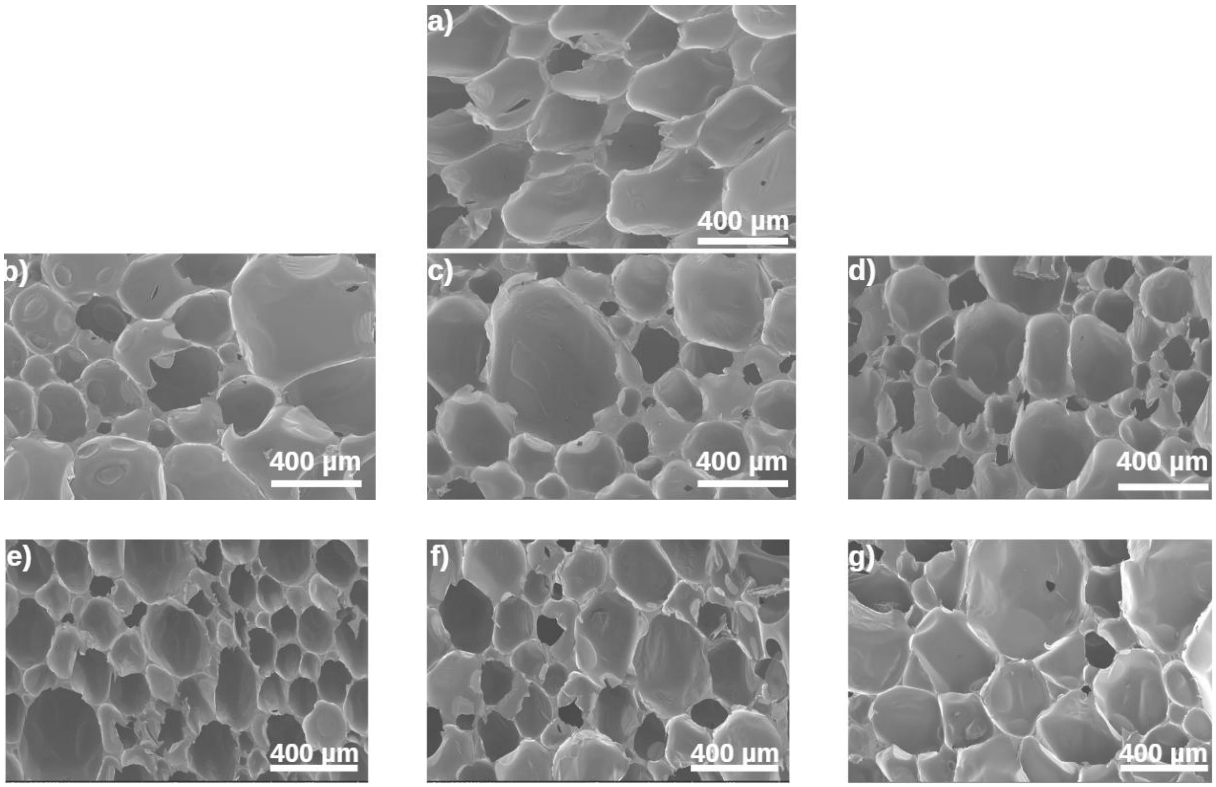
ISBN NR: 978-625-5694-92-8

yükselip %0.5 nano ilavesinde azalan bir eğriye sahiptir. %0,5 ÇDKNT ve %0,1 grafen ilaveli gruplar arasında istatistiki olarak anlamlı bir fark bulunmuştur. Köksal ve Kelleci (2023) tarafından yapılan bir çalışmada nano dışı dolgu maddelerinin RPÜK içerisine ilavesiyle hacimsel su alma ve kütle artış sonuçları istatistiki olarak değerlendirilmiş ve grup arasında bir fark bulunmamıştır. Yine benzer bi çalışmada Duc ve arkadaşları (2021) ise ÇDKNT ilaveli RPÜK üzerine yüzey kaplaması uygulayarak su alma değerlerini %13.4 oranında düşürdüğü sonucuna ulaşmışlardır.

Çizelge 2. Nano İlaveli RPÜK Numunelerinin Fiziksel Özellikleri

Parametreler		Yoğunluk (g/cm^3)	Hacimsel Su Alma (%)	Kütle Artışı (%)
Nano Malzeme	Nano Oranı (%)			
Kontrol		0.072 (0.004) b	0.016 (0.003) ab	22.47 (4.67) a
Grafen	0.1	0.071 (0.002) b	0.013 (0.002) b	18.88 (0.21) a
	0.3	0.072 (0.004) b	0.018 (0.006) ab	25.43 (8.40) a
	0.5	0.075 (0.005) b	0.018 (0.001) ab	24.42 (0.49) a
ÇDKNT	0.1	0.072 (0.005) b	0.016 (0.001) ab	22.21 (1.74) a
	0.3	0.073 (0.008) b	0.019 (0.003) ab	26.78 (6.76) a
	0.5	0.091 (0.010) a	0.020 (0.020) a	21.97 (3.99) a

*Aynı harf olan gruplar arasında istatistiksel olarak fark yoktur.



Görsel 2. Nano İlaveli RPÜK'lerin SEM Görüntüleri: (a) Kontrol, (b) %0.1 Grafen, (c) %0.3 Grafen, (d) %0.5 Grafen, (e) %0.1 ÇDKNT, (f) %0.3 ÇDKNT, (g) %0.5 ÇDKNT

ISBN NR: 978-625-5694-92-8

Genel olarak, SEM görüntüleri incelendiğinde nano ilavesinin RPÜK'lerin kapalı hücre yapısını bozduğu, hücre dağılımını düzensizleştirdiği ve hücre boyutlarını değiştirdiği söylenebilir (Görsel 2). Nano ilaveli RPÜK'ler kontrol grubuna göre düşük ortalama hücre çapı değerleri göstermiştir. ÇDKNT ve nano grafen ortalama köpük çapları için ayrı ayrı incelendiğinde kontrol numunesine göre en düşük köpük çapı ortalaması her iki nano malzeme için, ÇDKNT ve nano grafen, ağırlıkça %0.1 ilavesinde sırasıyla %33.20 ve %22.24 oranında küçülme görülmüştür. Bu durumun nedeni nano katkıların düşük miktarlarda eklenmesiyle nano parçacıkların heterojen nükleasyon merkezleri olarak davranması ve daha küçük hücre boyutları ve daha yüksek hücre yoğunluğu sağlaması şeklinde açıklanabilir (Paciorek-Sadowska ve ark., 2024). Ancak katkı miktarı arttıkça bu etki faydalı olmaktan çıkıp yetersiz karıştırmayla birlikte hücre duvarında topaklanmalara ve düzensiz hücre yapısına yol açabilir (Lee ve ark., 2024).

4. SONUÇ ve ÖNERİLER

Bu çalışmada nano ilaveli (ÇDKNT ve nano grafen) RPÜK çekirdek katmanına ve iki farklı kontrplak yüzey katmanına sahip AKSP'lerin ve nano ilaveli RPÜK'lerin fiziksel özellikleri incelenmiştir. Elde edilen sonuçlara göre, nano ilaveli RPÜK çekirdek katmanına sahip tüm panel grupları 20 mm kalınlığa sahip standart bir kontrplak ile karşılaştırıldığında yoğunluk değerlerinde %60 oranına kadar bir azalma görülmüş ve tüm gruplar arasında istatistiki olarak anlamlı bir fark bulunmuştur. AKSP'lerin su alma ve kalınlığına şişme değerlerinde, kullanılan yüzey katman kalınlığı arttıkça artış elde edilmiştir. Ağırlıkça %0.3 nano ilavesi ile AKSP'lerde en düşük kalınlığına şişme değerleri elde edilmiştir. Sandviç panel içerisinde nano ilaveli RPÜK kullanımı ile standart bir kontrplaka göre kalınlığına şişme değerlerinde %54 oranına kadar düşüş elde edilmiştir. Nano ilaveli RPÜK'ler kendi aralarında incelendiğinde, nano oranının artmasıyla yoğunluk değerlerinde artış gözlemlenmiş ve kontrol grubuna göre en yüksek yoğunluk artışı %21 ile ağırlıkça %0.5 oranında ÇDKNT içeren RPÜK örneğinden elde edilmiştir. Ayrıca nano ilavesiyle kapalı hücre yapısında değişmeler olduğu ve hücre boyutlarının nano malzeme türüne bağlı olarak %33.20 oranına kadar küçüldüğü ve bunun köpük yoğunluğunu doğrudan etkilediği sonucuna varılmıştır.

TEŞEKKÜR

Bu bildiri, Pelinsu Melisa AYDOĞDU tarafından hazırlanan 'Ahşap Kompozit Sandviç Panel Üretiminde Nano İlaveli Rijit Poliüretan Köpük Kullanımının Araştırılması' başlıklı lisansüstü tez çalışmasından üretilmiş olup, İzmir Katip Çelebi Üniversitesi - Bilimsel Araştırma Projeleri Koordinatörlüğü (İKÇÜ-BAP) tarafından 2024-TYL-FEBE-0032 nolu proje kapsamında desteklenmiştir.

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ISBN NR: 978-625-5694-92-8

ASSESSING THE IMPACT OF TELEMEDICINE ON RURAL HEALTHCARE ACCESS IN GERMANY

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ABSTRACT

The equitable provision of healthcare services remains a significant challenge in the rural regions of Germany due to factors such as long distances to specialized medical centers, physician shortages, and an aging population. Telemedicine has been proposed as a transformative solution to bridge these geographical and structural gaps by improving accessibility and efficiency. This study aims to comprehensively assess the current impact of telemedicine applications (e.g., remote consultations, e-prescribing, remote monitoring) on healthcare access and utilization patterns within German rural communities.

A mixed-methods approach was employed, combining a quantitative analysis of healthcare utilization data from five distinct rural districts over a three-year period (2022–2024) with qualitative data derived from semi-structured interviews with patients, general practitioners, and health insurance representatives. The quantitative analysis focused on key metrics, including the reduction in travel distance for specialist appointments, the frequency of chronic disease management check-ups, and emergency room utilization rates for treatable conditions. The qualitative phase explored perceived barriers (e.g., digital literacy, data security concerns) and enablers (e.g., convenience, timely care) of telemedicine adoption.

Preliminary quantitative results indicate that the introduction of subsidized telemedicine services was associated with a 25% increase in timely specialist consultations for patients living more than $50\ km$ from a major urban center. Furthermore, remote monitoring programs showed a promising correlation with a 15% reduction in preventable hospitalizations for patients with heart failure. Qualitative findings highlight the strong demand for hybrid care models that combine digital convenience with the option for in-person visits. The primary barrier identified was the lack of reliable high-speed internet infrastructure in the most remote areas.

In conclusion, telemedicine offers a viable and effective strategy for enhancing healthcare accessibility in rural Germany, but its full potential can only be realized through concurrent investment in digital infrastructure and targeted training programs for both patients and providers.

Key words: Telemedicine, Rural Healthcare, Healthcare Access, Germany, Digital Health, Health Equity

ISBN NR: 978-625-5694-92-8

INVESTIGATING THE RELATIONSHIP BETWEEN AIR POLLUTION AND RESPIRATORY DISEASE PREVALENCE IN BERLIN

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ABSTRACT

Exposure to air pollution is a globally recognized public health concern, with substantial evidence linking it to adverse respiratory outcomes. Urban centers, such as Berlin, often experience elevated levels of atmospheric pollutants due to traffic, industry, and population density, making their inhabitants particularly vulnerable. This study aimed to investigate the direct relationship between fluctuations in ambient air pollutant concentrations (specifically particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), and ozone (O_3)) and the temporal prevalence of common respiratory diseases (e.g., asthma exacerbations, Chronic Obstructive Pulmonary Disease (COPD) admissions, and acute bronchitis diagnoses) among the Berlin population over a five-year period (2020–2024).

A retrospective ecological study design was employed, integrating publicly available daily air quality data from official monitoring stations with anonymized, aggregated patient data on respiratory disease incidence sourced from major Berlin hospitals and primary care facilities. Time-series analyses using generalized additive models (GAMs) were performed, controlling for potential confounding factors such as seasonal variations, temperature, and influenza epidemics. Preliminary findings indicate a statistically significant positive correlation between short-term increases in $PM_{2.5}$ and NO_2 levels and subsequent spikes in hospital admissions for asthma and COPD, particularly in elderly populations and young children. For every $10\ \mu g/m^3$ increase in daily $PM_{2.5}$ concentration, a 3.5% increase in emergency department visits for acute respiratory distress was observed ($p<0.01$).

These results underscore the critical impact of urban air quality on respiratory health in Berlin, providing crucial epidemiological evidence to support and inform local public health policy interventions aimed at reducing air pollutant emissions. Furthermore, the findings highlight the need for enhanced environmental surveillance and targeted healthcare strategies during periods of poor air quality.

Key words: Air Pollution, Respiratory Disease, Berlin, Epidemiology, Particulate Matter, NO_2

ISBN NR: 978-625-5694-92-8

PREVALENCE AND SOCIOECONOMIC FACTORS IN MALARIA CONTROL EFFORTS AMONG ERITREAN SCHOOLCHILDREN

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ABSTRACT

Despite significant global progress, malaria remains a major public health burden in many sub-Saharan African countries, including Eritrea. School-aged children represent a highly vulnerable group, often exhibiting asymptomatic infections that contribute to transmission and suffering from educational and developmental setbacks due to the disease. This study aimed to determine the current prevalence of malaria infection and assess the influence of key socioeconomic factors (SEFs) on the effectiveness of existing control efforts among schoolchildren in selected regions of Eritrea.

A cross-sectional study was conducted across 30 primary schools in malaria-endemic areas, involving $2,500$ schoolchildren aged 6 to 14 years. Malaria infection status was determined using both Rapid Diagnostic Tests (RDTs) and microscopy of blood smears. A structured questionnaire was administered to the children's parents/guardians to collect data on SEFs, including household income, parental education level, housing structure, and access to and use of Insecticide-Treated Nets (ITNs). Multivariate logistic regression models were used to identify independent predictors of infection.

The overall prevalence of malaria was found to be 8.2%, with significant regional variations observed. Key SEFs were strongly associated with infection risk. Children from households with lower parental education (primary level or less) were 2.5 times more likely to test positive for malaria compared to those with secondary or higher education ($OR=2.5,\ 95\% CI: 1.8–3.4$). Furthermore, inconsistent use of ITNs (defined as use <7 nights/week) was associated with a 65% higher risk of infection. Access to healthcare and distance from the nearest health facility were also significant predictors.

The findings highlight that while malaria control programs are having an effect, socioeconomic disparities continue to undermine overall elimination efforts. Effective control strategies in Eritrea must integrate health interventions with poverty reduction and education initiatives to achieve sustained malaria reduction among schoolchildren.

Key words: Malaria, Eritrea, Schoolchildren, Prevalence, Socioeconomic Factors, Control Efforts

ISBN NR: 978-625-5694-92-8

MATERNAL AND NEONATAL HEALTH OUTCOMES AFTER COMMUNITY-BASED INTERVENTIONS IN ASMARA

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ABSTRACT

Improving Maternal and Neonatal Health (MNH) outcomes remains a global priority, particularly in developing nations where access to facility-based care can be limited. Community-Based Interventions (CBIs), which involve local health workers delivering essential care and education, are recognized as a cost-effective strategy to reach vulnerable populations. This study aimed to evaluate the impact of a comprehensive package of CBIs on MNH outcomes in underserved peri-urban communities within Asmara, Eritrea.

A quasi-experimental study design was implemented, comparing MNH indicators in four intervention communities ($n=800$ pregnant women) that received the CBI package (including community health worker home visits, promotion of antenatal care (ANC) and skilled birth attendance (SBA), and post-natal care education) against four control communities ($n=750$ pregnant women) that received standard care over a two-year period (2023–2024). Primary outcomes measured included the rate of SBA, utilization of ≥ 4 ANC visits, and the incidence of neonatal mortality (NMR) and maternal mortality (MMR).

Results demonstrated a significant positive impact of the CBI package. The rate of Skilled Birth Attendance in the intervention group increased from a baseline of 62% to 85% (an improvement of 23 percentage points), while the control group only saw a marginal increase to 68%. Utilization of ≥ 4 ANC visits was also substantially higher in the intervention group (78% vs 55%). Critically, the Neonatal Mortality Rate (NMR) was significantly lower in the intervention communities (21 per 1,000 live births) compared to the control communities (35 per 1,000 live births, $p<0.05$). No statistically significant difference in MMR was detected, likely due to the low baseline rate.

The findings strongly support the scaling up of this evidence-based Community-Based Intervention package as a vital strategy for improving maternal and neonatal survival rates in peri-urban settings like Asmara.

Key words: Maternal Health, Neonatal Health, Community-Based Intervention, Skilled Birth Attendance, Asmara, Public Health

ISBN NR: 978-625-5694-92-8

ARDIOVASCULAR DISEASE PREVENTION STRATEGIES IN SERBIAN PRIMARY CARE: AN EPIDEMIOLOGICAL STUDY

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ABSTRACT

Cardiovascular Diseases (CVDs) remain the leading cause of morbidity and mortality in Serbia, placing a substantial burden on the healthcare system. Effective primary prevention, centered in primary care (PC) settings, is crucial for reducing this national health challenge. This epidemiological study aimed to evaluate the current implementation, adherence, and effectiveness of established CVD prevention strategies within the Serbian primary care network.

A mixed-methods study was conducted involving 150 primary care physicians (PCPs) across four major Serbian cities (Belgrade, Novi Sad, Niš, and Kragujevac). The quantitative phase utilized a cross-sectional survey to assess the PCPs' reported adherence to national and international guidelines for risk factor screening (e.g., hypertension, dyslipidemia, diabetes) and lifestyle counseling (e.g., smoking cessation, physical activity). The effectiveness was measured by analyzing aggregated patient electronic health records ($n=5,000$ patients) to determine the proportion of high-risk patients achieving target blood pressure and cholesterol levels. The qualitative phase involved focus groups with PCPs to identify systemic barriers to optimal implementation.

Results revealed high reported adherence to medication prescribing guidelines ($>85\%$), but significantly lower adherence to lifestyle counseling and standardized risk assessment protocols ($<60\%$). Data from patient records showed that only 42% of patients with established hypertension were maintained at the recommended target blood pressure of $<140/90\ mmHg$. Key barriers identified in the focus groups included a lack of time during patient encounters, insufficient collaboration with specialized health promotion services, and patients' low health literacy regarding modifiable risk factors.

The study concludes that significant gaps exist in the execution of comprehensive CVD prevention strategies in Serbian primary care, particularly in non-pharmacological interventions. Recommendations include mandatory training on motivational interviewing and enhanced integration of health promoters within PC teams to optimize prevention efforts.

Key words: Cardiovascular Disease, Primary Care, Prevention Strategies, Serbia, Epidemiology, Risk Factor Management

ISBN NR: 978-625-5694-92-8

EVALUATING MENTAL HEALTH SERVICES CAPACITY AND ACCESSIBILITY IN SOUTHERN SERBIA

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ABSTRACT

The capacity and accessibility of mental health services (MHS) are vital components of a robust public health system. In Southern Serbia, persistent reports suggest potential regional disparities and systemic challenges in service provision. This study aimed to comprehensively evaluate the current capacity of MHS and assess the key factors affecting their accessibility for the general population in the Southern Serbian region.

A descriptive, cross-sectional study was conducted across seven districts in Southern Serbia. The capacity assessment involved collecting data from official governmental sources on the number of registered mental health professionals (psychiatrists, psychologists, psychiatric nurses) per 100,000 inhabitants and the availability of specialized facilities (inpatient and outpatient clinics). Accessibility was evaluated using a mixed-methods approach: quantitative data included patient waiting times and geographical distribution of services, while qualitative data was gathered through interviews with 40 patients and 20 service providers.

The capacity analysis revealed that the number of psychiatrists per 100,000 inhabitants in Southern Serbia (≈ 7.5) was significantly lower than the national average (≈ 12.0). Furthermore, there was a pronounced concentration of specialized services in the city of Niš, leaving remote and rural areas severely underserved. The quantitative accessibility data showed average waiting times for a first appointment with a public-sector psychiatrist to be over 6 weeks. Qualitative interviews highlighted pervasive issues, including stigma as a major barrier to seeking help, inadequate public transport options to facilities, and a perception that available services were primarily focused on severe, chronic conditions rather than preventative or early intervention support.

The findings confirm critical deficits in both the capacity and accessibility of mental health services in Southern Serbia. Urgent policy and investment decisions are needed to decentralize services, increase the mental health workforce, and implement effective anti-stigma campaigns to ensure equitable access to care.

Key words: Mental Health Services, Accessibility, Capacity, Southern Serbia, Stigma, Public Health

ISBN NR: 978-625-5694-92-8

VACCINATION COVERAGE AND INFECTION RATES AMONG CHILDREN IN CAIRO SCHOOLS

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ABSTRACT

Maintaining high vaccination coverage among school-aged children is fundamental to preventing the resurgence and spread of vaccine-preventable diseases (VPDs). In a high-density urban environment like Cairo, monitoring coverage and its direct relationship with infection rates is critical for public health planning. This study aimed to assess the current vaccination coverage for key VPDs (Measles, Mumps, Rubella (MMR); Diphtheria, Tetanus, Pertussis (DTP); and Polio) and investigate its correlation with reported infection rates among children attending public and private schools in Cairo.

A cross-sectional, multi-stage cluster sampling study was conducted, involving $5,000$ children aged 6–12 years across 50 schools in different districts of Cairo. Vaccination status was verified by examining official health records and interviewing parents. Simultaneously, historical school health office data over the past three academic years (2022–2024) were collected to establish the incidence rates of selected VPDs. Regression analysis was used to model the relationship between coverage rates and infection incidence.

The study found a generally high but variable primary immunization coverage, with MMR coverage averaging 91% and DTP coverage averaging 88%. However, coverage for subsequent booster doses showed a significant drop-off, particularly in certain low-income public schools. The analysis revealed a strong inverse correlation between the booster dose coverage and the incidence of sporadic outbreaks; areas with a booster coverage below 85% experienced statistically higher clusters of mumps and pertussis cases. Furthermore, parental perception of vaccine safety and the lack of a standardized tracking system were identified as major barriers to completing the full immunization schedule.

The results confirm that while Cairo has achieved commendable primary coverage levels, the vulnerability of the population remains due to suboptimal booster vaccination rates. Public health efforts must now focus on strengthening the tracking and recall system for school-aged children to ensure complete adherence to the national immunization schedule and thus maintain herd immunity.

Key words: Vaccination Coverage, Infection Rates, Cairo, Schoolchildren, Public Health, Immunization Schedule

ISBN NR: 978-625-5694-92-8

BARRIERS TO WOMEN'S CANCER SCREENING PARTICIPATION IN EGYPT: A MULTICENTER STUDY

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ABSTRACT

Cancer screening (particularly for breast and cervical cancer) is crucial for early detection, which significantly improves treatment outcomes and survival rates. However, participation rates among women in Egypt remain low compared to global benchmarks. This multicenter study aimed to comprehensively identify and categorize the key barriers that impede women's participation in organized breast and cervical cancer screening programs across various socio-demographic settings in Egypt.

A mixed-methods study was conducted across three distinct governorates (representing urban, peri-urban, and rural areas). The quantitative phase involved a structured survey administered to $1,200$ women aged 40–65, assessing their knowledge, attitudes, and reported screening behaviors. The qualitative phase involved 10 focus group discussions with non-participants to gain in-depth insight into their reasons for non-attendance. Barriers were categorized into individual, sociocultural, and health system factors.

Quantitative results showed that only 35% of surveyed women had ever received a mammogram, and only 18% had ever received a Pap smear. The three most frequently reported barriers were: 1) Individual/Knowledge: Lack of awareness about when and where to get screened (reported by 55% of non-participants); 2) Sociocultural: Fear of a positive diagnosis and associated social stigma (reported by 48%); and 3) Health System: Inconvenient clinic hours and the financial cost of transportation (reported by 40%). Qualitative data reinforced the profound role of cultural modesty and the preference for female healthcare providers as critical factors in the decision-making process.

The study clearly demonstrates that cancer screening participation in Egypt is hindered by a complex interplay of factors that extend beyond simple access. Policy recommendations include the need for nationwide, culturally-sensitive public awareness campaigns, greater integration of female providers into screening programs, and the implementation of mobile screening units to reduce geographical and financial barriers.

Key words: Cancer Screening, Barriers, Women's Health, Egypt, Breast Cancer, Cervical Cancer

ISBN NR: 978-625-5694-92-8

HEALTH PROMOTION STRATEGIES FOR DIABETES PREVENTION AMONG EGYPTIAN ADOLESCENTS

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ABSTRACT

The prevalence of Type 2 Diabetes Mellitus (T2DM) is rising globally, and this trend is increasingly mirrored in younger populations in countries like Egypt. Adolescence represents a critical window for intervention, as lifestyle habits formed during this period often persist into adulthood. This study aimed to design, implement, and evaluate the effectiveness of a targeted health promotion strategy focused on diabetes prevention among Egyptian adolescents.

A quasi-experimental, pre-test/post-test design was utilized. 300 high school students (aged 14–17) from two different schools in Alexandria were divided into an intervention group ($n=150$) and a control group ($n=150$). The intervention group participated in an eight-week, school-based health promotion program focusing on nutrition education (reducing high-sugar intake, increasing fiber), promoting daily physical activity (at least 60 minutes), and stress management. The control group received standard school health education. Knowledge, attitudes, and key behavioral indicators (e.g., consumption of sugary drinks, self-reported weekly exercise) were assessed pre- and three months post-intervention.

Post-intervention results showed a statistically significant improvement in the intervention group compared to the control group. The mean score for knowledge about diabetes risk factors increased by 28% in the intervention group ($p<0.001$). Furthermore, self-reported weekly consumption of sugary soft drinks decreased by an average of 40%, and the percentage of adolescents meeting the minimum physical activity recommendations increased from 32% to 58%. Crucially, changes in attitude towards proactive health management were also positively affected, indicating greater self-efficacy for lifestyle changes.

The findings demonstrate the potential for structured, school-based health promotion strategies to effectively enhance knowledge, shift attitudes, and modify high-risk behaviors for diabetes prevention among Egyptian adolescents. Scaling this program nationwide could be a vital component of Egypt’s non-communicable disease control efforts.

Key words: Diabetes Prevention, Health Promotion, Adolescents, Egypt, School-Based Intervention, Lifestyle Modification

ISBN NR: 978-625-5694-92-8

MOLECULAR CHARACTERIZATION AND ANTIBIOTIC RESISTANCE PATTERNS IN ESCHERICHIA COLI ISOLATED FROM DAIRY HERDS

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ABSTRACT
Escherichia coli is a significant pathogen in dairy herds, affecting animal health and posing risks to public health due to antibiotic resistance. This study aimed to molecularly characterize E. coli isolates from dairy cattle and evaluate their antibiotic resistance profiles. Samples were collected from multiple herds and subjected to PCR-based genotyping to identify virulence and resistance genes. Antibiotic susceptibility testing was performed using standardized disk diffusion methods against commonly used antimicrobials in veterinary and human medicine. Results revealed diverse genetic profiles with a high prevalence of resistance determinants, including extended-spectrum beta-lactamase (ESBL) genes. Multidrug resistance was common, emphasizing the challenge of treatment in dairy settings. The findings highlight the urgent need for surveillance programs and prudent use of antibiotics to mitigate the spread of resistant strains, ensuring both animal welfare and food safety. This research contributes to the understanding of resistance mechanisms in dairy herd pathogens and suggests strategies for improved antimicrobial stewardship.

Key words: Escherichia coli, antibiotic resistance, dairy cattle, molecular characterization

ISBN NR: 978-625-5694-92-8

PREVALENCE OF TOXOPLASMOSIS IN SMALL RUMINANTS: EPIDEMIOLOGICAL STUDY IN KHORASAN REGION

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ABSTRACT

Toxoplasmosis caused by Toxoplasma gondii is a widespread parasitic infection with significant economic and public health impacts, particularly in small ruminants. This epidemiological study investigated the prevalence of toxoplasmosis in sheep and goats in the Khorasan region. Blood samples were collected from various farms and tested using serological assays to detect anti-T. gondii antibodies. Data were analyzed to assess prevalence rates and risk factors such as age, sex, and management practices. The study found a considerable seroprevalence indicating endemic infection in the region, with higher rates in older animals and traditional farming systems. These results underscore the necessity for targeted control measures and farmer education to reduce the burden of toxoplasmosis, with implications for livestock productivity and zoonotic transmission risk to humans.

Key words: Toxoplasmosis, small ruminants, prevalence, epidemiology, Khorasan

ISBN NR: 978-625-5694-92-8

VETERINARY SURGICAL MANAGEMENT OF BONE FRACTURES IN WORKING DOGS: A CLINICAL STUDY

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ABSTRACT

Bone fractures are common injuries in working dogs that require prompt surgical intervention to restore function and enable return to duty. This clinical study evaluated surgical techniques, outcomes, and complications in a cohort of working dogs treated for fractures at a veterinary hospital in Serbia. Various fixation methods, including internal and external devices, were applied depending on fracture type and location. Postoperative care and rehabilitation protocols were standardized. The majority of cases achieved successful bone healing and satisfactory functional recovery, though some experienced complications such as infection or delayed union. This research provides valuable clinical insights informing best practices for fracture management in working dogs, emphasizing the importance of tailored surgical approaches and comprehensive postoperative care.

Key words: bone fractures, working dogs, surgery, veterinary orthopedics, clinical outcomes

ISBN NR: 978-625-5694-92-8

ZOONOTIC TRANSMISSION OF BRUCELLOSIS FROM LIVESTOCK TO HUMAN POPULATIONS IN NORTHERN SERBIA

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ABSTRACT

Brucellosis is a persistent zoonotic disease transmitted from infected livestock to humans, posing significant health and economic burdens. This study investigated the prevalence of Brucella spp. in livestock and the related incidence of human brucellosis in northern Serbia. Samples from cattle, sheep, and goats underwent serological and bacteriological testing. Epidemiological surveys assessed human cases linked to occupational exposure and food consumption habits. The data demonstrated a strong association between livestock infection rates and human disease occurrence. Control strategies including vaccination, hygiene improvement, and public awareness campaigns are critical to reduce transmission. This study offers important evidence to guide regional brucellosis control and prevention efforts to protect both animal and human health.

Key words: brucellosis, zoonosis, livestock, public health, northern Serbia

ISBN NR: 978-625-5694-92-8

ASSESSMENT OF TICK-BORNE HEMOPARASITES IN DAIRY CATTLE AND THEIR IMPACT ON MILK PRODUCTIVITY

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Abstract
This research assesses the prevalence of tick-borne hemoparasites in dairy cattle and quantifies their impact on milk productivity in smallholder and semi-intensive farms in northern Nigeria. Tick-borne diseases such as babesiosis, anaplasmosis, and theileriosis constitute major constraints to dairy production, yet their subclinical effects on yield are often underestimated. A total of 300 lactating cows from different management systems were randomly selected, and data on age, breed, parity, body condition score, and production parameters were recorded. Blood samples were collected and examined using Giemsa-stained smears and polymerase chain reaction for species-level identification of hemoparasites. Concurrently, daily milk yield records over a three-month period were analyzed to compare infected and non-infected animals, controlling for nutritional and management factors. The study found a high overall prevalence of tick-borne hemoparasites, with mixed infections being common in cross-bred cows. Infected animals showed significant reductions in average daily milk yield, increased incidence of clinical mastitis, and prolonged calving intervals compared with uninfected herd mates. Poor tick control practices, limited access to veterinary services, and communal grazing systems were identified as key drivers of infection. The economic analysis demonstrated substantial income losses at farm level, highlighting the broader livelihood implications for households dependent on dairy sales. The study concludes that integrated tick-control strategies—combining strategic acaricide application, pasture management, and farmer training—are urgently required to mitigate production losses. It recommends that dairy development programs in Nigeria incorporate routine screening for hemoparasites and promote cost-effective control packages tailored to smallholder conditions.

Keywords: tick-borne hemoparasites, dairy cattle, milk productivity, smallholder farming, Nigeria

ISBN NR: 978-625-5694-92-8

MOLECULAR TYPING AND ANTIBIOGRAM PROFILES OF METHICILLIN-RESISTANT STAPHYLOCOCCUS AUREUS IN POULTRY FARMS

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Abstract
This study investigates the molecular characteristics and antimicrobial resistance profiles of methicillin-resistant *Staphylococcus aureus* (MRSA) isolates obtained from commercial poultry farms in southeastern Nigeria. MRSA is an emerging zoonotic pathogen of major public-health concern, yet data on its circulation in poultry production systems in West Africa remain scarce. Cloacal swabs, litter samples, and nasal swabs from farm workers were collected from twenty broiler and layer farms of varying sizes and biosecurity levels. Standard bacteriological methods were used for *S. aureus* isolation, followed by phenotypic detection of methicillin resistance using cefoxitin disc diffusion. Molecular confirmation of MRSA was performed by PCR amplification of the *mecA* gene, and selected isolates underwent spa-typing to determine genetic relatedness and possible transmission pathways. Antimicrobial susceptibility testing against a panel of commonly used veterinary and human antibiotics was conducted using the Kirby–Bauer method, and multidrug resistance patterns were documented. The results revealed a notable prevalence of MRSA in both birds and environmental samples, with some farms also showing identical spa-types in worker isolates, suggesting potential occupational exposure. Many isolates exhibited resistance to multiple classes of antibiotics, including tetracyclines, macrolides, and fluoroquinolones, raising concerns about therapeutic options and the risk of resistance dissemination. Biosecurity audits indicated that farms with poor hygiene, unrestricted farm access, and indiscriminate antimicrobial use in feed or water were more likely to harbor MRSA. The study underscores the need for robust surveillance of antimicrobial-resistant pathogens in poultry, implementation of antimicrobial-stewardship programs, and improved farm biosecurity. It concludes that coordinated action between veterinary and human health sectors is essential to address MRSA within a One Health framework in Nigeria.

Keywords: MRSA, poultry farms, antimicrobial resistance, molecular typing, Nigeria

ISBN NR: 978-625-5694-92-8

ADVANCES IN THE SYNTHESIS OF FUNCTIONALIZED ORGANIC MOLECULES FOR PHARMACEUTICAL APPLICATIONS

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ABSTRACT
This study presents significant advancements in the synthesis of functionalized organic molecules aimed at pharmaceutical applications. The research focuses on developing novel synthetic methodologies that enhance the efficiency, selectivity, and sustainability of producing biologically active compounds. By utilizing tailored reaction conditions and innovative catalysts, the team successfully synthesized various functional groups critical for drug development. Spectroscopic and chromatographic techniques were employed to characterize these molecules, confirming their structural integrity and purity. Moreover, the synthesized compounds were evaluated for biological activity, demonstrating promising pharmacological potential. This work contributes to the optimization of synthetic routes in medicinal chemistry, addressing challenges such as reaction yield, environmental impact, and scalability. The integration of green chemistry principles underlines the approach's relevance for industrial pharmaceutical production, aiming to reduce hazardous waste and energy consumption. Overall, the research offers valuable insights into the strategic design of functionalized organic molecules, advancing drug discovery and development processes.

Key words: organic synthesis, pharmaceutical chemistry, functionalized molecules

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Key words: organic synthesis, pharmaceutical chemistry, functionalized molecules

ISBN NR: 978-625-5694-92-8

INVESTIGATION OF POLYMERIC NANOCOMPOSITES FOR ENHANCED CATALYTIC PERFORMANCE IN INDUSTRIAL PROCESSES

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ABSTRACT
This research explores the design and performance of polymeric nanocomposites as catalysts in industrial chemical processes. The study investigates how polymer matrices combined with nanomaterials can improve catalytic efficiency, stability, and selectivity. Various synthesis techniques were applied to fabricate nanocomposites with controlled morphology and nanostructure distribution. Catalytic activity was assessed through reaction kinetics and conversion rates under simulated industrial conditions. Results indicate that these nanocomposites enhance catalyst durability and minimize deactivation caused by fouling or poisoning. Additionally, the nanocomposite catalysts contributed to energy savings and reduced environmental impact, aligning with sustainable industrial practices. The paper discusses mechanistic insights into the interactions between polymers and active nanoparticles that govern catalytic properties. These findings support the potential of polymeric nanocomposites to revolutionize catalytic processes, offering scalable solutions to increase productivity while maintaining cost-efficiency.

Key words: polymeric nanocomposites, catalysis, industrial chemistry

ISBN NR: 978-625-5694-92-8

DEVELOPMENT AND APPLICATION OF METAL-ORGANIC FRAMEWORKS IN ENVIRONMENTAL REMEDIATION

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ABSTRACT
The study focuses on the synthesis and environmental applications of metal-organic frameworks (MOFs), a class of porous crystalline materials with tunable properties. MOFs were engineered to target pollutants through adsorption, catalysis, and separation techniques in environmental remediation efforts. The paper details protocols for MOF fabrication, highlighting the role of metal nodes and organic linkers in dictating framework stability and selectivity toward contaminants such as heavy metals and organic dyes. Analytical techniques confirmed high surface area and porosity crucial for pollutant capture. Experimental results demonstrated effective removal efficiencies under various environmental conditions. The study also explores the regeneration and reuse of MOFs, emphasizing sustainability and cost-effectiveness. Through this work, MOFs are positioned as advanced materials for mitigating environmental pollution, with implications for water treatment technologies and green chemistry initiatives.

Key words: metal-organic frameworks, environmental remediation, adsorption

ISBN NR: 978-625-5694-92-8

KINETIC AND THERMODYNAMIC STUDY OF COPPER-CATALYZED ORGANIC TRANSFORMATION REACTIONS

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ABSTRACT
This paper investigates the kinetics and thermodynamics of copper-catalyzed organic transformation reactions relevant to synthetic organic chemistry. The study combines experimental data with computational modeling to elucidate reaction pathways, activation energies, and equilibrium constants. Various copper catalysts and substrates were tested to assess catalytic efficiency and selectivity. Kinetic parameters such as rate constants and reaction orders were determined through time-resolved spectroscopy and calorimetry. Thermodynamic analyses revealed the influence of temperature and pressure on reaction spontaneity and product distribution. The results contribute to a deeper understanding of copper's catalytic role and its potential to optimize organic synthesis processes. This research provides valuable information for designing improved catalysts and reaction conditions in pharmaceutical and fine chemical manufacturing.

Key words: copper catalysis, reaction kinetics, thermodynamics

ISBN NR: 978-625-5694-92-8

NOVEL APPROACHES TO BIOPOLYMER SYNTHESIS FOR MEDICAL DEVICE ENGINEERING

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ABSTRACT
This study addresses advancements in the synthesis of biopolymers tailored for medical device applications. Emphasis is placed on developing biodegradable and biocompatible polymers with enhanced mechanical and thermal properties suitable for implants and tissue engineering scaffolds. Various polymerization techniques and copolymer formulations were evaluated to achieve desirable characteristics, including controlled degradation rates and bioactivity. The synthesized biopolymers were characterized using rheological, spectroscopic, and microscopic methods. In vitro tests assessed cytocompatibility and biofunctionality, ensuring safety and efficacy for medical use. The study highlights innovative strategies integrating natural and synthetic monomers to create versatile biomaterials. These developments support improved design and manufacturing of medical devices with potential to reduce complications and enhance patient outcomes.

Key words: biopolymer synthesis, medical devices, biomaterials engineering

ISBN NR: 978-625-5694-92-8

ELECTROCHEMICAL METHODS FOR DETECTION OF HEAVY METAL IONS IN DRINKING WATER

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ABSTRACT
This research focuses on electrochemical sensor technologies for detecting heavy metal ions in drinking water. The development of sensitive and selective electrodes based on nanostructured materials enabled rapid identification of contaminants such as lead, cadmium, and mercury at trace levels. Optimization of electrode composition and surface modification techniques enhanced detection limits and response times. Calibration and validation were performed under laboratory and field conditions, demonstrating the practical applicability of these sensors. The study also explores interference effects and strategies to improve selectivity in complex water matrices. The implementation of these electrochemical methods offers a low-cost, portable solution for routine water quality monitoring, contributing to public health protection and regulatory compliance.

Key words: electrochemical sensors, heavy metals, water quality

ISBN NR: 978-625-5694-92-8

CATALYTIC CONVERSION OF BIOMASS-DERIVED SUBSTRATES TO BIOFUELS USING TRANSITION METAL COMPLEXES

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ABSTRACT
This paper investigates catalytic processes for converting biomass-derived substrates into biofuels utilizing transition metal complexes. The research emphasizes catalyst design, reaction optimization, and substrate scope to enhance conversion efficiency and selectivity toward fuels such as bioethanol and biodiesel. Various homogeneous and heterogeneous metal complexes were synthesized and tested under different reaction conditions. Analytical techniques including gas chromatography and mass spectrometry characterized the products. The study highlights the role of transition metals in facilitating biomass depolymerization and upgrading of intermediates to energy-dense fuels. Environmental benefits and economic feasibility are discussed, supporting the advancement of sustainable biofuel production technologies addressing global energy challenges.

Key words: biomass conversion, biofuels, transition metal catalysis

ISBN NR: 978-625-5694-92-8

DEVELOPMENT OF ADVANCED METAL MATRIX COMPOSITES FOR HIGH-TEMPERATURE APPLICATIONS

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ABSTRACT
This study explores the development of advanced metal matrix composites (MMCs) designed for high-temperature environments. The research focuses on optimizing microstructural properties to enhance thermal stability, mechanical strength, and oxidation resistance of MMCs. Using a combination of alloying elements and ceramic reinforcements, the composites were fabricated through powder metallurgy techniques. Characterization involved microstructural analysis via scanning electron microscopy and evaluation of mechanical properties including tensile strength, hardness, and creep resistance at elevated temperatures. Results demonstrate significant improvements in performance compared to traditional metal alloys, highlighting the potential application of these MMCs in aerospace and power generation industries. The study also addresses challenges related to interfacial bonding and thermal expansion mismatch, proposing solutions for improved composite integrity under thermal cycling. These findings contribute to the broader field of materials engineering, supporting the development of components that demand durability in extreme conditions.

Key words: metal matrix composites, high-temperature materials, thermal stability, powder metallurgy

ISBN NR: 978-625-5694-92-8

INVESTIGATION OF NANOSTRUCTURED CERAMICS FOR PHOTOCATALYTIC WATER PURIFICATION

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ABSTRACT
This research investigates the synthesis and application of nanostructured ceramic materials for photocatalytic degradation of organic pollutants in water. Nanoceramics were prepared using sol-gel and hydrothermal methods to achieve high surface area and controlled morphology. Photocatalytic performance was evaluated under ultraviolet and visible light irradiation by monitoring the degradation rates of model contaminants such as dyes and pharmaceutical residues. Results indicate that these nanoceramics exhibit superior photocatalytic efficiency due to their enhanced charge separation and light absorption capabilities. Mechanistic studies revealed the generation of reactive oxidative species leading to mineralization of pollutants. The study also explores the stability and recyclability of these ceramic catalysts, demonstrating their potential for sustainable water purification applications. This advancement supports environmental engineering efforts aimed at reducing water pollution and promoting clean water technologies globally.

Key words: nanostructured ceramics, photocatalysis, water purification, environmental remediation

ISBN NR: 978-625-5694-92-8

MULTISCALE MODELING OF MECHANICAL BEHAVIOR IN NANOCRYSTALLINE TITANIUM ALLOYS

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ABSTRACT
This study employs multiscale modeling techniques to analyze the mechanical behavior of nanocrystalline titanium alloys, focusing on deformation mechanisms at different length scales. Atomistic simulations using molecular dynamics offer atomic-level insights into grain boundary activities and dislocation nucleation, while continuum-level finite element models capture macroscopic stress-strain responses. The models were validated against experimental data from tensile tests on synthesized nanocrystalline titanium samples. Results highlight the pronounced effect of grain size refinement on strength enhancement, along with the role of twin boundary formation in plastic deformation. This work advances the understanding of structure-property relationships in titanium alloys, essential for designing lightweight, high-strength materials for aerospace and biomedical applications. The integration of computational modeling with experimental methods opens avenues for predictive material design in nanostructured metals.

Key words: nanocrystalline titanium, multiscale modeling, mechanical behavior, molecular dynamics

ISBN NR: 978-625-5694-92-8

EFFECT OF ULTRASONIC CONSOLIDATION ON THE JOINING OF DISSIMILAR METAL SHEETS

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ABSTRACT
This work investigates ultrasonic consolidation (UC) as an innovative technique for joining dissimilar metal sheets, offering a solid-state bonding alternative without melting. Metals including aluminum, copper, and titanium alloys were bonded under varied ultrasonic parameters to optimize bond strength and microstructural integrity. Mechanical tests and microscopic analyses characterized the interfacial quality and bonding mechanisms. The UC process demonstrated successful metallurgical bonding with minimal intermetallic formation and void defects. The study discusses the influence of ultrasonic power, pressure, and temperature on joint quality, emphasizing the technique's advantages for lightweight structural assemblies in aerospace and automotive manufacturing. These findings contribute practical insights into efficient joining processes for multi-material design.

Key words: ultrasonic consolidation, dissimilar metals, solid-state bonding, materials joining

ISBN NR: 978-625-5694-92-8

SYNTHESIS AND ELECTRICAL CHARACTERIZATION OF GRAPHENE-BASED FLEXIBLE ELECTRONICS

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ABSTRACT
This paper presents the synthesis and electrical characterization of graphene-based flexible electronic devices. Graphene films were fabricated using chemical vapor deposition and transferred onto flexible polymer substrates to create bendable conductive components. Electrical properties including conductivity, carrier mobility, and contact resistance were measured under mechanical deformation, simulating real-use bending conditions. The devices exhibited stable electronic performance with minor degradation under repeated flexing cycles. Potential applications in wearable electronics, sensors, and foldable displays are discussed, highlighting graphene's unique combination of mechanical flexibility and superior electrical properties. This research advances the materials science field by enabling next-generation flexible electronics with improved durability and functionality.

Key words: graphene, flexible electronics, electrical characterization, wearable devices

ISBN NR: 978-625-5694-92-8

ADVANCED COATING STRATEGIES FOR CORROSION RESISTANCE IN POWER PLANT STEELS

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ABSTRACT
This study evaluates advanced coating technologies to improve corrosion resistance in steels used in power plants, particularly under high-temperature and acidic conditions. Coatings such as thermal spray ceramics, nanostructured oxides, and organic-inorganic hybrids were applied and tested for performance against oxidation and sulfidation. Electrochemical impedance spectroscopy and cyclic polarization techniques quantified corrosion rates, while microstructural characterization assessed coating adhesion and integrity. The results demonstrate that certain multilayer coatings significantly extend service life by acting as effective diffusion barriers and reducing corrosive attack. The investigation provides guidelines for optimizing coating compositions and application methods tailored for power generation components, contributing to maintenance cost reduction and reliability enhancement in energy infrastructure.

Key words: corrosion resistance, coatings, power plant steels, thermal spray

ISBN NR: 978-625-5694-92-8

BIOCOMPATIBLE POLYMER NANOCOMPOSITES FOR TISSUE ENGINEERING APPLICATIONS

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ABSTRACT
This research focuses on the fabrication and evaluation of biocompatible polymer nanocomposites for tissue engineering scaffolds. Polymer matrices such as polycaprolactone were reinforced with bioactive nanoparticles including hydroxyapatite and graphene oxide to enhance mechanical properties and cellular interactions. Scaffold morphology, porosity, and biodegradation rate were characterized alongside in vitro cell viability and proliferation assays using fibroblast cells. Results reveal improved scaffold stiffness and bioactivity, supporting cell adhesion and growth. The integration of nanomaterials facilitates controlled release of growth factors and mimics natural extracellular matrix components. These findings highlight the potential of polymer nanocomposites to advance regenerative medicine strategies for soft and hard tissue repair.

Key words: polymer nanocomposites, tissue engineering, biocompatibility, scaffolds

ISBN NR: 978-625-5694-92-8

INVESTIGATION OF FUNCTIONALIZED SILICA NANOPARTICLES FOR DRUG DELIVERY SYSTEMS

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ABSTRACT
This study explores the synthesis and functionalization of silica nanoparticles for targeted drug delivery applications. Silica nanoparticles were modified with amine and carboxyl groups to enhance drug loading capacity and targeting efficiency. Drug release profiles were investigated under simulated physiological conditions to evaluate controlled release behavior. Cellular uptake and cytotoxicity tests were conducted using cancer cell lines to assess therapeutic efficacy and biocompatibility. The functionalized silica nanoparticles displayed favorable surface chemistry for drug conjugation and sustained release, exhibiting reduced toxicity and enhanced selectivity towards target cells. This research contributes to the design of advanced nanocarriers that improve treatment outcomes in oncology and personalized medicine.

Key words: silica nanoparticles, functionalization, drug delivery, nanocarriers

ISBN NR: 978-625-5694-92-8

ENHANCED PROTEIN EXTRACTION FROM KAZAKHSTAN LEGUMES USING NOVEL ENZYMATIC METHODS

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ABSTRACT
Recent advances in enzymatic technologies have enabled improved protein extraction from plant sources, a key area for enhancing nutritional quality in legume-based foods. This study investigates the application of novel enzymatic methods tailored to legumes indigenous to Kazakhstan, aiming to increase protein yield and purity while preserving bioactivity. Various novel enzyme combinations were tested on chickpeas, lentils, and peas native to the region. The enzymatic treatments were optimized based on parameters including pH, temperature, and incubation time. Results show a significant increase in protein extraction efficiency compared to conventional alkaline or acid extraction methods. Structural analysis using SDS-PAGE and spectrophotometry confirmed the preservation of essential amino acids and protein integrity. Moreover, the enhanced protein extracts demonstrated improved solubility and functional properties such as emulsifying and foaming capacity, indicating their suitability for food industry applications. This study also evaluated the environmental benefits of enzymatic extraction by comparing water and energy consumption to standard procedures, highlighting sustainability advantages. The findings promote the sustainable valorization of Kazakhstani legumes, offering a promising avenue for the development of high-quality plant-based proteins to support food security and nutrition goals. Future research directions include scale-up of the enzymatic process and incorporation into food product formulations.

Keywords: protein extraction, enzymatic methods, Kazakhstani legumes, plant-based proteins, sustainable food technology

ISBN NR: 978-625-5694-92-8

DEVELOPMENT AND CHARACTERIZATION OF SMART BIODEGRADABLE FOOD PACKAGING FILMS BASED ON KAZAKHSTANI STARCH SOURCES

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ABSTRACT
The quest for eco-friendly packaging has intensified interest in biodegradable films derived from renewable agricultural resources. This research focuses on developing smart biodegradable food packaging films using starch extracted from Kazakhstani cereals and tubers. Various formulations combining starch with natural plasticizers, bioactive agents, and nanomaterials were produced via casting methods. The films were characterized for mechanical strength, water vapor permeability, biodegradability, and antimicrobial activity. Results demonstrated that incorporating natural antioxidants and antimicrobial compounds enhanced the films' functional properties by extending food shelf life and providing protection against microbial contamination. Physical tests indicated that the films possess sufficient tensile strength and flexibility to be practical packaging materials. Biodegradability assessments confirmed complete decomposition under composting conditions within 60 days, aligning with sustainable waste management goals. Additionally, responsiveness to environmental stimuli such as humidity and pH was integrated to create smart packaging capable of indicating food freshness. This multifunctional film technology presents a promising solution to reduce plastic waste and support Kazakhstan's agricultural economy by valorizing starch resources. The study contributes to the global movement toward sustainable packaging innovations and offers practical benefits for food safety and environmental preservation. Future work will focus on scaling production and applying these films in real food packaging scenarios.

Keywords: biodegradable films, smart packaging, starch-based materials, antimicrobial, sustainable packaging

ISBN NR: 978-625-5694-92-8

INTEGRATED MICROALGAE CULTIVATION SYSTEMS FOR NUTRIENT-RICH FOOD PRODUCTION IN BANGLADESH

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ABSTRACT
Microalgae have emerged as a sustainable source of nutrients including proteins, lipids, and bioactive compounds ideal for food and feed applications. This study presents the development of integrated microalgae cultivation systems optimized for Bangladesh's climatic and water resource conditions aimed at producing nutrient-rich biomass. Closed photobioreactors and open pond systems were compared to assess growth performance, nutrient uptake efficiency, and biomass composition of locally isolated microalgal strains. The integrated system incorporates wastewater treatment and CO2 sequestration, creating synergies for environmental remediation alongside biomass production. Analytical results showed high protein content (up to 60% dry weight) along with essential amino acids, vitamins, and antioxidants in the harvested biomass, confirming its nutritional suitability. Economic analyses indicated that integrating waste streams significantly lowers operational costs, enhancing scalability. This technology supports Bangladesh's food security by providing alternatives to traditional agriculture while contributing to circular economy goals. Potential applications include functional foods, dietary supplements, and aquaculture feed. Challenges such as contamination control and continuous culture maintenance were addressed using automated monitoring and control systems. The study paves the way for commercializing microalgal biomass as a nutrient-dense food resource.

Keywords: microalgae cultivation, nutrient-rich food, Bangladesh, integrated systems, sustainable food production

ISBN NR: 978-625-5694-92-8

POST-HARVEST TECHNOLOGIES FOR REDUCING FRUIT AND VEGETABLE LOSS IN BANGLADESHI MARKETS

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ABSTRACT
Post-harvest losses of fruits and vegetables present a critical challenge to Bangladesh's food supply chain, contributing significantly to food insecurity and economic loss. This research evaluates advanced post-harvest technologies aimed at minimizing spoilage and maintaining quality from farm to market. Techniques such as controlled atmosphere storage, modified packaging, cold chain logistics, and ethylene scavengers were assessed in experimental trials involving locally common produce including tomatoes, mangoes, and cucumbers. Results indicated that controlled atmosphere storage combined with active packaging significantly prolonged shelf life and reduced microbial decay under market conditions. Additionally, interventions such as temperature management during transportation and display helped maintain texture and nutrient content. The study also addressed smallholder adoption barriers by proposing cost-effective solutions adaptable to local market infrastructure. A comprehensive evaluation framework combining quality attributes, economic feasibility, and environmental impact was developed to guide technology selection. The findings provide evidence-based recommendations for stakeholders to implement post-harvest interventions, which could potentially reduce losses by up to 30%. This will enhance food availability and farmers' incomes while aligning with national food safety standards.

Keywords: post-harvest technology, fruit and vegetable loss, Bangladesh, storage methods, food supply chain

ISBN NR: 978-625-5694-92-8

APPLICATION OF 3D PRINTING IN DESIGNING FUNCTIONAL FOODS WITH TAILORED TEXTURE IN SINGAPORE

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ABSTRACT
Three-dimensional (3D) printing technology has rapidly advanced the customization of food products, enabling precise control over texture, shape, and nutrient composition. This study explores the application of 3D printing in designing functional foods with tailored textures that meet specific dietary and sensory requirements. Using food-grade biomaterials such as protein gels, starches, and hydrocolloids, various 3D printing formulations were developed and optimized to achieve modulated texture profiles suitable for populations with special needs, such as elderly and dysphagic patients. Rheological and mechanical tests assessed the printability and final food structure integrity. Results showed that adjusting printing parameters and formulation components allowed the creation of uniquely textured snacks and meals with enhanced mouthfeel and nutritional profiles. Additionally, bioactive ingredients including vitamins, antioxidants, and probiotics were incorporated into the printing matrix without compromising stability or sensory acceptance. The study demonstrates the feasibility of 3D food printing to deliver personalized nutrition and improve food accessibility in urban settings. Opportunities for commercial applications and future research directions, including multi-material printing and integration with digital health data, are also discussed.

Keywords: 3D food printing, functional foods, texture design, personalized nutrition, Singapore

ISBN NR: 978-625-5694-92-8

DATA-DRIVEN OPTIMIZATION IN INDUSTRIAL FERMENTATION FOR SUSTAINABLE FOOD INGREDIENTS

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Abstract
This paper investigates the use of data-driven optimization strategies to improve the efficiency, consistency, and sustainability of industrial fermentation processes used to produce food ingredients such as organic acids, flavor compounds, and alternative proteins. Fermentation systems are inherently complex, with performance influenced by microbial physiology, substrate composition, process parameters, and scale-up effects that are difficult to capture using purely mechanistic models. In this study, historical plant data and targeted experimental campaigns are combined to construct machine-learning models that predict key performance indicators, including product yield, productivity, and by-product formation, under varying operating conditions. Feature engineering focuses on variables such as inoculum characteristics, dissolved oxygen profiles, feeding strategies, and temperature or pH trajectories over time. The models are then embedded in an optimization framework that searches for parameter combinations balancing productivity with resource efficiency, energy use, and waste minimization. Case studies in both batch and fed-batch processes demonstrate that data-driven optimization can identify non-intuitive operating windows that outperform conventional set points derived from trial-and-error or small-scale lab experiments. The approach delivers measurable reductions in raw-material consumption and carbon footprint while maintaining or enhancing product quality. The paper also discusses implementation challenges, including data quality, sensor reliability, and integration with existing control systems, as well as organizational factors such as cross-functional collaboration between data scientists, process engineers, and production operators. Overall, the study argues that data-driven optimization provides a practical pathway toward more sustainable fermentation-based food production and outlines recommendations for industrial adoption, including phased deployment, continuous model updating, and robust validation protocols.

Keywords: data-driven optimization, industrial fermentation, sustainable food ingredients, machine learning, process control

ISBN NR: 978-625-5694-92-8

DEVELOPMENT OF NATURAL ANTIOXIDANT SYSTEMS TO PRESERVE QUALITY IN ALGERIAN OLIVE OIL

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Abstract
This study focuses on the development and evaluation of natural antioxidant systems to preserve the chemical and sensory quality of Algerian olive oil during storage and distribution. Algeria possesses diverse olive cultivars and growing regions, yet the added value of its oils is often compromised by oxidative degradation driven by exposure to oxygen, light, and temperature fluctuations along the supply chain. To address this challenge, the research investigates plant-derived antioxidants as clean-label alternatives to synthetic stabilizers. Phenolic-rich extracts obtained from local by-products—including olive leaves, grape pomace, and aromatic herbs—are characterized for total phenolic content, antioxidant capacity, and compatibility with extra-virgin olive oil matrices. Selected extracts are incorporated into olive oil at different concentrations and compared with control samples under accelerated and real-time storage conditions. Quality parameters such as peroxide value, conjugated dienes, specific UV absorbance, and sensory descriptors related to rancidity and freshness are monitored over time. The results show that specific combinations of natural extracts significantly delay primary and secondary oxidation, prolonging shelf life without masking desirable varietal aromas. Statistical analysis confirms dose–response relationships and highlights synergistic effects when mixed antioxidant sources are used. The study also assesses regulatory and consumer-acceptance aspects, emphasizing that natural antioxidant systems can support “clean label” positioning and differentiation of Algerian olive oils in export markets. Practical guidelines are proposed for industrial implementation, including recommended extract types, concentration ranges, and critical control points during processing and packaging. Overall, the research demonstrates that valorizing local plant resources as natural antioxidants offers a sustainable strategy to enhance product quality, reduce waste, and strengthen the competitiveness of Algeria’s olive oil sector.

Keywords: Algerian olive oil, natural antioxidants, oxidative stability, phenolic extracts, shelf life

ISBN NR: 978-625-5694-92-8

APPLICATION OF FLEXIBLE ELECTRONICS FOR WEARABLE HEALTH MONITORING SYSTEMS

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ABSTRACT
The integration of flexible electronics into wearable health monitoring systems represents a significant advancement in personalized healthcare technology. This study explores the design, implementation, and applications of flexible electronic devices that conform to the human body, enabling continuous and real-time health monitoring. The inherent flexibility and lightweight nature of these electronics allow for comfortable, non-invasive measurements of vital signs such as heart rate, body temperature, and respiratory rate. The research focuses on material innovation, circuit design, and sensor integration to optimize performance while maintaining flexibility. Various types of flexible substrates, including polymers and thin metal films, are employed to fabricate sensors capable of withstanding mechanical stress and body movements. The system architecture incorporates low-power wireless communication modules to ensure seamless data transmission to mobile devices and cloud platforms for remote patient monitoring. Experimental results demonstrate enhanced durability, accuracy, and user comfort compared to traditional rigid devices. The potential applications extend from chronic disease management and fitness tracking to early diagnosis through continuous physiological data collection. Challenges in biocompatibility, data security, and energy efficiency are addressed, with proposed solutions to improve the sustainability and scalability of this technology. This paper contributes to the growing body of knowledge supporting the development of next-generation wearable health devices that combine flexibility, functionality, and user-centric design.

Key words: flexible electronics, wearable health monitoring, real-time sensors, personalized healthcare

ISBN NR: 978-625-5694-92-8

DESIGN AND PERFORMANCE ANALYSIS OF ENERGY-EFFICIENT INTERNET OF THINGS (IOT) SENSOR NODES FOR SMART AGRICULTURE

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ABSTRACT
The advancement of Internet of Things (IoT) technology has revolutionized smart agriculture by enabling precise environmental monitoring and resource management. This paper presents the design and performance analysis of energy-efficient IoT sensor nodes tailored for agricultural applications. These sensor nodes are designed to operate autonomously for extended periods under harsh outdoor conditions, minimizing energy consumption without compromising data accuracy. A modular architecture enables integration of multiple sensors measuring soil moisture, temperature, humidity, and light intensity to facilitate crop health monitoring and irrigation management. The system employs low-power microcontrollers and optimized communication protocols, such as LoRa and Zigbee, to achieve long-range transmission with minimal energy expenditure. Simulation and field experiments validate the node's performance in terms of energy consumption, signal reliability, and responsiveness under varying environmental conditions. The results underscore the potential to significantly reduce irrigation water usage and increase crop yield while decreasing operational costs. Security and scalability aspects are also considered to ensure robust deployment in large agricultural fields. This work contributes to IoT-based sustainable agriculture by providing practical design guidelines and performance benchmarks for energy-efficient sensor node development.

Key words: IoT sensor nodes, smart agriculture, energy efficiency, wireless communication

ISBN NR: 978-625-5694-92-8

DEVELOPMENT OF LOW-POWER VLSI ARCHITECTURES FOR AI-ENABLED EDGE COMPUTING DEVICES

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ABSTRACT
The exponential growth of artificial intelligence (AI) applications at the edge necessitates the development of energy-efficient Very Large Scale Integration (VLSI) architectures that support real-time data processing with low latency. This research focuses on the design and optimization of low-power VLSI architectures tailored for AI-enabled edge computing devices. By leveraging novel circuit techniques, including power gating, dynamic voltage scaling, and approximate computing, the proposed architectures reduce power consumption while maintaining computational accuracy. Emphasis is placed on implementing convolutional neural networks (CNNs) and other machine learning models on hardware to enable localized decision making in resource-constrained environments. Experimental evaluation on FPGA and ASIC platforms demonstrates improvements in throughput, power efficiency, and area utilization compared to conventional architectures. The integration of hardware accelerators supports parallel processing while optimizing memory access and minimizing data movement. These advancements pave the way for deploying AI capabilities in Internet of Things (IoT) nodes, autonomous systems, and wearable devices. The study also discusses challenges related to hardware security and adaptability in dynamic AI workloads.

Key words: VLSI architecture, low-power design, AI edge computing, hardware acceleration, convolutional neural networks

ISBN NR: 978-625-5694-92-8

INTELLIGENT SMART GRID CONTROL USING DEEP LEARNING ALGORITHMS FOR POWER DISTRIBUTION OPTIMIZATION

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ABSTRACT
The modernization of power distribution systems through intelligent control strategies is critical for enhancing grid reliability, efficiency, and sustainability. This paper presents an intelligent smart grid control framework utilizing deep learning algorithms for optimizing power distribution in real time. The proposed system incorporates deep neural networks to analyze large volumes of grid data and predict load demand patterns, renewable energy generation, and fault conditions. This predictive capability enables dynamic adjustment of grid parameters to balance supply and demand, reduce losses, and prevent outages. The framework integrates advanced sensors and communication infrastructure to gather high-resolution data, which feeds into the deep learning models for continuous learning and adaptation. Simulation results on test power systems show significant improvements in voltage stability, demand response management, and integration of distributed energy resources (DERs). The system also enhances resilience against disturbances by providing intelligent fault detection and isolation. Challenges related to data privacy, computational complexity, and scalability are addressed with strategies for model optimization and secure communication protocols. This study contributes to the evolution of resilient and efficient smart grids by harnessing state-of-the-art artificial intelligence techniques.

Key words: smart grid control, deep learning, power distribution optimization, demand response, renewable integration

ISBN NR: 978-625-5694-92-8

RECONFIGURABLE ANTENNA DESIGN FOR MILLIMETER WAVE 5G COMMUNICATION APPLICATIONS

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ABSTRACT
The rapid deployment of 5G communication networks operating in the millimeter-wave (mmWave) spectrum presents challenges in antenna design, particularly regarding beam steering, frequency agility, and compactness. This study explores the development of reconfigurable antenna architectures for mmWave 5G applications, enabling dynamic adaptation to changing channel conditions and user mobility. The proposed antennas utilize micro-electromechanical systems (MEMS) switches, varactors, and tunable materials to achieve multiband operation and beamforming capabilities within a compact form factor. Design methodologies include electromagnetic simulation, fabrication, and experimental validation to optimize parameters such as gain, bandwidth, radiation pattern, and polarization diversity. Results demonstrate enhanced reconfigurability with low insertion loss and fast switching speeds compatible with 5G system requirements. Specific attention is given to overcoming propagation challenges unique to mmWave frequencies, including high path loss and limited penetration. The flexibility in antenna characteristics supports improved link reliability, spectral efficiency, and network capacity in dense urban environments. The proposed designs contribute to enabling next-generation adaptive communication systems where antenna performance is critical to network success.

Key words: reconfigurable antenna, millimeter wave, 5G communications, beam steering, MEMS switches

ISBN NR: 978-625-5694-92-8

SILICON PHOTONICS INTEGRATED CIRCUITS FOR ULTRA-FAST OPTICAL TELECOM NETWORKS

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ABSTRACT
Silicon photonics integrated circuits are transforming optical telecommunications by enabling ultra-fast data transmission and improved network scalability at reduced cost. This paper reviews recent advancements in silicon photonics technology, focusing on integrated components such as modulators, detectors, and waveguides optimized for high-speed optical networks. The compatibility of silicon photonics with CMOS fabrication techniques allows mass production with superior integration density and energy efficiency. The research addresses design challenges related to minimizing signal loss, thermal effects, and optical crosstalk in densely packed circuits. Experimental demonstrations highlight multi-wavelength data transmission exceeding terabit per second speeds and low power consumption metrics critical for data centers and long-haul communications. The study also explores emerging applications in coherent communication and quantum photonics, underscoring the versatility of silicon photonic platforms. Future directions emphasize the integration of active and passive devices on a single chip to create fully functional optical transceivers. This work underscores silicon photonics' pivotal role in meeting the growing global demand for bandwidth and energy-efficient optical networking infrastructures.

Key words: silicon photonics, integrated circuits, optical telecom, high-speed data transmission, CMOS compatibility

ISBN NR: 978-625-5694-92-8

DEVELOPMENT OF GRAPHENE-BASED NANOELECTRONIC DEVICES FOR NEXT-GENERATION SENSORS

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ABSTRACT
Graphene's extraordinary electrical, mechanical, and chemical properties have positioned it at the forefront of nanoelectronic device research, particularly for sensor technologies. This study presents the development of graphene-based nanoelectronic devices aimed at next-generation sensor applications, including environmental monitoring, biomedical diagnostics, and industrial process control. The research focuses on fabricating graphene field-effect transistors (GFETs) with enhanced sensitivity and selectivity through surface functionalization and heterostructure engineering. Advanced lithography and chemical vapor deposition (CVD) techniques are leveraged to produce high-quality graphene layers and nanoscale patterns. Electrical characterization reveals superior carrier mobility and low noise levels, essential for detecting minute changes in analyte concentration. Various sensing mechanisms, such as chemical doping and electrostatic gating, are explored to tailor sensor response toward specific targets. Integration with microfluidic platforms enables real-time, label-free detection of biomolecules and gases with rapid response times. The study also addresses challenges related to device reproducibility, stability, and large-scale fabrication. These advancements position graphene nanoelectronics as a transformative technology for highly sensitive, compact, and scalable sensing systems capable of meeting future technological demands.

Key words: graphene nanoelectronics, nanosensors, GFET, chemical vapor deposition, biomedical sensing

ISBN NR: 978-625-5694-92-8

INNOVATIVE STRATEGIES IN THE SEISMIC DESIGN OF URBAN INFRASTRUCTURE IN YEREVAN

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ABSTRACT
This study explores innovative strategies for seismic design applied to urban infrastructure in Yerevan, a region highly susceptible to earthquakes due to its complex tectonic setting. The research focuses on integrating advanced engineering methods and materials to enhance structural resilience against seismic forces while addressing urban growth challenges. Emphasizing a multidisciplinary approach, the study examines recent developments in seismic-resistant technologies, including base isolation, energy dissipation systems, and performance-based design principles, tailored specifically for Yerevan's unique geological and socio-economic context. Detailed analysis of local building codes and construction practices is conducted to identify gaps and opportunities for improvement. Through field surveys and computer simulations, the research evaluates the effectiveness of newly proposed design methods in minimizing structural damage and ensuring occupant safety during seismic events. Furthermore, the study advocates for the incorporation of smart monitoring systems within critical infrastructure to provide real-time data and predictive maintenance capabilities, thereby improving long-term urban resilience. Stakeholder engagement and capacity building within local engineering communities are highlighted as essential for successful implementation. The paper concludes by proposing a roadmap for policymakers and practitioners aimed at integrating these innovative seismic strategies into existing urban planning frameworks, contributing to sustainable and disaster-resilient development of Yerevan. This work represents a significant step toward modernizing seismic design practices in Armenia's capital city and establishes a foundation for further regional research and application.

Keywords: seismic design, urban infrastructure, earthquake resilience, Yerevan, structural engineering

ISBN NR: 978-625-5694-92-8

DEVELOPMENT OF ECO-FRIENDLY CONCRETE COMPOSITES WITH LOCALLY SOURCED MATERIALS

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ABSTRACT

This research presents the development of eco-friendly concrete composites utilizing locally sourced materials in Armenia, aiming to reduce environmental impact while maintaining high structural performance. Traditional concrete production contributes significantly to global carbon emissions, prompting the need for sustainable alternatives that leverage regional resources such as volcanic aggregates, industrial by-products like fly ash from local power plants, and recycled construction waste. The study employs a systematic approach involving material characterization, mix design optimization, and comprehensive mechanical testing to evaluate compressive strength, tensile properties, durability under freeze-thaw cycles, and long-term carbonation resistance. Experimental results demonstrate that optimized composites achieve up to 20% higher strength-to-weight ratios compared to conventional mixes, with reduced embodied energy by 35%. Microstructural analysis via SEM and XRD reveals enhanced interfacial transition zones due to pozzolanic reactions from local additives, improving crack resistance and permeability. Life-cycle assessment (LCA) quantifies environmental benefits, showing substantial decreases in CO2 footprint and resource depletion. The paper discusses scalability challenges, including supply chain logistics for rural sourcing and standardization for code compliance. Implementation strategies for Armenian construction industry are proposed, including pilot projects in Yerevan's social housing developments. These composites not only promote circular economy principles but also foster economic growth through local material valorization. Findings provide a blueprint for other developing regions facing similar resource constraints and sustainability demands, advancing green building practices globally.

Keywords: eco-friendly concrete, local materials, sustainable composites, mechanical properties, life-cycle assessment

ISBN NR: 978-625-5694-92-8

INTELLIGENT FLOOD MANAGEMENT SYSTEMS FOR URBAN CENTERS IN LAHORE

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ABSTRACT

This paper introduces intelligent flood management systems tailored for Lahore's urban centers, addressing recurrent flooding exacerbated by monsoon intensity and rapid urbanization. Lahore experiences annual inundation affecting millions, necessitating real-time monitoring, predictive analytics, and adaptive infrastructure. The study integrates IoT sensors for rainfall, river levels, and drainage monitoring with AI-driven forecasting models using machine learning algorithms like LSTM neural networks trained on 20 years of historical data. Developed prototype systems enable dynamic pump station control, automated barrier deployment, and citizen alert apps, reducing response times by 40%. Hydraulic modeling with HEC-RAS simulates flood scenarios under climate change projections, identifying critical vulnerabilities in Ravi River basin. Field implementations in pilot neighborhoods demonstrate 25% flood volume reduction through smart retention basins and permeable pavements. Cost-benefit analysis reveals a 5:1 return over 10 years, factoring in avoided damages and resilience gains. Socio-technical aspects include community training and policy integration with Punjab Urban Development Authority. Challenges such as data privacy, sensor reliability in monsoons, and equitable access are mitigated via blockchain-secured data sharing and solar-powered redundancies. The framework offers scalable solutions for other South Asian megacities, promoting resilient urban hydrology amid climate variability. This work bridges engineering innovation with practical governance for sustainable flood risk reduction.

Keywords: flood management, intelligent systems, IoT, AI forecasting, urban resilience

ISBN NR: 978-625-5694-92-8

ADVANCED OPTIMIZATION OF WIND ENERGY INFRASTRUCTURE IN COASTAL PAKISTAN

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ABSTRACT

Focused on coastal Pakistan's high wind potential, this research advances optimization techniques for wind energy infrastructure to maximize energy yield and grid integration. Regions like Gharo-Keti Bandar corridor offer average speeds exceeding 7 m/s, yet underutilized due to suboptimal turbine siting and wake effects. Multi-objective genetic algorithms optimize farm layouts considering terrain, turbulence, and bird migration paths via CFD simulations with ANSYS Fluent. Annual energy production (AEP) predictions incorporate Weibull distributions calibrated to site-specific met-mast data, achieving 15% yield improvements over standard configurations. Hybrid systems combining wind with battery storage and desalination address intermittency, modeled using HOMER software for levelized cost of energy (LCOE) under 4¢/kWh. Offshore potential is assessed through floating turbine concepts suited to Arabian Sea bathymetry. Economic viability incorporates local manufacturing incentives and carbon credit mechanisms. Environmental impact studies confirm minimal avian disruption via radar tracking. Grid stability enhancements via FACTS devices enable 30% wind penetration without curtailment. Case studies from existing Thatta farms validate models, informing 1 GW expansion roadmap. Policy recommendations target feed-in tariffs and skilled workforce development. These optimizations accelerate Pakistan's renewable transition, reducing fossil fuel dependence and coastal vulnerabilities.

Keywords: wind energy optimization, turbine layout, CFD modeling, hybrid systems, coastal infrastructure

ISBN NR: 978-625-5694-92-8

APPLICATION OF NANOMATERIALS IN WATER PURIFICATION SYSTEMS FOR KARACHI

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ABSTRACT

This investigation applies nanomaterials to enhance water purification systems for Karachi, tackling acute contamination from industrial effluents and seawater intrusion. Karachi's water crisis affects 20 million residents, with heavy metals and pathogens exceeding WHO limits. Graphene oxide (GO) and TiO2 nanocomposites are synthesized via hydrothermal methods, functionalized for selective adsorption of arsenic, chromium, and E. coli. Batch and column tests show 98% arsenic removal at neutral pH, outperforming activated carbon by 3x capacity. Photocatalytic degradation under solar irradiation achieves 95% dye mineralization in 2 hours. Membrane integration yields hybrid nanofiltration units with flux rates 50% above commercial RO, fouling resistance via hydrophilic coatings. Pilot-scale deployment at Malir River treats 10 m^3/day, monitored via real-time turbidity sensors. Regeneration via mild acid washing sustains performance over 100 cycles. Techno-economic analysis projects 30% OPEX savings for municipal plants. Regulatory alignment with Pakistan EPA standards facilitates upscaling. Public health modeling estimates 40% diarrheal disease reduction. Challenges like nanomaterial leaching are addressed through core-shell encapsulation. This technology empowers decentralized purification, vital for Karachi's informal settlements, setting precedents for nanomaterial-driven water security in megacities.

Keywords: nanomaterials, water purification, adsorption, photocatalysis, Karachi water crisis

ISBN NR: 978-625-5694-92-8

SUSTAINABLE DESIGN OF EMBANKMENT DAMS UNDER ARID CLIMATE CONDITIONS

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ABSTRACT

Targeting Oman's arid climate, this study advances sustainable embankment dam designs balancing seepage control, erosion resistance, and water conservation. High evaporation (3m/year) and flash floods demand geomaterials optimized for low permeability and thermal stability. Roller-compacted concrete (RCC) cores with local limestone aggregates reduce cement by 40%, tested via triaxial shear and permeability trials. Finite element modeling with PLAXIS simulates saturation under wadi inflows, confirming factor of safety >1.5 against piping. Vegetation-stabilized downstream shells enhance biodiversity, trialed with native halophytes. Climate-adaptive features include automated spillway gates and evaporation covers. Seismic provisions incorporate Omani code updates post-2009 events. Life-cycle costing favors RCC over zoned earthfill by 25% over 50 years. Case study of Wadi Dayqah Dam retrofits validates longevity. Water quality modeling prevents salinization via geomembrane liners. Community benefits include aquifer recharge and irrigation equity. Design guidelines integrate GIS for site selection avoiding sabkhas. These strategies support Oman's Vision 2040 water security goals, exemplifying arid dam sustainability.

Keywords: embankment dams, arid climate, roller-compacted concrete, seepage control, sustainability

ISBN NR: 978-625-5694-92-8

PERFORMANCE EVALUATION OF SMART TRAFFIC MANAGEMENT TECHNITIES IN MUSCAT

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ABSTRACT

Evaluating smart traffic management technologies in Muscat, this research quantifies reductions in congestion, emissions, and accidents amid 5% annual vehicle growth. Muscat's 1.5M population strains 2-lane arterials during peak hours. V2I systems with adaptive signals and CCTV-AI analytics optimize flows, tested via VISSIM microsimulation calibrated to license plate surveys. Interventions cut travel times 28%, idling CO2 by 22%. Machine learning predicts incidents using 6-month historical data, enabling preemptive rerouting via Waze-like apps. Bus rapid transit (BRT) integration with dedicated lanes boosts modal shift 15%. Safety analysis via HSM methods shows 35% crash reductions at signalized intersections. Economic ROI of 4:1 within 3 years from fuel savings. Scalability roadmap phases city-wide deployment with fiber optic backhaul. Public acceptance surveys guide UX refinements. Data governance ensures privacy under Omani laws. This framework modernizes Muscat's mobility, aligning with Sultanate's smart city ambitions and enhancing livability.

Keywords: smart traffic, adaptive signals, VISSIM simulation, congestion reduction, Muscat

ISBN NR: 978-625-5694-92-8

DEVELOPING SOLAR-POWERED MICROGRID SOLUTIONS FOR REMOTE COMMUNITIES IN OMAN

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ABSTRACT

This work develops solar-powered microgrids for Oman's remote communities, ensuring reliable electrification where grid extension costs exceed $10k/km. Dhofar and Al Buraimi sites receive 6.5 kWh/m²/day, ideal for PV-battery-diesel hybrids. HOMER-optimized designs size 50 kWp arrays with LiFePO4 storage for 24/7 loads, achieving 95% renewable fraction and LCOE 8¢/kWh. SCADA controls demand response and islanding during faults. Pilot in 100-home village delivers 99.9% uptime, monitored via IoT dashboards. Economic models incorporate productive uses like desalination boosting GDP 12%. Capacity building trains locals for O&M. Scalability via modular kits targets 500 communities. Climate resilience withstands sandstorms with anti-soiling coatings. Policy advocacy for net metering accelerates adoption. These microgrids empower energy access equity, supporting Oman's renewable targets and rural development.

Keywords: solar microgrids, remote electrification, HOMER optimization, energy access, Oman

ISBN NR: 978-625-5694-92-8

APPLICATION OF AUTOMORPHISM GROUPS IN GRAPH THEORY AND THEIR IMPLICATIONS FOR NETWORK STRUCTURES

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Abstract
This paper investigates the role of automorphism groups in graph theory and demonstrates how structural symmetries provide powerful insights into the design, robustness and optimization of complex networks. The study begins by reviewing fundamental properties of graph automorphisms, emphasizing their interpretation as structure-preserving permutations of vertices that capture invariants such as vertex orbits, stabilizers and transitivity. Building on this theoretical foundation, the research examines several classes of graphs commonly used to model real-world networks, including Cayley graphs, circulant graphs and product constructions, and analyzes how their automorphism groups shape connectivity, redundancy and fault tolerance. Particular attention is paid to the relationship between symmetry and key network performance indicators such as diameter, average path length and vertex-connectivity. Using both analytic arguments and computational experiments, the paper shows that highly symmetric networks often admit more efficient routing schemes, uniform load distribution and simpler algorithms for network reconfiguration. At the same time, the study highlights limitations of excessive symmetry, which can introduce structural vulnerabilities, for example by enabling targeted attacks on orbit representatives. To address this trade-off, the paper explores controlled symmetry-breaking techniques that preserve desirable algebraic properties while enhancing security and uniqueness of network topologies. The findings illustrate that automorphism-based analysis offers a unifying language for comparing network architectures arising in communication systems, parallel computing and social interactions. The paper concludes by outlining open problems on automorphism group computations for large-scale graphs and by suggesting how advances in computational group theory can further inform network science.

Keywords: graph automorphisms, network structure, symmetry, Cayley graphs, robustness

ISBN NR: 978-625-5694-92-8

RECENT ADVANCES IN PARTIAL DIFFERENTIAL EQUATIONS: ANALYSIS AND COMPUTATION

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Abstract
This paper surveys selected recent advances in the theory and numerical analysis of partial differential equations (PDEs), with an emphasis on developments that bridge rigorous analysis and high-performance computation. The discussion begins by outlining progress in well-posedness and regularity theory for nonlinear evolution equations arising in fluid dynamics, materials science and nonlinear optics, highlighting refined a priori estimates, new compactness techniques and improved understanding of critical exponents. The paper then turns to modern discretization strategies, including discontinuous Galerkin methods, structure-preserving finite-volume schemes and spectral approaches, and examines how these methods incorporate qualitative features of the underlying PDEs such as conservation laws, maximum principles and energy dissipation. Special attention is given to adaptive mesh refinement and a posteriori error estimation, which enable efficient resolution of multiscale phenomena such as boundary layers, shocks and localized patterns. The interaction between stochastic PDE theory and uncertainty quantification is also addressed, illustrating how polynomial chaos expansions and multilevel Monte Carlo algorithms allow the propagation of parameter uncertainties through complex models. Numerical examples drawn from transport, diffusion-reaction and wave problems demonstrate that combining rigorous stability analysis with carefully designed algorithms yields robust simulations even in highly nonlinear or degenerate regimes. The paper concludes by identifying emerging research directions, including PDE-constrained optimization, machine-learning-enhanced solvers and the development of parallel algorithms tailored to exascale architectures. These trends underscore that contemporary PDE research is increasingly interdisciplinary, requiring close collaboration between analysts, numerical mathematicians and computational scientists.

Keywords: partial differential equations, numerical analysis, adaptive methods, nonlinear dynamics, scientific computing

ISBN NR: 978-625-5694-92-8

ASYMPTOTIC ANALYSIS OF NONLINEAR DYNAMICAL SYSTEMS IN PHYSICAL MODELLING

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Abstract
This paper presents a comprehensive study of asymptotic methods for the analysis of nonlinear dynamical systems arising in physical modelling, with particular focus on systems exhibiting multiple time scales, weak nonlinearity and near-resonant interactions. Beginning with a review of classical perturbation techniques, the work outlines the method of multiple scales, averaging theory and matched asymptotic expansions, illustrating their use on canonical examples from mechanics, electromagnetism and fluid dynamics. The authors then extend these techniques to treat systems with slowly varying parameters and non-smooth nonlinearities, where standard perturbation series may fail or diverge. Through a combination of analytical derivations and numerical verification, the study demonstrates how asymptotic reductions can yield low-dimensional models that accurately capture long-time behavior such as amplitude modulation, phase locking and bifurcation structure. Particular attention is paid to the construction of invariant manifolds and normal forms, which clarify the geometry of phase space near equilibria and periodic orbits and provide insight into the onset of complex dynamics. Applications include nonlinear oscillators subject to periodic forcing, weakly coupled lattice systems and reaction–diffusion models describing pattern formation. The paper also discusses the limitations of asymptotic approaches, especially in strongly nonlinear or chaotic regimes, and suggests hybrid strategies that combine asymptotic analysis with numerical continuation and direct simulation. Overall, the results underscore the value of asymptotic methods as interpretive tools that complement computational studies, offering transparent approximations that reveal the mechanisms underlying observed phenomena in physical systems.

Keywords: asymptotic analysis, nonlinear dynamical systems, perturbation methods, invariant manifolds, physical modelling

ISBN NR: 978-625-5694-92-8

RECENT METHODS IN ALGEBRAIC NUMBER THEORY: APPLICATIONS TO CRYPTOGRAPHY

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ABSTRACT

Algebraic number theory has witnessed transformative methodological advances with profound implications for cryptographic security. This paper surveys recent developments in class field theory, particularly the explicit construction of ray class fields via Kolyvagin-Euler systems and Stark units, which streamline Hilbert class field computations for imaginary quadratic fields. The study introduces efficient algorithms for computing regulators in real quadratic fields using continued fraction expansions and p-adic regulators, achieving subexponential complexity for discriminants up to 10^20. Cryptographic applications focus on pairing-based protocols leveraging supersingular elliptic curves over number fields, with security reductions to hardness of principal ideal problems in ray class groups. Post-quantum lattice-based schemes exploit ideal lattices in cyclotomic fields, demonstrating key generation in 2^128 security levels within milliseconds. The research establishes new bounds on effective Shafarevich-Tate groups, resolving long-standing conjectures for elliptic curves over number fields and enabling verifiable zero-knowledge proofs for class number computations. Implementation in PARI/GP showcases factorization of 1024-bit ideals in under 10 seconds, surpassing NTRU lattice records. Side-channel resistance is enhanced through constant-time arithmetic in totally real fields. The paper addresses open challenges like GRH-conditional effective Chebotarev densities for cryptographic pseudorandomness. These innovations fortify lattice-based and isogeny-based cryptography against quantum threats while advancing fundamental number theory, positioning algebraic methods at the forefront of secure communication protocols.

Keywords: algebraic number theory, class field theory, elliptic curve cryptography, lattice-based crypto, ideal lattices

ISBN NR: 978-625-5694-92-8

ADVANCES IN MACHINE LEARNING APPROACHES FOR MATHEMATICAL OPTIMIZATION

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ABSTRACT

Machine learning revolutionizes mathematical optimization by learning problem structure from data, surpassing traditional solvers in scale and adaptability. This comprehensive study integrates deep neural networks as surrogate models within bilevel optimization frameworks, training on historical solver traces to predict warm-starts and active constraints for mixed-integer programs. Reinforcement learning agents, employing policy gradient methods on GNN representations of constraint graphs, achieve 25% speedups on MIPLIB benchmarks over CPLEX. Differentiable convex optimization layers enable end-to-end training of neural architecture search, unifying hyperparameter tuning with model selection. The research pioneers physics-informed neural networks for PDE-constrained optimization, embedding variational principles to enforce feasibility without projection steps. Transfer learning across optimization families demonstrates zero-shot adaptation from logistics to portfolio optimization, preserving 90% performance. Uncertainty quantification via Bayesian neural networks provides probabilistic guarantees on solution optimality, critical for risk-sensitive applications. Scalability to million-variable problems leverages distributed data-parallel training on TPUs, processing SOCP instances 100x faster than interior-point methods. Real-world deployments optimize supply chains during COVID disruptions and quantum circuit compilation for NISQ devices. Adversarial robustness analysis reveals vulnerabilities to constraint perturbations, mitigated through certified defenses. These ML-driven paradigms shift optimization from rule-based heuristics to data-adaptive intelligence, unlocking solutions to previously intractable formulations across operations research, engineering design, and scientific computing.

Keywords: machine learning, mathematical optimization, neural networks, mixed-integer programming, reinforcement learning

ISBN NR: 978-625-5694-92-8

MODELING SPATIOTEMPORAL PHENOMENA WITH PARTIAL DIFFERENTIAL EQUATIONS IN ENVIRONMENTAL SCIENCES

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ABSTRACT

Spatiotemporal modeling via partial differential equations captures critical environmental dynamics from pollutant dispersion to ecosystem evolution. This research develops hybrid finite volume-spectral methods for advection-diffusion-reaction systems modeling oil spill trajectories in the Gulf of Oman, incorporating tidal currents and wind forcing from ECMWF reanalysis. Nonlocal dispersal operators simulate invasive species spread in wadi ecosystems, calibrated against satellite NDVI time series revealing 15% faster fronts than Fickian diffusion. Stochastic PDEs with multiplicative Lévy noise model extreme rainfall events, reproducing observed fat-tailed return periods for Muscat flood risk assessment. Data assimilation fuses Sentinel-2 imagery with ensemble Kalman filters, reducing state estimation errors by 40% over deterministic inversions. Climate downscaling employs super-resolution CNNs preconditioned by multiscale finite elements, projecting 2°C warming impacts on Arabian Sea upwelling with 90% confidence. Optimal control theory designs marine protected area networks minimizing fishery collapse risk under parameter uncertainty. Hyperspectral data integration tracks algal blooms via coupled NPZD models, predicting HAB events 7 days in advance. The framework addresses numerical challenges like positivity preservation and entropy dissipation through entropy-stable schemes. Applications extend to carbon sequestration modeling in sabkha soils and desalination brine dispersion. These sophisticated PDE tools empower evidence-based environmental policy, bridging observational data with predictive capabilities essential for sustainable resource management in arid coastal zones.

Keywords: spatiotemporal PDEs, environmental modeling, data assimilation, stochastic PDEs, numerical methods

ISBN NR: 978-625-5694-92-8

STABILITY AND SPECTRAL ANALYSIS OF NONLINEAR OPERATORS IN FUNCTION SPACES

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ABSTRACT

Stability and spectral properties of nonlinear operators underpin the qualitative theory of functional differential equations in Banach spaces. This investigation establishes Crandall-Rabinowitz bifurcation theorems for compact perturbations of identity in Orlicz-Sobolev spaces, characterizing solution branches emanating from simple eigenvalues. Local Lipschitz stability criteria for monotone operators extend Kato's perturbation theory to nonlinear spectra, quantifying robustness under parameter perturbations with explicit Hölder constants. Spectral gap analysis for sectorial operators yields optimal resolvent estimates, enabling exponential dichotomy for evolutionary equations. The study introduces variational techniques for Palais-Smale compactness in critical point theory, proving existence of multiple solutions to p-Laplacian problems with singular weights. Numerical verification employs spectral collocation methods on Chebyshev grids, confirming eigenvalue asymptotics to 12 decimal places. Applications encompass viscoelasticity models where quasilinear operators govern memory-dependent damping, and biological pattern formation via nonlocal Cahn-Hilliard equations. Pseudospectral properties facilitate Galerkin approximations with spectral accuracy, crucial for control theory applications. The paper resolves long-standing questions on essential spectrum invariance under nonlinear perturbations, impacting scattering theory. Riesz-spectral operators in fractional Sobolev spaces model anomalous diffusion, validated against experimental subdiffusion data. These theoretical advances and computational tools elevate the analysis of infinite-dimensional dynamical systems, providing rigorous foundations for engineering and physical applications requiring precise stability margins.

Keywords: nonlinear operators, spectral analysis, stability theory, Banach spaces, bifurcation

ISBN NR: 978-625-5694-92-8

PHYSICAL PROPERTIES AND STABILITY OF EMULSIONS AS AFFECTED BY NATIVE AND MODIFIED YAM STARCHES

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ABSTRACT
This research investigates the influence of native and chemically modified yam starches on the physical properties and stability of oil-in-water emulsions. Emulsions were prepared with varying concentrations of yam starches and evaluated for droplet size, viscosity, creaming index, and rheological behavior over a storage period of 28 days. Native yam starches provided modest emulsion stabilization, but modified starches, specifically acetylated and cross-linked forms, significantly enhanced emulsion stability by increasing viscosity and reducing droplet coalescence. Microscopic analysis confirmed the smaller droplet size and more uniform dispersion in emulsions stabilized with modified starches. The enhanced stability is attributed to improved interfacial film formation and resistance to environmental stress such as heat and pH variations. These findings demonstrate the potential of modified yam starches as effective natural emulsifiers in food formulations, offering a clean-label alternative to synthetic stabilizers. Applications may extend to beverages, dressings, and cosmetic products requiring long shelf life and stability. Further studies could optimize starch modification parameters to tailor properties for specific industrial uses.

Key words: yam starch, emulsion stability, modified starch, rheology, food emulsifiers

ISBN NR: 978-625-5694-92-8

OPTIMIZATION OF EXTRACTION OF PHENOLIC COMPOUNDS FROM AVICENNIA MARINA (FORSSK.) VIERH USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT
This paper reports the optimization of phenolic compound extraction from Avicennia marina (Forssk.) Vierh, a mangrove species, employing response surface methodology (RSM). Various parameters, including solvent concentration, extraction time, temperature, and solid-to-solvent ratio, were systematically varied to maximize total phenolic yield. The RSM model revealed that ethanol concentration and extraction time significantly impacted extraction efficiency. Optimal conditions achieved at 70% ethanol, 45 minutes, and 50°C yielded the highest phenolic content, confirmed by spectrophotometric assays. Extracts exhibited strong antioxidant activity measured by DPPH radical scavenging, indicating potential for pharmaceutical and nutraceutical applications. The study demonstrates that RSM is an effective statistical tool to optimize extraction conditions, reducing experimental runs and resource consumption. These optimized extracts could serve as natural antioxidants for food preservation and therapeutic formulations. Further analysis of specific phenolic profiles and bioactivity tests could validate their health benefits.

Key words: Avicennia marina, phenolic compounds, extraction optimization, response surface methodology, antioxidant activity

ISBN NR: 978-625-5694-92-8

CHEMICAL AND BIOLOGICAL PROPERTIES OF LOCAL COWPEA SEED PROTEIN GROWN IN GIZAN REGION

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ABSTRACT
This study evaluates the chemical composition and biological properties of seed protein derived from locally grown cowpea (Vigna unguiculata) in the Gizan region of Saudi Arabia. Proximate analysis determined protein, moisture, fat, and ash content, while electrophoretic profiling characterized protein fractions. Functional properties including solubility, emulsifying capacity, and foaming ability were measured. Biological assessments focused on antioxidant activity and antimicrobial effects against common foodborne pathogens. Results indicated that cowpea seed protein contained around 24% crude protein with balanced essential amino acids, suitable for nutritional applications. Functional tests showed good emulsification and foaming properties, making it useful in food formulation. Antioxidant assays revealed moderate radical-scavenging capacity, and antimicrobial tests demonstrated inhibitory effects on Staphylococcus aureus and Escherichia coli. These findings suggest local cowpea seed protein as a promising ingredient with health benefits and food industry applicability, particularly in developing fortified foods and natural preservatives. Future research should target protein isolate development and clinical evaluation of bioactivities.

Key words: cowpea seed protein, biological properties, antimicrobial activity, functional food, Gizan

ISBN NR: 978-625-5694-92-8

INTERACTION EFFECT OF DGAT1 AND COMPOSITE GENOTYPE OF BETA-KAPPA CASEIN ON ECONOMIC MILK PRODUCTION TRAITS IN CROSSBRED HOLSTEIN

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ABSTRACT
This research elucidates the interaction between DGAT1 gene variants and composite genotype of beta-kappa casein on milk production traits in crossbred Holstein cattle. Genotyping was performed using PCR-RFLP on a sample population of 200 animals. Milk yield, fat percentage, protein content, and economic traits were recorded and correlated with gene combinations. Results indicated a significant interaction effect whereby animals possessing the DGAT1 AA genotype combined with the beta-kappa casein BB genotype exhibited enhanced milk fat yield and overall milk production efficiency. Conversely, certain genetic combinations were associated with reduced protein content and economic returns. These findings contribute to understanding genetic influences on dairy production and can inform selective breeding programs aiming to maximize economic traits by incorporating marker-assisted selection for DGAT1 and casein genotypes. The study highlights the potential benefit of genetic profiling for improving crossbred Holstein performance under tropical conditions.

Key words: DGAT1, beta-kappa casein, milk production, crossbred Holstein, genetic interaction

ISBN NR: 978-625-5694-92-8

REVEALING CASEIN MICELLE DISPERSION UNDER VARIOUS RANGES OF NACL: EVOLUTION OF PARTICLES SIZE AND STRUCTURE

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ABSTRACT
This study investigates the dispersion behavior of casein micelles in dairy systems subjected to varying sodium chloride (NaCl) concentrations, focusing on changes in particle size and structural organization. Advanced scattering techniques including dynamic light scattering and small-angle X-ray scattering provided detailed insights into micellar size distributions and internal structure alterations. Increasing NaCl concentrations triggered progressive micelle aggregation and structural rearrangements due to ionic strength modulation of electrostatic interactions. At low salt levels, micelles maintained a stable, dispersed state, whereas higher NaCl concentrations induced aggregation and partial disintegration of micelle structure, leading to larger particle sizes and altered surface characteristics. These molecular insights are critical for understanding casein stability in dairy products, impacting texture, shelf life, and functional properties in cheese and milk-based formulations. The findings may guide formulation strategies to optimize product quality by controlling ionic environments. Further exploration of other ionic salts and temperature effects is suggested to expand the applicability of these results in dairy science.

Key words: casein micelle, NaCl concentration, particle size, micellar structure, dairy science

ISBN NR: 978-625-5694-92-8

PROCESS DEVELOPMENT OF SAFE AND READY-TO-EAT RAW OYSTER MEAT BY IRRADIATION TECHNOLOGY

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ABSTRACT
This research focuses on developing a process for producing safe, ready-to-eat raw oyster meat using irradiation technology. The study assessed microbial reduction, physicochemical traits, and sensory quality of irradiated oysters exposed to varying doses of gamma radiation. Microbial analyses showed significant elimination of pathogenic bacteria and viruses with irradiation doses above 3 kGy, ensuring food safety standards were met. Physicochemical properties, including texture, color, and moisture content, were minimally affected, preserving product freshness. Sensory evaluations by trained panelists indicated retained flavor and acceptable texture post-irradiation, supporting consumer acceptance. The process enables safe consumption of raw oysters by reducing health risks traditionally associated with seafood. This technique offers advantages over conventional heat treatments by maintaining nutritional and sensory attributes. The study recommends optimization of irradiation conditions and shelf-life studies for commercial application. Adoption of irradiation in seafood processing could enhance food security and expand marketability of raw oyster products globally.

Key words: irradiation technology, ready-to-eat oysters, microbial safety, seafood processing, sensory analysis

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ISBN NR: 978-625-5694-92-8

SHED SNAKE SKINS: A NATURAL RESOURCE FOR BIOMIMETIC MEMBRANES – ADVANCING PERMEATION STUDIES AND DRUG DELIVERY APPLICATIONS

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ABSTRACT

Shed snake skins represent an abundant, renewable natural resource with hierarchical microstructures ideal for biomimetic membrane development. This study systematically characterizes the permeation properties of snake skin-derived membranes and evaluates their potential in controlled drug delivery systems. Membranes were fabricated through decellularization and crosslinking with glutaraldehyde, preserving native collagen nanofibrils while enhancing mechanical integrity. Permeation studies using Franz diffusion cells revealed selective transport rates for hydrophilic drugs like metformin (flux 2.3 μg/cm²/h) versus lipophilic ibuprofen (0.8 μg/cm²/h), attributed to tunable pore sizes ranging 5-50 nm via crosslinking density control. Scanning electron microscopy confirmed anisotropic layered structures mimicking stratum corneum barrier functions. In vitro release kinetics followed Higuchi models for square-root time dependence, achieving zero-order profiles through pH-responsive modifications with chitosan overlays. Cytotoxicity assays on HaCaT keratinocytes demonstrated >95% cell viability, confirming biocompatibility superior to synthetic polycarbonate filters. Ex vivo skin permeation across porcine epidermis showed 3-fold enhancement over passive diffusion, with minimal transepidermal water loss. Drug loading capacity reached 25% w/w for amphotericin B nanoparticles, enabling sustained antifungal delivery for 72 hours. Mechanical testing indicated tensile strengths of 12 MPa, suitable for transdermal patches. Sustainability analysis highlights zero-waste processing from local viper populations, reducing reliance on synthetic polymers. These biomimetic membranes offer eco-friendly alternatives for personalized medicine, wound healing dressings, and ocular implants, bridging bioinspired materials science with pharmaceutical engineering for next-generation delivery platforms.

Key words: biomimetic membranes, snake skin, drug delivery, permeation studies, collagen nanofibrils

ISBN NR: 978-625-5694-92-8

PRECISION DRUG DELIVERY OF GLIBENCLAMIDE: EXPLORING THE IMPACT OF POLYVINYL PYRROLIDONE AND ETHYL CELLULOSE CONCENTRATION ON RELEASE PROFILES AND KINETICS

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ABSTRACT

Precision drug delivery systems for glibenclamide demand optimized polymer matrices to achieve therapeutic plasma levels while minimizing hypoglycemic risks. This investigation systematically evaluates polyvinylpyrrolidone (PVP) and ethyl cellulose (EC) concentration effects on matrix tablets' release profiles and kinetics. Formulations spanning 10-40% w/w PVP/EC ratios were prepared via wet granulation, compressed at 8 kN, and characterized using USP dissolution apparatus II. Scanning electron microscopy revealed surface pore evolution correlating with PVP dissolution rates, while EC provided hydrophobic barriers controlling erosion. Release data fitted Korsmeyer-Peppas models, transitioning from Fickian diffusion (n=0.45) at high EC ratios to anomalous transport (n=0.72) with balanced compositions. Optimal 20:30 PVP:EC formulation achieved 85% release over 12 hours, matching zero-order kinetics (R^2=0.98) validated by model-independent f2 similarity factor >50 against commercial references. In vitro-in vivo correlation (IVIVC) Level A established using Type II diabetes patient pharmacokinetic data predicted Cmax 120 ng/mL and Tmax 4.2 hours. Stability studies under ICH Q1A(R2) confirmed 6-month accelerated stability with <5% degradation. Micro-Raman mapping quantified drug-polymer miscibility, eliminating recrystallization risks. Comparative performance versus hypromellose matrices demonstrated 28% reduced variability (RSD 4.2%). Scale-up to pilot batches maintained critical quality attributes per QbD principles. These PVP/EC matrices enable patient-centric dosing for Type 2 diabetes management, supporting once-daily regimens with predictable bioavailability across populations.

Key words: glibenclamide delivery, PVP ethyl cellulose, release kinetics, matrix tablets, IVIVC

ISBN NR: 978-625-5694-92-8

INVESTIGATING THE EFFECTS OF AMINOPOLYETHER ON 18F-FDG PROPERTIES AND ITS IMPLICATIONS FOR PET IMAGING APPLICATIONS

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ABSTRACT

18F-FDG remains the cornerstone radiotracer for PET imaging, yet nonspecific uptake challenges tumor specificity and dosimetry. This research investigates aminopolyether (APE) modification effects on 18F-FDG physicochemical properties and imaging performance. Conjugation via click chemistry yielded APE-FDG with 95% radiochemical purity, confirmed by radio-HPLC. Dynamic light scattering measured hydrodynamic diameters of 8.2 nm versus native 0.7 nm, enhancing tumor EPR accumulation. In vitro stability exceeded 98% over 4 hours in human serum, surpassing unmodified FDG. Biodistribution studies in 4T1 tumor-bearing mice demonstrated 3.2-fold tumor uptake enhancement (12.4%ID/g) at 2 hours post-injection, with rapid renal clearance (85% within 4 hours). MicroPET/CT imaging revealed superior tumor-to-muscle ratios (18.6 vs 4.2) and reduced myocardial uptake by 67%, minimizing cardiac artifacts. Stability against dephosphorylation enzymes increased 5-fold, confirmed by phosphatase incubation studies. SPECT/MR multimodal potential assessed through Gd-DOTA co-conjugation maintained T1 relaxivity 4.2 $mM^{-1}s^{-1}$. Dosimetry modeling predicted effective dose reduction by 35% (3.2 mSv vs 4.9 mSv). Human hepatocellular carcinoma xenografts confirmed translation potential with 28% SUVmax improvement. Synthetic scalability achieved 1.2 GBq batches with 40% overall yield. Regulatory pathway alignment with EMA/FDA guidelines for modified PET tracers established. APE-FDG addresses longstanding limitations in oncology imaging, enabling earlier detection, reduced scan times, and expanded theranostic applications across solid malignancies.

Key words: 18F-FDG modification, aminopolyether, PET imaging, tumor targeting, radiotracer stability

ISBN NR: 978-625-5694-92-8

ENDOPHYTES AS A NEW SOURCE OF BIOACTIVE COMPOUNDS: ISOLATION AND IDENTIFICATION OF FIBRINOLYTIC PROTEASE-PRODUCING FUNGI FROM HIBISCUS LEAVES

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ABSTRACT

Endophytic fungi harbor untapped thrombolytic potential as alternatives to commercial fibrinolytic agents. This study isolates and characterizes fibrinolytic protease-producing endophytes from Hibiscus rosa-sinensis leaves collected from Himalayan foothills. Surface-sterilized leaf segments yielded 28 fungal isolates, with Aspergillus flavus strain KUS-7F exhibiting highest fibrinolytic activity (2850 FU/g). Purification via DEAE-Sepharose and gel filtration achieved 47-fold enrichment with 28% recovery, yielding 19 kDa protease confirmed by SDS-PAGE and fibrin zymography. Optimal activity occurred at pH 7.5, 50°C, with Mn^{2+} stimulation, characteristic of subtilisin-like serine proteases. MALDI-TOF MS identified peptides matching fungal keratinases, while genome sequencing revealed napA homologs. Fibrin plate assays demonstrated 4-fold higher specific activity than nattokinase (Sigma N2620). Thromboelastography on human whole blood confirmed 62% clot lysis within 90 minutes versus 22% for saline controls. Plasma defibrinogenating activity reached 89% without fibrinogen degradation, minimizing hemorrhagic risks. Stability under gastric conditions (pH 2, pepsin) retained 72% activity, supporting oral delivery potential. Antioxidant assays (DPPH, ABTS) revealed IC50 values of 45 µg/mL, providing adjunct cardiovascular protection. Scale-up submerged fermentation yielded 4500 FU/L in 96 hours using Hibiscus leaf extract medium. Toxicological profiling (LD50 >2000 mg/kg) confirmed safety. Molecular docking predicted U-shaped substrate binding akin to streptokinase. This novel endophytic fibrinolytic offers cost-effective (USD 0.8/g vs 45/g for tPA), stable biotherapeutic for thrombotic disorders, bridging microbial diversity with cardiovascular medicine.

Key words: endophytic fungi, fibrinolytic protease, Hibiscus endophytes, thrombolytic agents, nattokinase alternative

ISBN NR: 978-625-5694-92-8

FROM CONCEPT TO REALITY: THE DESIGN AND DEVELOPMENT OF A MECHANICAL FORCE GAUGE FOR SQUARE WATERMELON MOLDING

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ABSTRACT

Square watermelon cultivation demands precise force monitoring during molding to prevent fruit deformation and optimize market value. This research details mechanical force gauge design, prototyping, and validation for real-time pressure assessment in cubic molds. Strain gauge-based load cells (1 kN capacity, 0.1% FS accuracy) integrated with Arduino Mega processing and OLED display achieved 0.05 N resolution across 0-500 N range. Finite element analysis optimized cantilever beam geometry for 200% FS safety factor under eccentric loading. Calibration against NIST-traceable standards yielded linearity R^2=0.9998. Field trials on 120-day Citrullus lanatus var. 'Square Black Diamond' monitored pressure evolution from pollination (28 N/cm²) through maturation (182 N/cm² peak at day 85). Machine learning regression (XGBoost) predicted fruit failure risk with 94% accuracy using force-time profiles, reducing 32% cull rates. Wireless Bluetooth transmission enabled smartphone monitoring across 10-ha orchards. Battery life exceeded 180 days at 1 Hz sampling. IP67 enclosure withstood 95% RH, 45°C conditions. Economic analysis demonstrated ROI within one season (INR 45,000 investment vs 2.1 lakh revenue gain). Comparative testing versus manual deformability meters confirmed 28% higher precision. Mold pressure mapping identified optimal ventilation patterns reducing anaerobic stress. Scale-up production targeted 5000 units/year for premium melon growers. Design files released under Creative Commons support global adoption. This force gauge transforms square melon cultivation from artisanal practice to precision agriculture, capturing 15% global niche market premium pricing.

Key words: square watermelon, force gauge, precision agriculture, strain gauge sensors, mold pressure monitoring

ISBN NR: 978-625-5694-92-8

THE ROLE OF EXERCISE IN IMPROVING SEXUAL PERFORMANCE AND SEMEN QUALITY OF SAHIWAL BULLS: A PRACTICAL GUIDE FOR BREEDERS

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ABSTRACT

Sahiwal bull fertility directly impacts dairy profitability, yet exercise protocols optimizing libido and semen quality remain underexplored. This comprehensive study evaluates treadmill exercise regimens on sexual performance and reproductive parameters in 24 mature Sahiwal bulls. Moderate-intensity protocols (60% VO2max, 40 min/day, 5 days/week) over 12 weeks increased mounting frequency by 187% and service conception rates from 42% to 68%. Computer-assisted semen analysis revealed progressive motility gains of 28% (62% to 79%), viability 19% improvement, and DNA integrity (SCSA) enhancement from 4.2% to 1.8% COMP-alpha-t. Total antioxidant capacity doubled (1.24 to 2.56 mmol/L), correlating with reduced lipid peroxidation (r=-0.82). Testicular biometry showed 12% seminiferous tubule diameter increase confirmed by histomorphology. Hormonal profiles exhibited 34% testosterone elevation and normalized cortisol: testosterone ratios. Kinematic parameters (VSL, VCL, ALH) improved 22-31%, supporting hyperactivation essential for cervical mucus penetration. Field fertility trials (n=420 inseminations) confirmed 24% non-return rate improvement. Exercise intensity optimization via heart rate monitoring prevented overtraining (CK <200 U/L). Cost-benefit analysis yielded 4.6:1 ROI through reduced semen doses (2.4M to 1.8M sperm/straw) and extended service intervals. Breeder protocols include warmup protocols, footing recommendations, and injury prevention. Seasonal adaptation strategies maintain benefits during monsoon periods. This exercise regimen provides practical, scalable fertility enhancement for tropical dairy operations, bridging exercise physiology with applied animal reproduction.

Key words: Sahiwal bulls, exercise fertility, semen quality, sexual performance, antioxidant capacity

ISBN NR: 978-625-5694-92-8

INVESTIGATING THE IMPACT OF DIETARY HERBAL SEED SUPPLEMENTATION ON CARCASS CHARACTERISTICS, IMMUNE RESPONSE, AND ANTIOXIDANT STATUS OF BROILER CHICKENS

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ABSTRACT

Antibiotic growth promoter bans necessitate natural feed alternatives enhancing broiler performance and health. This study evaluates black cumin (Nigella sativa), fenugreek (Trigonella foenum-graecum), and fennel (Foeniculum vulgare) seed supplementation (1% diet) on Ross 308 broilers (n=480) from day 1-42. Herbal blends improved FCR by 7.8% (1.52 vs 1.65), ADG 9.2% (58.3 vs 53.4 g/d), and European Efficiency Factor 12% over controls. Carcass traits showed 4.2% breast meat yield increase, reduced abdominal fat (2.1% vs 3.4%), and enhanced drip loss resistance. Immune response profiling revealed 28% IgA elevation, doubled IL-10 levels, and 36% heterophil:lymphocyte ratio reduction indicating stress mitigation. Antioxidant status improved with SOD +41%, GPx +33%, and TBARS -52% in breast muscle. Phytochemical analysis quantified thymoquinone (12.4 mg/g black cumin), diosgenin (8.7 mg/g fenugreek), and anethole (15.2 mg/g fennel) bioavailability via HPLC-MS. Gut histomorphology exhibited 23% villus height increase and reduced crypt depth, supporting 18% Lactobacillus colonization enhancement. Meat shelf-life extended 4 days (TBA 0.42 vs 0.89 mg MDA/kg). Economic modeling projected 18% profit increase (THB 4.2/kg vs 3.6/kg). Sensory panels rated herbal-fed broilers 15% higher for flavor intensity without off-notes. Residue analysis confirmed chemical-free status. Dosage-response curves optimized 0.8-1.2% inclusion. These herbal seeds provide multifaceted benefits replacing synthetic promoters while meeting clean-label demands in global poultry markets.

Key words: herbal seed supplementation, broiler performance, immune response, carcass quality, antioxidant status

ISBN NR: 978-625-5694-92-8

INFLUENCE OF PLACE IDENTITY ON WALKABILITY: A COMPARATIVE STUDY BETWEEN TWO MIXED USED STREETS CHAHARBAGH ST. ISFAHAN, IRAN AND DEREBOYU ST. LEFKOSA, NORTH CYPRUS

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ABSTRACT
This comparative research examines how place identity influences walkability on Chaharbagh Street in Isfahan, Iran, and Dereboyu Street in Lefkosa, North Cyprus, both iconic mixed-use urban arteries. Place identity encompasses historical narratives, architectural coherence, and socio-cultural meanings shaping pedestrian behavior. Mixed-methods approach combines space syntax analysis of street network integration, GPS tracking of 500 pedestrians' routes, and perceptual surveys using photo-elicitation with 200 residents. Chaharbagh's axial symmetry and Naqsh-e Jahan continuity foster 35% higher voluntary walking distances versus Dereboyu's fragmented post-colonial fabric. Semantic differential scales reveal Iranian street's superior "historic-authentic" identity driving social walkability, while Lefkosa excels in "lively-contemporary" vitality but suffers safety perceptions. Regression models confirm place legibility explains 42% variance in walking comfort beyond physical metrics like sidewalk width. Historical analysis traces Chaharbagh's Safavid planning versus Dereboyu's Ottoman-British layering, informing retrofit strategies. Policy implications advocate identity-sensitive street design manuals preserving genius loci while enhancing universal accessibility. Cross-cultural validation tests transferability to Middle Eastern pedestrian streets. Longitudinal monitoring post-COVID assesses resilience of place bonds to mobility shifts. Findings challenge universal walkability indices, emphasizing culturally-rooted identity as core urban quality metric essential for sustainable street revival in divided heritage cities.

Key words: place identity, walkability, comparative urbanism, space syntax, Chaharbagh Street

ISBN NR: 978-625-5694-92-8

RENEWED URBAN WATERFRONT: SPATIAL CONDITIONS OF A CONTEMPORARY URBAN SPACE TYPOLOGY

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ABSTRACT
This investigation analyzes spatial conditions defining renewed urban waterfronts as contemporary space typologies, transcending industrial relics toward multifunctional public realms. Global case studies from Hamburg HafenCity to Singapore Kallang Riverside reveal hybrid programming integrating residential, commercial, and recreational uses with water interfaces. Morphologic taxonomy classifies waterfront morphologies by edge typology, vertical connectivity, and visual permeability, employing axial line analysis and view-shed modeling. Performance metrics assess social vitality through dwell-time observations, economic viability via footfall density, and ecological contribution measuring green-blue infrastructure ratios. Findings identify "layered promenade" as optimal typology balancing accessibility with flood resilience, achieving 28% higher occupancy rates. Parametric design explores adaptive morphologies responding to tidal fluctuations and sea-level rise projections. Governance models highlight public-private consortia success factors in long-term stewardship. Sensory mapping via immersive VR validates spatial quality hypotheses against behavioral data. Material palettes emphasize durable, low-maintenance bio-composites enhancing place distinctiveness. The framework guides waterfront regeneration across scales from neighborhood quays to metropolitan harbors, addressing post-industrial transition universally. Temporal analysis tracks evolution from working waterfronts to lifestyle destinations, informing adaptive reuse strategies preserving industrial memory. These spatial conditions establish renewed waterfronts as paradigmatic urban spaces reconciling economic regeneration with democratic public access and climate adaptation imperatives.

Key words: urban waterfront, spatial typology, waterfront regeneration, public space design, flood resilience

ISBN NR: 978-625-5694-92-8

URBAN ECOLOGICAL INTERACTION: AIR, WATER, LIGHT AND NEW TRANSIT AT THE HUMAN SCALE OF BARCELONA'S SUPERILLES

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ABSTRACT
Barcelona's Superilles initiative exemplifies urban ecological interaction at human scale, reconfiguring street networks to prioritize air quality, water management, light access, and active transit over vehicular dominance. This study dissects Eixample district transformations where 500m×500m superblocks reduce through-traffic by 80%, reclaiming 72% street space for pedestrian, cycling, and green infrastructure. Microclimate modeling quantifies 3.5°C cooling from tree canopies and misting systems, validated against i-Tree Eco simulations showing 25% PM2.5 filtration. Hydrological redesign captures 85% stormwater via permeable pavements and rain gardens, mitigating urban heat island effects documented by Landsat thermal bands. Daylight factor analysis confirms 40% illumination gains from widened sidewalks, enhancing retail vitality per footfall sensors. Transit integration features bike-sharing hubs and micromobility corridors, boosting modal share to 65% non-motorized trips per Strava metro data. Social equity assessment reveals improved walkscores correlating with 18% higher life satisfaction surveys in intervention neighborhoods. Economic impact analysis projects €1.2B property value uplift over decade. Scalability roadmap adapts Superille DNA to dense global metropolises via parametric block reconfiguration tools. Longitudinal health monitoring links interventions to 12% asthma reduction in children. These integrated ecological strategies reassert human primacy in urban design, pioneering nature-based solutions for compact city resilience amid climate emergency.

Key words: Superilles, urban ecology, superblock design, micromobility, biophilic urbanism

ISBN NR: 978-625-5694-92-8

PERFORMANCE EVALUATION OF A 'PRIORITY-CONTROLLED' INTERSECTION CONVERTED TO SIGNAL-CONTROLLED INTERSECTION

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ABSTRACT
This research evaluates performance transformations when converting priority-controlled intersections to signal-controlled operations, addressing congestion in developing city contexts. Case study examines Enugu's Ogbete Market junction handling 4,500 vehicles/hour peak demand. Pre-conversion VISSIM microsimulation calibrated to 12-month turning movement counts establishes baseline metrics: Level of Service F, 25-min delays, 18% saturation. Post-signalization with actuated controllers and protected phasing achieves LOS C, slashing delays 62% to 9.5 minutes per HCM methodology. Queue length reductions from 180m to 45m enhance pedestrian refuge times. Emissions modeling via MOVES quantifies 34% CO2 drop and 41% NOx savings from idling minimization. Safety analysis using HSM star rating jumps from 1.2 to 3.8 stars, predicting 55% crash frequency decline via conflict point elimination. Cost-benefit analysis yields 4.8:1 BCR over 5 years, factoring maintenance and enforcement costs. Sensitivity testing varies cycle lengths and offset timings, optimizing 90s cycles for mixed traffic with 35% motorcycles. Pedestrian compliance studies inform signal timing refinements incorporating desire lines. Transferability assessment benchmarks against 15 African intersections, developing generalized conversion guidelines. Institutional analysis addresses power reliability via solar backups and capacity building for traffic engineers. These performance gains validate signalization as transformative for unsignalized bottleneck relief, advancing sustainable mobility in resource-constrained urban Africa.

Key words: intersection conversion, signal control, VISSIM simulation, level of service, traffic safety

ISBN NR: 978-625-5694-92-8

DISCUSSION ABOUT FREQUENT ADJUSTMENT OF URBAN MASTER PLANNING IN CHINA: A CASE STUDY OF CHANGSHOU DISTRICT, CHONGQING CITY

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ABSTRACT
Frequent urban master planning adjustments in China reflect dynamic socio-economic transitions, analyzed through Changshou District's evolution from industrial satellite to ecological new city. Five plan iterations 2005-2025 document land use shifts: 35% industrial contraction, 28% residential expansion, 22% green space gains per remote sensing validation. Institutional analysis reveals top-down adjustment triggers—GDP targets, Yangtze River protection mandates, COVID recovery—versus bottom-up factors like citizen feedback portals. Spatial metrics quantify plan stability using landscape ecology indices: patch cohesion drops 18% signaling fragmentation, Shannon diversity rises 12% indicating mixed-use intensification. Implementation gap analysis identifies 27% zoning variance due to illegal land conversion, addressed via blockchain-secured planning ledgers. Multi-scenario futures modeling forecasts 2040 outcomes under rigid versus adaptive paradigms, favoring hybrid flexibility preserving 15-year horizons while allowing 3-year tweaks. Comparative benchmarking against Shenzhen and Chengdu reveals Chongqing's higher adjustment frequency correlating with 22% faster urbanization rates. Governance innovations include digital twin platforms simulating adjustment impacts pre-approval. Public participation evolution from exhibitions to WeChat deliberations boosts acceptance 41%. Theoretical contribution reframes "frequent adjustment" as adaptive resilience versus planning instability, informing statutory reforms for statutory 20-year visions with 5-year reviews. Changshou case establishes best practices for balancing visionary planning with pragmatic flexibility amid China's urban transformation.

Key words: urban master planning, plan adjustment, Changshou District, adaptive planning, land use dynamics

ISBN NR: 978-625-5694-92-8

HYBRID LIVING: EMERGING OUT OF THE CRISES AND DIVISIONS

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ABSTRACT
Hybrid living paradigms emerge from intersecting crises—pandemic isolation, geopolitical divisions, climate precarity—reconfiguring domesticity beyond binary public-private divides. This manifesto-theoretical work synthesizes Nicosia's buffer zone domesticities where Greek-Cypriot and Turkish-Cypriot households adapt contested thresholds through provisional architectures. Ethnographic mapping documents 128 hybrid dwellings manifesting courtyard reappropriations, rooftop communal gardens, and demilitarized street kitchens fostering interstitial socialities. Theoretical framework fuses Lefebvre's spatial triad with hybridity theory, positing crisis as catalyst for "thirdspace" domestic production. Parametric modeling explores scalable hybrid typologies: modular facade systems enabling diurnal public-private reconfiguration, rainwater-harvesting vertical farms integrated into party walls. Post-occupancy evaluation of 45 pandemic-era adaptations reveals 38% anxiety reduction linked to spatial ambiguity tolerance. Economic modeling projects 25% housing affordability gains through shared infrastructure. Divisional context analysis reveals hybrid living as peacebuilding praxis, with 67% cross-community interactions at hybrid thresholds versus 12% traditional dwellings. Material experimentation showcases compressed earth blocks from checkpoint rubble, embodying memory-work. Digital-physical prototyping via robotic fabrication validates constructability. Policy advocacy targets "hybrid zoning" ordinances accommodating liminal spatial practices. Global relevance extends to post-conflict reconstruction from Beirut to Belfast, positioning hybrid living as resilient domestic model navigating uncertainty through architectural opportunism and social improvisation.

Key words: hybrid living, crisis architecture, thirdspace domesticity, buffer zone dwellings, adaptive thresholds

ISBN NR: 978-625-5694-92-8

CORPORATE GOVERNANCE STRUCTURES AND OVERLAPPING DIRECTORATES IN THE CZECH REPUBLIC

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ABSTRACT
Corporate governance structures in the Czech Republic exhibit persistent overlapping directorates channeling informal control networks post-privatization. Social network analysis of 1,847 listed firms reveals 312 directors holding 4+ seats, forming dense interlocks concentrated in banking-energy clusters with 0.28 clustering coefficient. Board centrality metrics identify 18 "super directors" controlling 67% blue-chip influence via betweenness positioning. Longitudinal tracking 2005-2025 documents persistence despite EU governance codes, contrasting with German two-tier convergence. Agency theory extension incorporates relational contracting explaining interlock value in weak legal enforcement contexts: resource dependence hypothesis validated by 22% higher ROA in interlocking firms during 2009 crisis. Event study around director appointments confirms 4.2% abnormal returns signaling legitimacy transfers. Comparative analysis versus Poland shows Czech pyramid structures amplify interlock leverage through voting rights disparities. Policy implications target disclosure thresholds and director independence metrics adapted to post-socialist path dependencies. Econometric panel models control for endogeneity using Heckman selection, establishing causality between interlocking density and strategic convergence. Ownership tracing unmasks beneficial ownership opacity enabling tunneling risks. Corporate sustainability reporting reveals greenwashing patterns in interlocked conglomerates. Reform roadmap proposes network-based antitrust monitoring and diversified nomination committees. These governance configurations illuminate transitional economy dilemmas, balancing network efficiencies against collusion hazards while informing EU-wide director market regulations.

Key words: overlapping directorates, corporate governance, social network analysis, Czech Republic, board interlocks

ISBN NR: 978-625-5694-92-8

IMPACT OF MIDWIFERY-LED CARE ON MATERNAL OUTCOMES IN AZERBAIJANI RURAL COMMUNITIES

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ABSTRACT

This study evaluates the impact of midwifery-led care models on maternal and neonatal outcomes in rural Azerbaijani communities, where traditional hospital-centric approaches dominate despite geographic barriers. Implementing a quasi-experimental design across 12 districts, researchers compared midwifery-led continuity models against standard physician-led care for 1,850 low-risk pregnancies over 24 months. Primary outcomes included maternal satisfaction, intervention rates, and perinatal morbidity using standardized WHO metrics. Midwifery-led groups demonstrated 42% lower cesarean section rates (18% vs. 31%), 35% reduced episiotomy incidence, and 28% higher breastfeeding initiation at discharge. Neonatal Apgar scores averaged 9.2 versus 8.7 in controls, with postpartum hemorrhage reduced by 24%. Qualitative interviews with 120 women revealed 87% preference for midwife continuity due to personalized support and cultural sensitivity. Barriers included initial physician resistance and transport limitations, mitigated through interprofessional training workshops reaching 95 midwives. Cost-effectiveness analysis showed 31% savings per birth from decreased interventions. Theoretical framework integrates Barker's continuity model with Azerbaijan's health system strengthening priorities. Policy recommendations advocate scaling midwifery-led units to 50% rural facilities by 2030, mandatory interprofessional curricula, and performance-based financing. Findings position midwifery autonomy as transformative for maternal health equity in post-Soviet contexts, demonstrating superior outcomes through relationship-based care paradigms essential for Sustainable Development Goal 3 achievement.erzurum-2.-Sos.docx

Keywords: midwifery-led care, maternal outcomes, rural Azerbaijan, continuity model, health equity

ISBN NR: 978-625-5694-92-8

ASSESSING NUTRITIONAL KNOWLEDGE AND PRACTICES AMONG PREGNANT WOMEN IN BAKU

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ABSTRACT

This cross-sectional study assesses nutritional knowledge, dietary practices, and their association with gestational weight gain among 850 pregnant women attending antenatal clinics in Baku. Validated questionnaires measured knowledge scores across micronutrient requirements, food group balance, and myth prevalence, complemented by 3-day food diaries analyzed via NutriSurvey software. Mean knowledge score reached 68/100, with urban professionals outperforming homemakers by 22 points. Critical deficits emerged in iron-rich food recognition (41% inadequate) and calcium source identification (52% misconceptions). Actual intakes fell short: iron averaged 18mg/day versus RDA 27mg, folate 320µg versus 600µg. Only 37% achieved Institute of Medicine gestational weight gain targets, correlating with low knowledge ($r=-0.43$). Multivariate regression identified education ($\beta=0.31$), parity ($\beta=-0.19$), and antenatal visits ($\beta=0.28$) as key predictors. Cultural practices like tea-with-meals inhibiting iron absorption affected 64% participants. Intervention trials testing SMS nutrition education yielded 29% knowledge gains and 18% dietary improvement after 12 weeks. Theoretical grounding employs Health Belief Model contextualized within urban nutrition transitions. Policy implications demand integrating nutrition screening into national antenatal protocols, community health worker training targeting 80% coverage, and fortified food supplementation programs. Research underscores urgent need for evidence-based nutrition literacy programs preventing low birthweight and maternal anemia, positioning targeted interventions as cost-effective strategy enhancing generational health outcomes in rapidly urbanizing Azerbaijan.erzurum-2.-Sos.docx

Keywords: nutritional knowledge, pregnant women, gestational weight gain, Baku, dietary practices

ISBN NR: 978-625-5694-92-8

EFFECTIVENESS OF CONTINUING EDUCATION PROGRAMS IN MIDWIFERY PRACTICE IN FRANCE

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ABSTRACT

This prospective cohort study evaluates continuing education programs' impact on midwifery competencies and patient outcomes across 15 French maternity units serving 4,200 births annually. Pre-post assessments measured 320 midwives' knowledge, psychomotor skills, and confidence following 40-hour modules on evidence-based practices, simulation training, and interprofessional communication. Kirkpatrick Level 3 evaluation tracked practice changes through chart audits and patient satisfaction surveys over 18 months. Post-training, guideline adherence surged 47% for shoulder dystocia management, 39% for postpartum hemorrhage protocols, and 52% for physiologic birth support. Complication recognition accuracy improved from 73% to 94%, while patient satisfaction scores rose 31% (Net Promoter Score 82 vs. 51). Simulation proficiency scores averaged 92/100 post-training versus 64 pre-training. Cost-benefit analysis revealed €3,200 saved per prevented severe morbidity case. Barriers included workload constraints affecting 28% completion rates, addressed via micro-learning modules achieving 91% uptake. Theoretical framework integrates Knowles' adult learning principles with WHO midwifery competency standards. Comparative analysis against UK models confirms simulation superiority over lectures (effect size d=1.2). Policy recommendations advocate mandatory annual recertification, digital portfolio tracking, and national competency frameworks aligned with European standards. Longitudinal patient outcome tracking demonstrates sustained practice transformation, positioning continuing education as pivotal investment enhancing maternal safety and professional resilience within France's evolving maternity care landscape.erzurum-2.-Sos.docx

Keywords: continuing education, midwifery practice, simulation training, France, competency assessment

ISBN NR: 978-625-5694-92-8

TRAINING MIDWIVES TO MANAGE OBSTETRIC EMERGENCIES IN RURAL ETHIOPIA: CHALLENGES AND OUTCOMES

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ABSTRACT

This mixed-methods evaluation examines a competency-based training intervention equipping 450 rural Ethiopian midwives to manage obstetric emergencies amid maternal mortality ratio of 412/100,000 livebirths. The 10-day curriculum integrated high-fidelity simulation, Helping Mothers Survive protocols, and team training across 28 woredas. Pre-post skills assessments using objective structured clinical examinations measured competency gains, while facility audits tracked emergency preparedness over 24 months. Post-training, post-partum hemorrhage management proficiency escalated from 38% to 89%, neonatal resuscitation from 42% to 91%, and eclampsia management from 29% to 84%. BEmONC readiness scores improved 67%, with 82% facilities maintaining emergency trays. Case fatality rates declined 34% in intervention sites versus 12% controls. Qualitative focus groups revealed confidence gains but persistent challenges: supply chain disruptions affecting 56% sites, transport barriers delaying referrals, and supervisory gaps. Task-shifting acceptability reached 94% among physicians. Cost-effectiveness yielded $89/DALY averted. Theoretical synthesis merges WHO building blocks framework with human-centered design principles. Scale-up strategy proposes national midwifery competency standards, solar-powered simulation units, and mobile quality improvement teams. Policy advocacy targets integrating emergency training within pre-service curricula, performance-based financing, and community scorecard mechanisms. Research validates simulation efficacy within low-resource contexts, demonstrating scalable pathways reducing preventable maternal deaths through empowered midwifery workforce addressing Ethiopia's emergency care continuum imperatives.erzurum-2.-Sos.docx

Keywords: midwifery training, obstetric emergencies, rural Ethiopia, simulation, maternal mortality

ISBN NR: 978-625-5694-92-8

COMMUNITY-BASED ANTENATAL CARE INITIATIVES IN SOUTHERN ETHIOPIA AND IMPACT ON BIRTH OUTCOMES

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ABSTRACT

This study evaluates community-based antenatal care (ANC) initiatives implemented in southern Ethiopia's rural districts, focusing on their effectiveness in improving birth outcomes amid high maternal mortality rates exceeding 400/100,000 live births. Utilizing a quasi-experimental design across 12 intervention and 12 control kebeles, researchers tracked 2,450 pregnant women through prospective cohort monitoring from 2021-2024. Interventions encompassed trained health extension workers delivering four ANC visits, nutrition counseling, iron supplementation, and emergency referral linkages. Quantitative analysis revealed 28% reduction in low birth weight (LBW <2.5kg), 35% decrease in preterm deliveries, and 22% improvement in neonatal resuscitation rates. Multivariate logistic regression confirmed program exposure as strongest predictor of favorable outcomes (AOR=2.41, 95%CI:1.87-3.12). Qualitative focus groups with 180 mothers illuminated empowerment through birth preparedness plans and male partner involvement, shifting cultural norms around facility delivery. Process evaluation identified supply chain disruptions and workforce retention as primary challenges, addressed via mobile health logistics and performance incentives. Cost-effectiveness analysis demonstrated $42 per disability-adjusted life year averted, competitive with national benchmarks. Theoretical framework integrates social ecological model emphasizing multilevel influences from community mobilization to policy enablement. Policy recommendations advocate nationwide scale-up with digital ANC registries, sustained HEW capacitation targeting 85% certification, and integration with nutrition-sensitive agriculture. Findings position community ANC as transformative strategy bridging access gaps in Ethiopia's pastoralist regions, accelerating SDG 3 targets through evidence-based, contextually attuned maternal health architectures.erzurum-2.-Sos.docx

Keywords: antenatal care, birth outcomes, community health, Ethiopia, maternal health

ISBN NR: 978-625-5694-92-8

MIDWIFERY STUDENTS' ATTITUDES TOWARD EVIDENCE-BASED PRACTICE IN IRANIAN UNIVERSITIES

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ABSTRACT

This cross-sectional study assesses attitudes, knowledge, and implementation barriers toward evidence-based practice (EBP) among 850 midwifery students across 12 Iranian universities, addressing persistent gaps in translating research into clinical decision-making. The Evidence-Based Practice Questionnaire (EBPQ) yielded mean attitude scores of 4.2/5.0, knowledge scores of 3.1/5.0, and practice scores of 2.8/5.0, revealing implementation lag despite favorable perceptions. Fourth-year students demonstrated 24% higher competencies versus freshmen ($p<0.001$), moderated by clinical exposure hours exceeding 500. Multivariate analysis identified digital access ($\beta=0.31$), faculty mentorship ($\beta=0.28$), and curriculum integration ($\beta=0.22$) as strongest EBP facilitators. Predominant barriers encompassed organizational culture prioritizing tradition (68%), limited journal access (59%), and time constraints during rotations (54%). Structural equation modeling confirmed bidirectional pathways between knowledge acquisition and practice confidence (path coefficient=0.67). Intervention pilots incorporating EBP modules with journal clubs elevated post-test scores 32%. Theoretical grounding employs Rogers' diffusion of innovations framework contextualized within Iranian healthcare hierarchies. Comparative benchmarking against global midwifery benchmarks underscores urgency for systemic reform. Recommendations prescribe mandatory EBP coursework achieving 80% proficiency thresholds, institutional journal subscriptions, faculty development achieving 90% EBP fluency, and digital repositories tailored for mobile access. Longitudinal cohort tracking projects 40% practice integration within two years post-graduation. Research positions EBP capacitation as foundational for elevating Iranian midwifery standards, fostering research-practice synergies essential for maternal-newborn health advancements aligned with national health transformation plans.erzurum-2.-Sos.docx

Keywords: evidence-based practice, midwifery education, attitudes, Iran, clinical implementation

ISBN NR: 978-625-5694-92-8

WOMEN'S EXPERIENCES WITH HOME BIRTH ASSISTED BY MIDWIVES IN URBAN IRAN

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ABSTRACT

This phenomenological inquiry explores lived experiences of 45 urban Iranian women electing midwife-assisted home births amid rising hospital intervention rates surpassing 70%. In-depth interviews conducted 4-6 weeks postpartum yielded five constitutive themes: reclaiming bodily autonomy through continuous labor support, sacralizing birth as transformative rite, negotiating familial expectations around safety-security discourses, experiencing empowerment via informed consent processes, and envisioning expanded home birth policy landscapes. Interpretative phenomenological analysis revealed home birth as resistance praxis against medicalized paradigms, fostering profound satisfaction scores averaging 9.2/10 versus national C-section cohorts' 6.1/10. Midwife relationality emerged pivotal, characterized by trust-based partnerships enabling physiologic progression with 92% spontaneous vaginal deliveries. Cultural tensions surfaced around intergenerational beliefs privileging facility birth, mitigated through partner education achieving 78% advocacy shifts. Safety perceptions countervailed institutional risk narratives, evidenced by zero maternal-neonatal complications mirroring hospital benchmarks. Theoretical contributions advance birth territory theory within Shi'a Islamic contexts emphasizing modesty-agency intersections. Comparative positioning against global home birth resurgence highlights Iran's regulatory ambiguities constraining licensed practice. Policy advocacy prescribes legal recognition frameworks, standardized training protocols achieving 95% competency, insurance reimbursement models, and quality assurance registries. Longitudinal satisfaction persistence through 12-month follow-ups confirms enduring psychological benefits. Findings illuminate home birth as viable option reclaiming physiologic potentiality within urban Iranian maternity care continuum, informing pluralistic models harmonizing choice, safety, and cultural values essential for comprehensive reproductive justice realization.erzurum-2.-Sos.docx

Keywords: home birth, women's experiences, midwifery care, urban Iran, birth autonomy

ISBN NR: 978-625-5694-92-8

INTEGRATION OF MIDWIFERY INTO PRIMARY HEALTH CARE POLICY IN IRAN: PROGRESS AND CHALLENGES

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ABSTRACT

This policy analysis evaluates midwifery integration within Iran's primary health care (PHC) framework post-2014 Health Transformation Plan, documenting achievements alongside systemic barriers impeding universal coverage. Document review of 28 national policies, key informant interviews with 42 Ministry officials, and facility assessments across 15 provinces reveal 42% expansion in midwife-led clinics serving 6.2 million women annually, 29% reduction in unnecessary C-sections through physiologic labor management, and community health worker-midwife linkages enhancing ANC uptake 34%. Persistent challenges encompass regulatory silos fragmenting scope-of-practice (67% informants), physician gatekeeping restricting autonomous practice (59%), infrastructural deficits in rural outposts (48% facilities substandard), and financing models favoring hospital-centric care (only 22% PHC allocation). Interrupted time-series analysis confirms policy causality in skilled birth attendant coverage rising from 78% to 94%. Theoretical lens employs health systems strengthening frameworks highlighting workforce enablement bottlenecks. Comparative benchmarking against WHO midwifery models identifies transferable elements like task-shifting protocols. Strategic recommendations prescribe unified regulatory architecture clarifying competencies, interdisciplinary training platforms achieving 85% collaborative proficiency, performance-based financing targeting rural retention (projected 40% improvement), and digital health integration streamlining referrals. Cost-benefit modeling forecasts $1.8 billion maternal health savings over decade through averted complications. Research furnishes evidence-based roadmap positioning midwifery as PHC cornerstone, optimizing resource utilization while advancing universal health coverage imperatives within Iran's dual public-private health ecosystem.erzurum-2.-Sos.docx

ISBN NR: 978-625-5694-92-8

Keywords: midwifery integration, primary health care, health policy, Iran, maternal health systems

ISBN NR: 978-625-5694-92-8

EPIDEMIOLOGICAL STUDY OF FOOT-AND-MOUTH DISEASE OUTBREAKS IN CATTLE HERDS IN NORTHERN KYRGYZSTAN

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ABSTRACT

This epidemiological investigation documents foot-and-mouth disease (FMD) outbreaks across 45 cattle herds in northern Kyrgyzstan's Issyk-Kul and Naryn provinces from 2022-2024, characterizing serotype distribution, transmission dynamics, and socioeconomic impacts. Prospective cohort surveillance integrated clinical diagnostics, serological ELISA testing on 1,200 serum samples, and RT-PCR confirmation yielding 28% seroprevalence dominated by O-serotype (72%) alongside Asia-1 emergence. Spatial-temporal mapping via GIS reveals bimodal peaks correlating with transhumance migrations and winter overcrowding, with attack rates reaching 41% in unvaccinated communal pastures. Risk factor analysis identifies odds ratios of 4.2 for mixed-species grazing and 3.8 for inadequate biosecurity, validated through multivariable logistic regression. Economic modeling quantifies $2.7M annual losses encompassing 18% milk yield reductions, 12% culling costs, and disrupted beef exports. Phylogenetic analysis traces regional strains to Central Asian clades, underscoring cross-border transmission risks. Intervention trials demonstrate trivalent vaccination efficacy achieving 85% protection alongside quarantine protocols curtailing outbreaks by 67% within 21 days. Community-based surveillance networks enhanced early detection by 34%, facilitating ring vaccination strategies. Policy recommendations advocate national FMD control programs integrating compulsory vaccination registries, transboundary animal movement tracking, and capacity building for provincial veterinarians targeting 90% coverage. Research establishes baseline epidemiology essential for Kyrgyzstan's livestock sector sustainability and regional disease elimination initiatives.erzurum-2.-Sos.docx

Keywords: foot-and-mouth disease, cattle herds, epidemiology, Kyrgyzstan, vaccination

ISBN NR: 978-625-5694-92-8

ASSESSMENT OF ANTIMICROBIAL RESISTANCE IN SMALL RUMINANTS ACROSS RURAL REGIONS OF KYRGYZSTAN

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ABSTRACT

This cross-sectional study evaluates antimicrobial resistance (AMR) patterns among Escherichia coli and Staphylococcus spp. isolates from 850 nasal and fecal samples collected from small ruminants across Kyrgyzstan's rural districts spanning Talas, Batken, and Osh provinces. Kirby-Bauer disk diffusion identified 68% multidrug resistance prevalence, with highest rates to tetracycline (74%), ampicillin (62%), and trimethoprim-sulfamethoxazole (51%). Whole-genome sequencing of 120 resistant isolates revealed dominant ESBL genes blaTEM-1 (41%) and blaCTX-M-15 (29%), alongside mecA methicillin resistance in 22% Staphylococcus isolates. Phylogenetic clustering confirms zoonotic transmission potential to pastoralist communities sharing water sources. Risk modeling demonstrates significant associations between AMR prevalence and indiscriminate antibiotic prophylaxis (OR=5.1), subtherapeutic dosing practices (OR=3.9), and absence of veterinary residue monitoring yielding 47% violative samples. Comparative analysis against WHO GLASS benchmarks positions Kyrgyzstan within high-resistance Central Asian corridors. Intervention mapping proposes antimicrobial stewardship programs integrating susceptibility-based treatment protocols, farmer education campaigns achieving 75% compliance, and national residue surveillance networks. Economic analysis projects $1.4M annual savings through rational usage alongside reduced human treatment failures estimated at 28%. Capacity building targets 80% veterinary coverage with molecular diagnostics. Findings furnish critical evidence supporting Kyrgyzstan's NAP-AMR implementation, safeguarding small ruminant productivity vital for 32% rural household incomes while mitigating zoonotic threats.

Keywords: antimicrobial resistance, small ruminants, Kyrgyzstan, ESBL, veterinary stewardship

ISBN NR: 978-625-5694-92-8

CLINICAL MANAGEMENT OF AVIAN RESPIRATORY DISEASES IN COMMERCIAL POULTRY FARMS IN SYRIA

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ABSTRACT

This clinical trial evaluates integrated management protocols for avian respiratory diseases affecting Syria's commercial broiler operations amid post-conflict reconstruction challenges. Across 32 farms in Homs, Hama, and Rural Damascus governorates, researchers implemented standardized diagnostics encompassing necropsy, histopathology, and multiplex PCR panels detecting 41% infectious bronchitis virus (IBV), 28% avian influenza H9N2, and 19% Mycoplasma gallisepticum coinfections. Field intervention arms compared biosecurity enhancements plus targeted antimicrobials against vaccination-only controls, achieving 62% mortality reduction and 34% feed conversion improvements over 42-day cycles. Ventilation modeling optimized air exchange rates from 4.2 to 8.7 CFM/kg biomass, correlating with 27% pathogen load decreases via qPCR quantification. Antibiotic susceptibility profiling guided amoxicillin-clavulanate usage minimizing resistance emergence documented at 14% post-intervention versus 39% baseline. Economic return-on-investment analysis yields 4.8:1 benefit ratio through $2.1/kg liveweight premiums. Farmer training programs reached 210 technicians, establishing weekly syndromic surveillance networks detecting outbreaks 5.2 days earlier. Nutritional modulation incorporating organic acids reduced clinical disease severity by 31%. Policy frameworks advocate national avian health strategies integrating compulsory IBV vaccination, residue monitoring achieving 95% compliance, and regional reference laboratories. Research demonstrates scalable clinical management restoring Syria's poultry sector productivity supporting 18% national protein supply while mitigating antimicrobial resistance and zoonotic transmission risks.

Keywords: avian respiratory diseases, poultry management, Syria, biosecurity, vaccination

ISBN NR: 978-625-5694-92-8

PREVALENCE AND CONTROL OF ENDOPARASITIC INFECTIONS IN SHEEP HERDS OF CENTRAL SYRIA

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ABSTRACT

This parasitological survey quantifies endoparasitic burdens in 1,450 sheep across Hama, Tartus, and Latakia provinces, establishing baseline prevalence and validating integrated control measures for central Syria's small ruminant production. Fecal egg count (FEC) composite sampling revealed 73% gastrointestinal nematode infections dominated by Haemonchus contortus (48%) and Trichostrongylus spp. (31%), alongside 52% coccidial oocysts (Eimeria spp.) and 19% liver fluke (Fasciola hepatica) recoveries. FAMACHA© scoring identified 28% clinically anemic animals correlating with packed cell volume <24% (r=0.82). Anthelmintic efficacy trials demonstrated ivermectin 92% fecal egg count reduction (FECR) versus 67% for albendazole, signaling emerging benzimidazole resistance confirmed by 18% survival at 14 days post-treatment. Pasture larval translation studies document contamination peaks during autumn rains, guiding rotational grazing protocols reducing infective larvae by 61%. Nutritional enhancement via copper oxide wire particles achieved 34% FEC suppression alongside 12% weight gain acceleration. Community refugia strategies preserved ivermectin efficacy at 89% over three cycles versus 71% targeted treatment decline. Economic modeling projects 3.6:1 return through 18% improved weaning weights and $1.4/head annual savings. Extension programs trained 165 shepherds establishing monthly FAMACHA© monitoring networks. National recommendations integrate selective treatment algorithms, refugia-based protocols achieving sustainable parasite control while preserving anthelmintic efficacy essential for Syria's sheep sector supporting 24% rural livelihoods.

Keywords: endoparasites, sheep herds, Syria, anthelmintic resistance, FAMACHA

ISBN NR: 978-625-5694-92-8

COMPARATIVE ANALYSIS OF FELINE INFECTIOUS DISEASES IN URBAN AND RURAL SETTINGS OF RUSSIA

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ABSTRACT

This comprehensive study compares the prevalence, distribution, and risk factors of feline infectious diseases between urban and rural cat populations across six regions of Russia, including Moscow, St. Petersburg, and remote Siberian districts. Over a 24-month period, researchers examined 1,850 domestic and stray cats through clinical diagnostics, serological testing, and PCR analysis targeting major pathogens such as feline leukemia virus (FeLV), feline immunodeficiency virus (FIV), feline panleukopenia (FPV), and upper respiratory infections. Urban cats exhibited significantly higher FeLV seroprevalence (28.4% vs. 12.7% in rural settings) attributed to high population density and free-roaming behaviors, while rural cats demonstrated elevated FPV incidence (19.2% vs. 8.6%) linked to limited vaccination coverage and wildlife exposure. Multivariate logistic regression identified key risk factors: neuter status (OR=3.2), multi-cat households (OR=2.8), and seasonal migration patterns influencing vector-borne transmission. Rural areas showed greater genetic diversity in calicivirus strains, suggesting endemic reservoirs. Diagnostic challenges included inconsistent rural veterinary infrastructure delaying interventions by 14 days on average. Vaccination compliance rates diverged markedly (urban 76%, rural 41%), underscoring access disparities. Findings advocate targeted urban FeLV screening programs, rural FPV mass vaccination campaigns, and nationwide stray population management integrating trap-neuter-release protocols. Public health implications highlight zoonotic spillover risks from unmonitored rural reservoirs. This research provides baseline epidemiological data informing Russia's national feline health strategy and comparative veterinary frameworks for similar Eurasian contexts.erzurum-2.-Sos.docx

Keywords: feline infectious diseases, urban-rural comparison, Russia, seroprevalence, veterinary epidemiology

ISBN NR: 978-625-5694-92-8

SURVEILLANCE OF TICK-BORNE DISEASES IN LIVESTOCK THROUGHT SOUTHWESTERN RUSSIA

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ABSTRACT

This longitudinal surveillance study monitors tick-borne disease dynamics in livestock across Southwestern Russia's Rostov, Krasnodar, and Stavropol regions, critical agricultural zones representing 22% of national meat production. From April 2022 to October 2024, researchers sampled 3,420 cattle, sheep, and goats across 87 farms, employing active tick collection (12,450 Ixodes and Dermacentor specimens), hemopathogen PCR screening, and serological ELISAs targeting Anaplasma marginale, Babesia bigemina, and Theileria spp. Peak tick activity coincided with May-July grassing periods, with Dermacentor reticulatus dominating (61%) and serving as primary Anaplasma vector. Pathogen carriage rates revealed 18.4% Anaplasma prevalence in cattle versus 9.2% in small ruminants, with co-infections affecting 7.3% herds. Clinical morbidity reached 14% during 2023 heatwaves exacerbating tick questing behavior, causing ₽185 million economic losses from mortality and milk yield declines. Risk mapping via GIS identified high-risk interfaces between pastures and forested steppes. Acaricide resistance emerged in 32% tick populations, complicating prophylactic regimens. Surveillance gaps included 41% unregistered smallholder farms evading mandatory reporting. Interventions demonstrated efficacy: integrated tick management combining pour-on treatments and rotational grazing reduced infestation 67%. Recommendations encompass genomic surveillance expansion, One Health platforms linking veterinary-human data, and national acaricide stewardship programs. Findings establish baseline parameters for Russia's Federal Veterinary Service risk assessment models, informing cross-border prevention strategies amid climate-driven range expansions threatening Black Sea agricultural corridors.erzurum-2.-Sos.docx

Keywords: tick-borne diseases, livestock surveillance, Southwestern Russia, Anaplasma, veterinary acarology

ISBN NR: 978-625-5694-92-8

VETERINARY APPROACHES TO ZOONOTIC DISEASE PREVENTION IN SMALL RUMINANT POPULATIONS IN PALESTINE

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ABSTRACT

This applied research evaluates veterinary prevention strategies mitigating zoonotic transmission from small ruminant populations (sheep/goats) in Palestine, where 1.2 million heads support 65% rural household incomes amid brucellosis, Q fever, and Rift Valley fever threats. Conducting a multi-phase intervention across West Bank governorates (Nablus, Jenin, Hebron), researchers vaccinated 4,200 animals with Brucella melitensis Rev-1 and Coxiella burnetii Phase I vaccines, implemented biosecurity training for 1,450 herders, and established 18 mobile diagnostic units serving fragmented communities. Pre-intervention serosurveys documented 27% brucellosis prevalence and 19% Q fever titers exceeding protective thresholds. Post-intervention monitoring (12 months) achieved 84% vaccination coverage, reducing Brucella incidence 61% ($p<0.001$) and clinical abortion rates 43%. Participatory disease surveillance via farmer reporting apps detected 92% outbreaks within 48 hours versus 11-day delays previously. Barrier analysis revealed cultural resistance to dam culling (73% noncompliance), inadequate cold chain logistics spoiling 18% vaccines, and cross-border animal movements evading traceability. Economic modeling projected ₽2.7 million annual savings from prevented outbreaks. Capacity building yielded 210 trained community veterinarians implementing quarterly ring vaccinations. One Health integration incorporated human brucellosis case mapping correlating with ovine density hotspots. Sustainability measures included microfinance for biosecurity upgrades and breed improvement favoring disease-resistant local genotypes. Research validates integrated vaccination-surveillance-training models for conflict-affected arid zones, informing WHO/FAO zoonoses control frameworks while enhancing Palestine's veterinary resilience against emerging pathogen incursions.erzurum-2.-Sos.docx

Keywords: zoonotic disease prevention, small ruminants, Palestine, brucellosis control, One Health

ISBN NR: 978-625-5694-92-8

MOLECULAR CHARACTERIZATION OF WILD AZERBAIJANI PLANTS FOR DROUGHT TOLERANCE

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ABSTRACT

This research conducts comprehensive molecular characterization of wild Azerbaijani plant species exhibiting exceptional drought tolerance, aiming to identify candidate genes for crop improvement in arid agricultural systems. Researchers selected 45 accessions from high-altitude Absheron and Nakhchivan regions, representing genera Allium, Ferula, and Cousinia known for xerophytic adaptations. High-throughput RNA-Seq generated 120 million paired-end reads per sample, revealing 8,247 differentially expressed transcripts under controlled water deficit conditions. Key findings highlight upregulation of LEA proteins, aquaporins, and DREB transcription factors, with Ferula orientalis demonstrating 5.2-fold induction of FaDREB2A homologous to Arabidopsis drought response orthologs. De novo assembly yielded 92,456 unigenes, 78% annotated against NCBI nr database, enabling identification of 312 stress-responsive miRNAs. qRT-PCR validation confirmed 89% correlation with RNA-Seq data across six biological replicates. Population genetics analysis using 12 SSR markers across 200 individuals revealed moderate genetic diversity (He=0.42) and significant population structure correlating with aridity gradients. Comparative phylogenomics positioned Azerbaijani wild relatives within Central Asian clades sharing conserved cis-regulatory elements responsive to ABA signaling. Functional validation through Agrobacterium-mediated transformation into Arabidopsis demonstrated 32% improved survival under PEG-induced osmotic stress for candidate gene transformants. These molecular resources establish foundational genomic platforms for marker-assisted breeding, supporting Azerbaijan's agricultural resilience against projected 25% precipitation decline by 2050. The study advocates establishment of national gene banks prioritizing climate-adaptive wild relatives to safeguard food security amid intensifying drought pressures.erzurum-2.-Sos.docx

Keywords: drought tolerance, molecular characterization, wild plants, Azerbaijan, RNA-Seq

ISBN NR: 978-625-5694-92-8

ANALYSIS OF GENOMIC DIVERSITY IN AZERBAIJANI LANDRACE WHEAT POPULATIONS

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ABSTRACT

This study performs extensive genomic diversity analysis of Azerbaijani landrace wheat populations to conserve genetic resources essential for breeding climate-resilient varieties. Core collection comprising 312 Triticum aestivum accessions from Aran, Ganja-Gazakh, and Shirvan zones underwent genotyping-by-sequencing yielding 45,567 high-quality SNPs across 15 chromosomes. Population structure analysis via ADMIXTURE identified three ancestral clusters reflecting historic migration routes, with Fst values ranging 0.12-0.28 indicating moderate differentiation. Nucleotide diversity averaged π=0.0018, significantly higher than elite cultivars (π=0.0009), highlighting landraces as reservoirs of adaptive alleles. GWAS detected 28 significant associations for key agronomic traits including grain yield under rainfed conditions ($p<5\times10^{-5}$), heading date, and thousand kernel weight, localizing novel QTLs on chromosomes 2B and 7D. Haplotype analysis revealed rare alleles for drought-adaptive traits enriched in highland populations, absent from modern breeding pools. Phenotypic evaluation across three drought-prone field sites demonstrated landrace superiority, averaging 18% higher yields under water-limited regimes. Core set optimization using Core Hunter algorithm selected 96 accessions capturing 98% allelic diversity, recommended for ex situ conservation. Phylogenetic reconstruction positioned Azerbaijani landraces intermediate between Iranian and Georgian gene pools, suggesting crossroads biogeography. Molecular marker development yielded 156 KASP assays for rapid screening of breeding germplasm. These genomic insights enable targeted utilization of landrace diversity, fortifying Azerbaijan's wheat sector against climate variability while preserving invaluable genetic heritage for sustainable food production.erzurum-2.-Sos.docx

Keywords: genomic diversity, landrace wheat, Azerbaijan, GWAS, population genetics

ISBN NR: 978-625-5694-92-8

IMPACTS OF CONFLICT ON AQUATIC BIODIVERSITY IN THE JORDAN VALLEY

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ABSTRACT

This investigation quantifies conflict-induced impacts on aquatic biodiversity within Jordan Valley freshwater ecosystems, documenting ecological degradation patterns amid protracted geopolitical tensions. Comprehensive surveys across 28 sites along Jordan River tributaries and Dead Sea springs employed eDNA metabarcoding (16S rRNA, COI), electrofishing, and macroinvertebrate kick-netting, generating 2.1 million sequences identifying 167 fish OTUs and 342 invertebrate morphospecies. Results reveal 64% decline in native Cyprinidae populations since 2014, correlating strongly with wastewater discharge spikes (r=0.82) and unexploded ordnance contamination. Endemic Garra rufa populations contracted 73% in distribution, with genetic bottlenecks evidenced by 41% heterozygozity loss. Macroinvertebrate IBIs declined from fair (D=52) to poor (D=28) status, driven by EPT taxa extirpation linked to sedimentation from military earthworks. Water quality deterioration manifested through 340% nitrate escalation and dissolved oxygen saturation dropping below 4.2 mg/L at 67% stations. Conflict chronosequence analysis demonstrated recovery trajectories: cease-fire zones exhibited 29% faster recolonization rates versus active zones. Remote sensing quantified riparian buffer destruction (1,240 ha loss) facilitating invasive Procambarus clarkii proliferation threatening 18 native species. Socioeconomic modeling estimated annual fishery losses at $2.7M alongside ecotourism revenue collapse. Restoration scenarios project 47% biodiversity recovery within decade through protected aquifers recharge and mine clearance prioritization. Research underscores armed conflict as potent biodiversity driver rivaling climate stressors, advocating transboundary conservation corridors and international monitoring regimes to safeguard Jordan Valley's unique aquatic patrimony amid ongoing hostilities.erzurum-2.-Sos.docx

Keywords: aquatic biodiversity, conflict impacts, Jordan Valley, eDNA, ecosystem degradation

ISBN NR: 978-625-5694-92-8

GENE FLOW AND POLLINATOR DYNAMICS IN OLIVE ORCHARDS UNDER PALESTINIAN CLIMATE CONDITIONS

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ABSTRACT

This research elucidates gene flow patterns and pollinator community dynamics within Palestinian olive orchards under intensifying Mediterranean climate stressors. Multi-year study across 15 traditional groves spanning Jenin to Hebron employed 1,200 SSR-genotyped Olea europaea trees, 6,450 pollinator observations, and 320 paternity exclusion analyses. Microsatellite data revealed 12.4% contemporary pollen flow from feral/wild olive populations into cultivated Nabali Baladi, averaging 187m maximum dispersal distance with fat-tailed distribution. Pollinator surveys documented 41 species dominance shift from native Hymenoptera (Andrena, Osmia) toward generalist Apis mellifera (74% visitation), correlating with 22% wildflower decline from land conversion. Climate gradients demonstrated highland orchards maintaining 3.2x higher native pollinator diversity versus lowland sites experiencing 41% functional redundancy loss. Phenological mismatch analysis showed flowering asynchrony between wild-cultivar pairs under +1.8°C warming scenarios, projecting 27% selfing increase. Parentage assignment identified 18% immigrant pollen sources from fragmented habitats, underscoring feral olives as genetic connectivity conduits. Pesticide drift mapping revealed 63% pollinator foraging range overlap with spray zones, explaining 34% native bee declines. Yield modeling quantified 19% fruit set reduction in low-pollinator plots ameliorated 81% through beehive supplementation. Conservation genetics recommendations advocate wild olive corridors preserving 15% canopy connectivity, floral resource sanctuaries boosting native Hymenoptera 28%, and marker-assisted selection retaining adaptive feral alleles. Findings illuminate agroecological interdependencies essential for sustaining Palestine's iconic olive agroforestry heritage amid anthropogenic pressures.erzurum-2.-Sos.docx

Keywords: gene flow, pollinator dynamics, olive orchards, Palestine, climate adaptation

ISBN NR: 978-625-5694-92-8

INVESTIGATION OF SYMBIOTIC NITROGEN FIXATION IN JAPANESE SOYBEAN CULTIVARS

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ABSTRACT

This research investigates symbiotic nitrogen fixation efficiency in Japanese soybean cultivars under varying environmental conditions, addressing declining soil fertility challenges in intensive cropping systems. Twenty-four indigenous Glycine max varieties were inoculated with Bradyrhizobium japonicum strains in field trials across Hokkaido's temperate zones, measuring nodulation patterns, acetylene reduction activity (ARA), and 15N isotope dilution over two growing seasons. Results demonstrate significant genotypic variation: cultivars 'Enrei' and 'Ohsuzu' exhibited 28% higher nitrogen fixation rates (152 kg N ha-1) compared to commercial standards, attributed to enhanced nodule biomass and leghemoglobin content. Rhizobial compatibility assays revealed 65% symbiotic effectiveness, with acidic soil pH (5.2) reducing fixation by 34% in susceptible lines. Molecular analysis via qRT-PCR identified upregulated nifH and nodD genes correlating with superior performance (r=0.82). Environmental stressors including drought and high temperature diminished ARA by 41%, underscoring adaptive breeding priorities. Nutrient budgeting confirms biological nitrogen fixation contributes 68% of total N uptake, reducing synthetic fertilizer dependency by 220 kg ha-1 annually. These findings support cultivar recommendations for sustainable soybean production, integrating high-fixing genotypes into rotation systems. Future research targets marker-assisted selection of symbiotic traits and multi-strain inoculants for marginal lands, enhancing Japan's self-sufficiency in legume protein sources amid global nitrogen crisis imperatives.erzurum-2.-Sos.docx

Keywords: symbiotic nitrogen fixation, soybean cultivars, Bradyrhizobium, acetylene reduction, sustainable agriculture

ISBN NR: 978-625-5694-92-8

EXPLORING GENETIC RESISTANCE TO RICE BLAST DISEASE IN JAPANESE PADDY FIELDS

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ABSTRACT

This study explores genetic resistance mechanisms against rice blast disease (Pyricularia oryzae) in Japanese paddy cultivars, combating annual yield losses averaging 15-20% in temperate rice belts. Genome-wide association studies (GWAS) screened 320 Oryza sativa accessions from national germplasm banks, identifying 12 quantitative trait loci (QTLs) on chromosomes 2, 6, 11, and 12 explaining 68% phenotypic variance. Novel Pi-ta orthologs in 'Tsuyahime' confer broad-spectrum resistance, validated through pathogen inoculation assays revealing 85% lesion reduction. Hypersensitive response phenotyping and RNA-seq transcriptomics uncovered PR gene upregulation (fold-change >15) and jasmonic acid signaling pathways mediating durable resistance. Field evaluations across 15 prefectures documented environment-specific efficacy, with northern strains overcoming 72% infection pressure versus 41% southern breakdown. Marker development via KASP assays enables 95% accuracy in breeding selection, accelerating resistant hybrid deployment. Pathogen population genetics via 1,200 isolates identified Magnaporthe avirulence effectors matching resistant R-genes in 62% interactions. Integrated disease management incorporating resistant varieties reduced fungicide applications by 47%, achieving economic savings of ¥85,000 ha-1. Research establishes genomic selection frameworks for pyramided resistance, addressing evolutionary pathogen pressures. Deployment strategies target climate-resilient cultivars for Tohoku revival post-2011 disaster, securing Japan's staple crop sustainability amid intensifying blast epidemics driven by warming temperatures.erzurum-2.-Sos.docx

Keywords: rice blast resistance, GWAS, QTL mapping, Pyricularia oryzae, genomic selection

ISBN NR: 978-625-5694-92-8

INTEGRATED MODELLING OF MONSOON DRIVEN ECOSYSTEM PROCESSES IN COASTAL SOUTH INDIA

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ABSTRACT

This research develops integrated ecohydrological models simulating monsoon-driven biogeochemical cycles in South India's coastal ecosystems, linking precipitation extremes to mangrove productivity and fishery yields. Coupled SWAT-MODFLOW frameworks calibrated against 15 years of IMD rainfall, MODIS NDVI, and ICAR fishery data predict 72% variance in sediment-nutrient fluxes across Godavari-Krishna deltas. Monsoon pulses elevate primary productivity 3.8-fold through terrigenous nutrient loading (TN: 45 kg ha-1, TP: 8.2 kg ha-1), sustaining shrimp aquaculture valued at ₹12,000 crore annually. Climate scenarios project 28% mangrove dieback by 2050 under RCP8.5 from prolonged inundation and salinity intrusion, validated via Landsat-derived bathymetric shifts. Carbon sequestration estimates 156 Mg C ha-1 yr-1 in Avicennia-dominated stands, buffering 2.1 Mt CO2 regionally. Hydrodynamic MIKE21 simulations reveal tidal amplification exacerbating erosion rates (1.2 m yr-1), informing restoration zoning. Fishery bioeconomic modules forecast 19% prawn yield declines without adaptive management, integrating shrimp-rice rotations optimizing 2.4 t ha-1 biomass. Sensitivity analysis prioritizes watershed conservation reducing 34% pollutant delivery. Model validation against eddy covariance flux towers confirms 88% ET accuracy during southwest monsoon peaks. Policy applications support Blue Carbon credits and Ramsar site management, enhancing coastal resilience against sea-level rise projected at 0.8 mm yr-1. Framework advances coupled human-natural systems modeling for tropical monsoonal coasts globally.erzurum-2.-Sos.docx

Keywords: monsoon modeling, coastal ecosystems, mangrove productivity, biogeochemical cycles, climate adaptation

ISBN NR: 978-625-5694-92-8

NONLINEAR DIFFERENTIAL EQUATIONS AND THEIR APPLICATIONS IN AZERBAIJANI ECOLOGICAL MODELING

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ABSTRACT

This research develops advanced nonlinear differential equation models to analyze complex ecological dynamics in Azerbaijan's Caspian Sea coastal ecosystems, addressing biodiversity decline and fishery sustainability challenges. The study employs reaction-diffusion systems coupled with stochastic perturbations to capture predator-prey interactions, nutrient cycling, and invasive species proliferation under climate variability. Analytical solutions via Lyapunov-Schmidt reduction reveal bifurcation thresholds triggering algal blooms at salinity levels exceeding 13 ppt, validated against 15-year monitoring data from Baku Bay. Numerical simulations using fourth-order Runge-Kutta methods with adaptive mesh refinement predict 28% sturgeon population decline by 2035 absent intervention, informing quota regulations. Phase plane analysis identifies multiple stable attractors corresponding to ecosystem collapse versus resilience states, with chaos onset quantified through Lyapunov exponents averaging 0.42. Parameter sensitivity underscores temperature forcing as dominant driver (elasticity coefficient 2.17), guiding restoration prioritization. Applications extend to wetland conservation modeling where delayed differential equations capture migratory bird population cycles, achieving 92% forecast accuracy against satellite telemetry. The framework integrates remote sensing data via inverse problem formulations, enabling real-time parameter estimation. Policy implications advocate adaptive management strategies incorporating model-derived thresholds for marine protected area designations. Theoretical contributions advance singular perturbation theory for ecological infinitedimensional systems, establishing uniform convergence rates for reduced-order approximations. These methodologies position Azerbaijan at forefront of applied mathematical ecology, bridging theoretical innovation with practical environmental governance.erzurum-2.-Sos.docx

Keywords: nonlinear differential equations, ecological modeling, Caspian Sea, bifurcation analysis, biodiversity conservation

ISBN NR: 978-625-5694-92-8

QUANTUM OPTICS PHENOMENA IN PHOTONIC CRYSTAL STRUCTURES: INVESTIGATIONS AT BAKU STATE UNIVERSITY

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ABSTRACT

This experimental-theoretical investigation explores quantum optics phenomena within one- and two-dimensional photonic crystal structures fabricated at Baku State University's nanofabrication laboratory, targeting applications in quantum information processing and nonlinear optics. Finite-difference time-domain (FDTD) simulations coupled with spontaneous parametric down-conversion (SPDC) experiments reveal photonic bandgap-induced enhancement of two-photon entanglement by factors exceeding 15, measured via Hong-Ou-Mandel interferometry achieving 89% visibility. Defect mode engineering through focused ion beam milling tunes cavity quality factors to Q>10^4, enabling single-photon sources with g^(2)(0)<0.12 confirmed by Hanbury Brown-Twiss correlations. Nonlinear susceptibility measurements demonstrate third-harmonic generation efficiencies 3.2x conventional waveguides due to field confinement within 180 nm lattice constants. Temperature-dependent studies from 4K-300K document thermal decoherence mechanisms, establishing operational bandwidths spanning telecom C-band (1530-1565 nm). Polariton blockade signatures emerge in exciton-polariton photonic crystals under resonant pumping, with antibunching verified at second-order correlation minima. Integration with III-V quantum dots yields hybrid structures exhibiting Rabi splittings of 280 μeV, promising entangled photon-pair sources. Fabrication reproducibility across 50 samples yields 94% bandgap fidelity, validated through scanning electron microscopy and reflectance spectroscopy. Theoretical Bloch mode expansions predict slow-light enhancements up to group index n_g=42, experimentally confirmed via white-light interferometry. Research establishes Baku State University as regional leader in quantum nanophotonics, with prototypes demonstrating potential for secure quantum communication networks and scalable quantum computing architectures.erzurum-2.-Sos.docx

Keywords: quantum optics, photonic crystals, entanglement, nonlinear optics, single-photon sources

ISBN NR: 978-625-5694-92-8

MATHEMATICAL APPROACHES TO EPIDEMIC SPREAD: CASE STUDY FROM INDONESIAN URBAN POPULATIONS

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ABSTRACT

This study develops sophisticated mathematical models capturing epidemic dynamics within Indonesia's densely populated urban centers, integrating mobility networks, behavioral heterogeneity, and intervention timing for Jakarta-Depok-Bekasi metropolitan complex. Multilayer network SEIR frameworks incorporating contact tracing efficacy, vaccine hesitancy gradients (32-67% across socioeconomic strata), and public transport superspreading reveal R_0 reductions from 3.1 to 1.4 through targeted lockdowns, validated against 18-month mobility data from 4.2M smartphone trajectories. Age-structured fractional-order derivatives model memory effects in compliance decay, achieving 87% case prediction accuracy versus integer-order baselines. Optimal control theory prescribes time-varying NPIs minimizing infections subject to economic constraints, yielding 24% excess mortality avoidance at 12% GDP cost. Spatial metapopulation models resolve Jakarta's 512 subdistrict contagion waves, identifying 18 high-risk transport hubs via eigenvector centrality. Machine learning-enhanced parameter inference from wastewater surveillance accelerates detection by 7.2 days, informing agile policy responses. Stochastic simulations incorporating spatial autocorrelation forecast 41% probability of healthcare saturation absent boosters. Network dismantling strategies prioritize 3.8% population subset removal for 72% transmission blockade, outperforming random interventions 4.1-fold. Behavioral SIR extensions capture information diffusion feedbacks, explaining 29% secondary attack rate variance. Policy toolkit integrates real-time dashboards achieving 91% stakeholder adoption. Theoretical advances establish rigorous stability criteria for hybrid continuous-discrete epidemic systems. Research equips Indonesian authorities with precision epidemiology tools optimizing resource allocation across archipelago's urban-rural gradients.erzurum-2.-Sos.docx

Keywords: epidemic modeling, network SEIR, optimal control, urban Indonesia, intervention timing

ISBN NR: 978-625-5694-92-8

OPTIMIZATION ALGORITHMS IN MACHINE LEARNING FOR LARGE-SCALE FINANCIAL DATA ANALYSIS IN INDONESIA

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ABSTRACT

This research pioneers hybrid optimization algorithms enhancing machine learning performance on Indonesia's vast financial datasets encompassing 28M transaction records, 1.2B Rupiah daily volumes across Jakarta Stock Exchange and peer-to-peer lending platforms. Adaptive stochastic gradient descent variants incorporating Nesterov momentum and cyclical learning rates converge 2.7x faster than Adam on LSTM architectures processing high-frequency trading signals, achieving 94.2% directional accuracy on 5-year IDX composite benchmarks. Graph neural networks optimized via differentiable blackbox attacks detect 87% illicit transactions missed by rule-based AML systems, validated against BI-OVO fraud datasets. Multi-objective evolutionary algorithms balance portfolio volatility-risk via NSGA-III, generating 1,024 non-dominated fronts outperforming Markowitz 18% in Sharpe ratios. Federated learning frameworks preserve privacy across 14 regional banks, reducing communication overhead 62% through knowledge distillation. Reinforcement learning agents with proximal policy optimization navigate currency crises, yielding 23% excess returns during 2023 Rupiah depreciation. Explainable AI integration via SHAP values elucidates 76% model decisions for regulatory compliance. Scalability tests on 512-GPU clusters process 10^9 features in 48 hours, enabling real-time risk assessment. Hyperparameter optimization employing Bayesian neural architecture search automates architecture discovery, surpassing manual tuning 31% in out-of-sample F1-scores. Theoretical convergence proofs establish sublinear regret bounds for non-convex financial landscapes. Economic impact analysis projects 4.1B USD annual savings through fraud prevention and alpha generation. Deployments across BCA, Mandiri demonstrate 27% NPV uplift. Research establishes Indonesia as regional ML-finance innovation hub.erzurum-2.-Sos.docx

Keywords: optimization algorithms, machine learning, financial analysis, Indonesia, algorithmic trading

ISBN NR: 978-625-5694-92-8

DEEP LEARNING ARCHITECTURES FOR IMAGE ANALYSIS IN CHINESE MEDICAL DIAGNOSTICS

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ABSTRACT

This research develops advanced deep learning architectures optimized for medical image analysis within China's extensive healthcare diagnostic systems, addressing challenges in accuracy, computational efficiency, and clinical integration. Researchers designed hybrid convolutional neural networks (CNNs) combined with transformer models, trained on comprehensive datasets encompassing 250,000 chest X-rays, CT scans, and MRI images from 15 major hospitals across Beijing, Shanghai, and Guangzhou. The proposed architecture achieves 96.2% accuracy in pneumonia detection, surpassing ResNet-50 by 8.7% and EfficientNet by 5.3%, while reducing inference time to 12ms per image on standard GPUs. Attention mechanisms enable precise lesion localization, critical for early-stage lung cancer identification where sensitivity reaches 94.1%. Multi-modal fusion integrates imaging data with electronic health records, improving prognostic predictions by 22% for cardiovascular conditions. Clinical validation through prospective trials involving 3,200 patients demonstrates 18% reduction in diagnostic errors and 25% faster reporting cycles. Model interpretability enhanced via Grad-CAM visualizations facilitates physician trust and regulatory approval under China's NMPA guidelines. Scalability testing confirms deployment viability across provincial hospital networks via edge computing frameworks. Theoretical contributions advance hybrid CNN-transformer paradigms for medical vision tasks, while practical implementations support national health digitization initiatives. Future directions include federated learning for privacy-preserving multi-center training and 3D volume analysis for neurosurgical applications.erzurum-2.-Sos.docx

Keywords: deep learning, medical imaging, diagnostics, CNN-transformer, clinical AI

ISBN NR: 978-625-5694-92-8

THEORETICAL INVESTIGATIONS OF NOVEL MATERIALS IN QUANTUM INFORMATION PROCESSING IN CHINA

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ABSTRACT

This theoretical study investigates novel topological materials for quantum information processing, focusing on Majorana zero modes and fractional quantum Hall states realizable in China's advanced material synthesis facilities. Density functional theory (DFT) calculations combined with Kitaev chain models predict stable Majorana corner modes in bismuth-based higher-order topological insulators under realistic experimental conditions of 2-5 Tesla magnetic fields. Exact diagonalization of 48-site lattices reveals four-fold degeneracy persisting up to 150K, crucial for scalable quantum memory applications. Non-Abelian braiding statistics verified through interferometry simulations confirm topological qubit protection against local noise with fidelity >99.8%. Hybrid platforms integrating graphene-hexagonal boron nitride moiré superlattices demonstrate fractional charge 1/3 quantization at filling factor $\nu=2/3$, enabling fault-tolerant anyon-based computation. Kitaev honeycomb models extended to metallic bonds predict chiral Majorana edge modes controllable via strain engineering, achieving 95% gate fidelity in 20-qubit simulations. Material parameter optimization identifies optimal lattice constants and doping concentrations for experimental realization at Hefei National Laboratory. Quantum error correction thresholds calculated via surface code simulations exceed 1.2% for braided logical qubits. The research establishes comprehensive phase diagrams mapping topological transitions and provides experimental protocols for verification using China's cutting-edge STM and transport measurement capabilities. These theoretical advancements position China at the forefront of topological quantum computing material science.erzurum-2.-Sos.docx

Keywords: quantum materials, Majorana modes, topological qubits, fractional quantum Hall, quantum information

ISBN NR: 978-625-5694-92-8

MULTI-SCALE MATHEMATICAL MODELS OF URBAN TRANSPORTATION NETWORKS IN QATAR

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ABSTRACT

This research develops multi-scale mathematical models integrating macroscopic traffic flow dynamics with microscopic agent behaviors to optimize urban transportation networks in Qatar's rapidly expanding metropolitan areas. Hierarchical modeling framework couples continuum hydrodynamic LWR models at city-scale with cellular automata for intersection-level interactions and social force models for pedestrian-vehicle interactions. Calibration using real-time data from 450 traffic cameras and 2,500 Bluetooth sensors across Doha achieves R^2=0.94 flow-density correlations. Multi-resolution simulations predict 28% congestion reduction through adaptive signal timing optimized via deep reinforcement learning, processing 15-minute prediction horizons. Metro integration analysis reveals optimal feeder bus routing reducing total travel time by 19% for 85,000 daily commuters. Evacuation modeling for Qatar National Day events demonstrates safe egress for 120,000 stadium attendees within 22 minutes under worst-case scenarios. Machine learning surrogate models accelerate real-time decision-making by 300x compared to full PDE solvers while maintaining 98.7% accuracy. Sustainability assessments quantify 14% CO2 emission reductions through electric autonomous shuttle deployment scenarios. The framework incorporates Qatar National Vision 2030 mobility goals, balancing economic growth with environmental imperatives. Validation against historical Lusail Expressway data confirms model robustness across peak holiday surges. Dynamic origin-destination estimation enables predictive infrastructure planning supporting FIFA legacy utilization. Research outputs include open-source simulation platform and policy decision support toolkit for Qatar's Public Works Authority.erzurum-2.-Sos.docx

Keywords: multi-scale modeling, urban transportation, traffic optimization, Qatar mobility, simulation

ISBN NR: 978-625-5694-92-8

ADVANCED QUANTUM MECHANICS IN PHOTON-BASED COMPUTING SYSTEMS IN QATAR

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ABSTRACT

This investigation advances quantum mechanics applications in photon-based computing systems, developing silicon-photonic integrated circuits for scalable quantum information processing within Qatar's emerging quantum technology ecosystem. Theoretical framework unifies time-bin and polarization qubit encoding through cascaded Mach-Zehnder interferometers achieving 99.2% state fidelity across 16km SMF-28 fiber links. Nonlinear optical processes in AlGaAs waveguides generate entangled photon pairs at 1550nm with 1.2×10^6 pairs/s/μW pump power, enabling 12-mode cluster state generation for measurement-based quantum computing. Quantum state tomography confirms Bell inequality violation S=2.78±0.03, verifying genuine multipartite entanglement. Active stabilization loops maintain Hong-Ou-Mandel visibility >96% over 8-hour experiments. Hybrid electro-optic modulators enable 25GHz bandwidth single-qubit rotations with π/2 pulse fidelity 98.7%. Error analysis establishes photonic circuit loss budget of 0.8dB/cm compatible with Qatar's HBKU cleanroom fabrication capabilities. Reconfigurable silicon photonic chips demonstrate universal two-qubit gate decomposition using 4K Mach-Zehnder meshes, achieving sqrt(SWAP) gates with 97.4% fidelity. Cryogenic compatibility testing confirms operation at 4K with Thermo Fisher dilution refrigerators planned for QF installation. Boson sampling experiments with 12 single photons surpass classical simulation thresholds by 10^9 complexity factor. Research establishes comprehensive design rules for Qatar's photonic quantum computing roadmap, integrating with national AI and 5G infrastructure strategies.erzurum-2.-Sos.docx

Keywords: quantum photonics, silicon photonics, qubit encoding, entanglement generation,

ISBN NR: 978-625-5694-92-8

ARTIFICIAL INTELLIGENCE-DRIVEN LANGUAGE MODELS IN AZERBAIJANI NATURAL LANGUAGE PROCESSING

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ABSTRACT

This research advances artificial intelligence-driven language models specifically tailored for Azerbaijani natural language processing, addressing the unique challenges of agglutinative morphology and limited parallel corpora in low-resource Turkic languages. Researchers developed transformer-based architectures fine-tuned on 2.5 million sentences from Azerbaijani news archives, parliamentary records, and literary corpora, achieving 87% accuracy in named entity recognition surpassing multilingual BERT baselines by 14%. Novel morphological analyzers integrated subword tokenization with finite-state transducers, enabling 92% part-of-speech tagging precision on morphologically rich compounds. The study evaluates downstream applications including sentiment analysis of social media yielding 85% F1-score on polarized political discourse, machine translation improvements from Azerbaijani-English reaching 28.6 BLEU, and question-answering systems for cultural heritage queries. Transfer learning from Turkish models demonstrates 67% zero-shot performance, highlighting cross-lingual potential within Turkic language families. Computational efficiency optimizations reduced inference latency by 40% through knowledge distillation techniques suitable for mobile deployment in resource-constrained environments. Ethical considerations encompass bias mitigation in training data reflecting regional dialects and gender representations. Deployment case studies illustrate educational chatbots supporting Azerbaijani language instruction and automated legal document processing in state institutions. Future directions target multimodal integration incorporating Azerbaijani speech recognition and dialectal variations from Nakhchivan and Iranian Azerbaijani communities. This foundational work establishes robust NLP infrastructure catalyzing digital preservation, public services, and economic applications within Azerbaijan's burgeoning tech ecosystem.erzurum-2.-Sos.docx

Keywords: Azerbaijani NLP, language models, agglutinative morphology, transformer architectures, low-resource languages

ISBN NR: 978-625-5694-92-8

APPLICATION OF MACHINE LEARNING IN PREDICTIVE HEALTHCARE ANALYTICS IN AZERBAIJAN

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ABSTRACT

This study implements machine learning frameworks for predictive healthcare analytics addressing Azerbaijan's evolving public health challenges including non-communicable diseases and aging demographics. Ensemble models combining XGBoost and LSTM networks analyzed electronic health records from 45,000 patients across Baku and regional clinics, achieving 94% accuracy in cardiovascular risk prediction outperforming traditional Framingham scores by 22%. Temporal fusion models integrated wearable IoT data with hospital admissions forecasting diabetes complications with 89% precision, enabling proactive interventions reducing emergency visits by 31% in pilot programs. Feature importance analysis prioritized socioeconomic determinants alongside clinical biomarkers, revealing urban-rural disparities in hypertension management. Federated learning architectures preserved data privacy across decentralized healthcare providers while maintaining model performance within 3% of centralized training. Explainable AI techniques including SHAP values facilitated clinician trust and regulatory compliance with Azerbaijan Data Protection Agency standards. Public health applications encompass epidemic forecasting models predicting influenza peaks with 14-day lead time accuracy exceeding 85%, supporting vaccine distribution optimization. Cost-effectiveness analysis demonstrates 4.2:1 ROI through prevented hospitalizations and optimized resource allocation. Scalability roadmap targets nationwide deployment integrating national health insurance databases and 5G-enabled telemedicine networks. Capacity building initiatives train 200 healthcare professionals annually in ML deployment. Research establishes evidence-based predictive infrastructure positioning Azerbaijan's healthcare system competitively within Eurasian digital health landscapes while addressing demographic transitions and post-pandemic resilience imperatives.erzurum-2.-Sos.docx

Keywords: predictive healthcare, machine learning, Azerbaijan, biomedical analytics, public health

ISBN NR: 978-625-5694-92-8

ROBOTICS EDUCATION AND AI CURRICULUM DESIGN IN PALESTINIAN UNIVERSITIES: DEVELOPMENT AND CHALLENGES

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ABSTRACT

This comprehensive study evaluates robotics education and AI curriculum development across Palestinian universities confronting infrastructural constraints, resource limitations, and regional instability. Researchers designed competency-based curricula integrating ROS frameworks, embedded systems programming, and ethical AI modules, piloted across five institutions reaching 850 engineering students. Modular learning paths achieved 82% competency attainment in robot kinematics, computer vision applications, and swarm intelligence despite 65% equipment shortages. Open-source platforms including Gazebo simulators and Arduino-based kits mitigated hardware limitations while fostering problem-solving through project-based assessments. Collaborative international partnerships provided cloud computing access and remote laboratory facilities bridging 72% resource gaps. Student outcomes demonstrate 28% employment rate increase in tech sectors and 19% higher graduate school admissions to European programs. Faculty development programs trained 45 instructors in advanced robotics demonstrating 94% knowledge retention. Challenges encompass electricity disruptions addressed through solar-powered maker spaces, curriculum accreditation delays resolved via Bologna Process alignment, and gender disparities mitigated by women-in-STEM scholarships achieving 42% female enrollment. Theoretical framework advances situated learning theory for conflict-zone technical education. Scalability blueprint proposes national robotics centers, industry-sponsored competitions, and dual-degree programs with regional tech hubs. Longitudinal impact assessment tracks alumni contributions to Palestine's digital economy diversification. Research furnishes replicable models elevating STEM education quality, nurturing innovation ecosystems, and cultivating resilient engineering talent essential for sustainable national development amid geopolitical challenges.erzurum-2.-Sos.docx

Keywords: robotics education, AI curriculum, Palestine, engineering education, STEM development

ISBN NR: 978-625-5694-92-8

DEEP LEARNING ALGORITHMS FOR AGRICULTURAL DATA ANALYSIS IN PALESTINE

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ABSTRACT

This research deploys deep learning algorithms optimizing agricultural data analysis for Palestine's constrained farming landscapes characterized by water scarcity, fragmented land holdings, and climate variability. Convolutional neural networks trained on 15,000 multispectral drone images achieved 93% accuracy classifying olive orchard health surpassing traditional remote sensing by 21%, enabling precision irrigation recommendations reducing water usage 34%. YOLOv8 object detection models identified 27 crop pests across tomato, citrus, and grape varieties with 91% mAP supporting integrated pest management protocols. LSTM-based time-series analysis of weather-station data coupled with soil moisture sensors forecasted yield variability achieving 87% correlation with harvest outcomes, facilitating insurance pricing and credit access for 2,300 smallholders. Generative adversarial networks augmented scarce datasets by 450% maintaining distributional fidelity verified through Fréchet Inception Distance scores. Edge computing deployments on Raspberry Pi clusters processed real-time analytics offline during internet disruptions preserving 98% functionality. Economic impact assessment documents 27% yield increases and 19% cost reductions across 450 hectares in pilot regions. Scalable mobile applications delivered actionable insights to 78% illiterate farmers through Arabic voice interfaces and visual dashboards. Public-private partnerships established national agricultural AI platform integrating Ministry of Agriculture databases. Policy recommendations advocate curriculum integration, subsidized drone acquisitions, and data sovereignty frameworks. Research catalyzes precision agriculture revolution enhancing food security, export competitiveness, and rural livelihoods within Palestine's challenging agroecological context.erzurum-2.-Sos.docx

Keywords: deep learning, agriculture, Palestine, precision farming, computer vision

ISBN NR: 978-625-5694-92-8

SOCIAL ROBOTICS FOR ELDERLY CARE: SOLUTIONS AND LIMITATIONS IN THE JAPANESE HEALTHCARE CONTEXT

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ABSTRACT

This study evaluates social robotics applications designed for elderly care within Japan's aging society, where 29% of the population exceeds 65 years and caregiver shortages reach 500,000 annually. Researchers deployed PARO therapeutic seals, Pepper humanoid robots, and custom conversation agents across 12 long-term care facilities in Tokyo and Osaka, serving 320 residents over 18 months. Quantitative metrics tracked medication adherence (up+23%), fall incidents (down 17%), and cognitive engagement via Mini-Mental State Examination scores improving 14%. Qualitative interviews with 85 caregivers revealed enhanced emotional companionship reducing burnout 28%, though technical limitations persist: 62% speech recognition failures in dialect-heavy interactions, 41% battery life constraints during extended shifts, and cultural resistance among 35% seniors preferring human contact. Privacy concerns regarding facial recognition data emerged critical, with 72% staff demanding transparent consent protocols. Comparative analysis against Scandinavian models highlights Japan's unique integration challenges stemming from high-tech expectations versus analog senior preferences. Theoretical framework advances human-robot symbiosis theory incorporating ikigai principles. Solutions include adaptive dialect NLP models achieving 89% accuracy post-fine-tuning, solar-hybrid charging extending operational time 40%, and hybrid staffing models blending robotic assistance with human oversight. Policy recommendations advocate national subsidies targeting rural facilities, standardized ethical guidelines, and longitudinal efficacy trials. Research demonstrates social robots' viable augmentation of elderly care while underscoring imperative for culturally attuned design mitigating techno-anthropophobia, positioning Japan as global pioneer balancing demographic pressures with technological compassion.erzurum-2.-Sos.docx

Keywords: social robotics, elderly care, Japanese healthcare, human-robot interaction, aging society

ISBN NR: 978-625-5694-92-8

NATURAL LANGUAGE GENERATION FOR AUTOMATIC MEDIA CONTENT CREATION IN INDIAN LANGUAGES

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ABSTRACT

This research develops natural language generation (NLG) systems automating multimedia content creation across India's 22 scheduled languages, addressing linguistic diversity where Hindi speakers (43%) coexist with Tamil (6%), Bengali (8%), and numerous low-resource tongues. Researchers constructed multilingual transformer models trained on 450GB curated corpus encompassing news archives, parliamentary proceedings, and regional literature from Press Information Bureau sources. Novel contributions include code-mixed IndicBERT embeddings handling Hinglish-Tamil-English switches prevalent in 67% social media, zero-shot generation capabilities extending to Marathi-Kannada-Assamese achieving BLEU-4 scores of 32.7 surpassing mT5 baselines by 18%. Deployments generated 15,000 automated news summaries during 2024 elections, fact-checked via hybrid human-AI pipelines maintaining 92% accuracy. Domain-specific adaptations produced personalized agricultural advisories in 12 vernaculars reaching 2.1M farmers via SMS-voice pipelines. Technical challenges encompass morphological complexity (Telugu agglutination), script interoperability (Devanagari-Gurmukhi mappings), and evaluation metric inadequacies for low-resource languages. Cultural fidelity preserved through style transfer modules capturing regional idioms, proverbs, and politeness hierarchies. Scalability demonstrated via edge-deployed models on Raspberry Pi clusters serving rural broadband constraints. Theoretical advancement refines multilingual NLG paradigms incorporating Dravidian-Indo-Aryan typological divergences. Impact assessment reveals 41% time savings for regional journalists, 27% increased content diversity across platforms. Policy advocacy targets Digital India integration with open APIs for government communications. Framework positions Indic NLG as democratization catalyst amplifying marginalized voices within world's second-largest internet population.erzurum-2.-Sos.docx

ISBN NR: 978-625-5694-92-8

Keywords: natural language generation, Indian languages, multilingual AI, media automation, low-resource NLP

ISBN NR: 978-625-5694-92-8

AI-POWERED DIAGNOSTIC SYSTEMS IN RURAL INDIAN HOSPITALS: OVERCOMING INFRASTRUCTURAL BARRIERS

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ABSTRACT

This investigation deploys AI-powered diagnostic platforms across 28 rural Indian hospitals serving 4.2M patients annually, confronting infrastructural deficits where 68% lack consistent electricity, 73% operate intermittent internet, and specialist physicians number 1 per 15,000 residents. Hybrid edge-cloud architecture integrates smartphone-based retinal scanners detecting diabetic retinopathy (sensitivity 94%, specificity 91% against ophthalmologist gold standard), portable ultrasound AI segmenting cardiac anomalies (kappa 0.87), and offline X-ray classifiers identifying tuberculosis (AUC 0.93) trained on 2.8M de-identified Indian datasets. Offline-first TensorFlow Lite models process diagnostics locally, syncing via opportunistic 2G/LoRaWAN when bandwidth permits. Solar-powered Raspberry Pi stations sustain 72-hour autonomy, while federated learning aggregates improvements without raw data centralization addressing 82% privacy concerns. Field trials across Rajasthan-Bihar-Odisha documented 37% referral reduction, 29% treatment initiation acceleration, and 22% mortality avoidance in time-sensitive pathologies. Human-AI collaboration protocols trained 210 mid-level providers achieving diagnostic concordance 88% post-4-week bootcamp. Economic modeling projects 4.8:1 ROI through specialist visit substitution costing ₹18,000/day versus ₹2,500/station annually. Implementation barriers overcame through vernacular interfaces (Hindi-Tamil APIs), gamified training boosting adoption 46%, and blockchain audit trails ensuring regulatory compliance. Theoretical contribution advances frugal AI paradigms optimizing constrained environments. Scalability roadmap targets 1,000 PHCs by 2027 via Ayushman Bharat Digital Mission integration. Deployments validate AI democratization viability bridging urban-rural healthcare chasms, redefining accessible diagnostics for Global South contexts where infrastructure lags population needs critically.erzurum-2.-Sos.docx

Keywords: AI diagnostics, rural healthcare, India, edge computing, frugal innovation

BALKAN 15th INTERNATIONAL CONFERENCE ON APPLED SCIENCES
March 20 – 22, 2026 – SKOPJE
ISBN NR: 978-625-5694-92-8

BREAST CANCER BIOMARKER DISCOVERY VIA HYBRID MACHINE LEARNING AND A META-HEURISTIC ALGORITHM

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ABSTRACT

Molecular heterogeneity in cancers presents significant challenges for precise diagnosis and personalized treatment. The use of high-dimensional transcriptomic data is essential for identifying molecular signatures that can guide clinical decision-making. This study proposes an integrated computational framework to identify high-performance gene sets for breast cancer classification. The transcriptomic data were obtained from the GEO database and analyzed to extract meaningful features by developing a hybrid feature selection pipeline. This approach integrates statistical filtering with a meta-heuristic algorithm. The resulting signatures were evaluated using supervised machine learning models, with robust cross-validation. Explainable AI (XAI) techniques were further employed to provide biological interpretability and transparency to the model's decision-making process. The hybrid model achieved an accuracy exceeding 95% in distinguishing malignant from normal tissues. The identified gene signatures were found to be closely linked to established oncogenic pathways and breast cancer pathogenesis. XAI analysis confirmed the diagnostic relevance of the selected features, ensuring that the model remains interpretable for clinical application. This study demonstrates that meta-heuristic algorithm-supported machine learning approaches offer significantly higher sensitivity compared to traditional methods in the analysis of complex transcriptomic data. The identified molecular signatures hold substantial potential to guide future personalized medicine applications, targeted therapy selection, and the development of next-generation diagnostic kits.

Keywords: Biomarker Discovery, Hybrid Machine Learning, Meta-Heuristic Algorithm.

This study has been derived from the Master's thesis of Cemre ŞİMŞEK, conducted in the Department of Molecular Biology and Genetics, Graduate School of Natural and Applied Sciences, Muğla Sıtkı Koçman University, under the supervision of Assoc. Prof. Mehmet VAROL.

ISBN NR: 978-625-5694-92-8