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INTRODUCTION

We had the great honor of of 3rd International Conference on Pioneer and Innovative Studies ICPIIS 2025. It was truly a great pleasure for us to greet a lot of participants from many different countries attending ICPIIS 2025! We firmly believe that the conference will become an important international event in the field of cross-industry discussion about innovations in Academic Studies.

Three cooperating organizations supported the two-day conference. There were 156 papers accepted for presentation at ICPIIS 2025, contributed from different countries. We had plenary speeches and several well-known scientists and experts, to give invited talks at different sessions.

The purpose of ICPIIS 2025 was to provide a forum for the participants to report and review innovative ideas, with up-to-date progress and developments, and discuss novel approaches to the application in the field of their own research areas and discuss challenges of doing science.

We sincerely hope that the exchange of ideas on doing research, science and improving education will help the participants, and international cooperation sharing the common interest will be enhanced.

On behalf the Organization Committee of ICPIIS 2025, we would like to heartily thank our cooperating organizations for all they have done for the conference. We would also like to thank the authors for their contribution to the proceedings; the participants and friends of ICPIIS 2025, for their interest and efforts in helping us to make the conference possible; and the Editorial boards for their effective work and valuable advice, especially the ICPIIS 2025 secretariat and the ICPIIS 2025 staff, for their tireless efforts and outstanding services in preparing the conference and publishing the Proceedings.

Publisher: All Sciences Academy

TABLE OF CONTENTS

Introduction	I
Table of Contents	II
Conference Chairs	VIII
Scientific Committees	IX
Document of Academic Incentive	X
Document of International Conference	XI

Table List of Content

Content of Full Papers

Page No	Title	Authors	Country	Submission ID
1-8	Random Forest and Boosting Algorithm for Wildfire Prediction based on Time and Environmental Factors	Yasemin Ayaz Atalan	Turkey	Submission 9
9-14	Aerodynamic Resistance in Land Vehicles: Comparative CFD and Experimental Analysis	Hüseyin Kahraman, Aslan Çoban, Adem Tüylü	Turkey, Turkey, Turkey	Submission 14
15-17	Aluminum-Based Sandwich Structures in Aircraft	Selim Gürge	Turkey	Submission 17
18-21	Laminated Composites in Aircraft Applications	Selim Gürge	Turkey	Submission 18
22-25	The Use of Rosemary (Rosmarinus officinalis L.) in Cosmetic Products	Betül GİDİK	Turkey	Submission 24
26-31	Design and Performance Evaluation of a 30 t/h Capacity Screw Conveyor System	Hüseyin Kahraman, Aslan Çoban, Nusret Fatih Aktaş	Turkey, Turkey, Turkey	Submission 26
32-39	Design and Analysis of a Tennis Ball Launcher for Standard Court Applications	Hüseyin Kahraman, Aslan Çoban	Turkey, Turkey	Submission 27
40-55	VisionGuard: Hybrid Deep Ensemble Feature Fusion for Robust Malware Detection Across Mobile and Desktop Platforms	Muhammet Tan, Halit Bakır, Metin Zontul	Turkey, Turkey, Turkey	Submission 28
56-60	VIS-NIR Spektroskopi ve Hiperspektral Görüntüleme Teknolojilerinin Gıda, Tarım ve Biyomedikal Alanlardaki Uygulamaları	Yeliz DURGUN, Mahmut DURGUN	Turkey, Turkey	Submission 30
61-67	Entropy Generation Analysis of a Microchannel Heatsink	Ahmad Najafpour, Morteza Bayareh	Iran, Iran	Submission 31
68-72	Pseudo Random Number Generator Based on Hash Algorithm and Chaotic map	Fırat Artuğer, Songül Karakuş	Turkey, Turkey	Submission 39
73-79	Assessment of Drought Variability in Kastamonu Using the Standardized Precipitation Index (SPI)	Senem GÜNEŞ ŞEN	Turkey	Submission 42
80-86	Life-Cycle Cost Optimization of Highway Pavements Using Artificial Intelligence Techniques	Sebnem Karahancer	Turkey	Submission 43
87-91	Determination of Vitamin C in Fruit and Juice Samples of Albanian Market	Ardit Shehi, Kleva Shpati, Aida Dama, Aurora Napuce, Ederina Haxhia, Erjona Sheqeri, Aurel Nuro	Albania, Albania, Albania, Albania, Albania, Albania	Submission 47
92-101	A Computational Approach for the Development of Novel Cyclophilin D Protein Inhibitors	Gözde YALÇIN-ÖZKAT	Turkey	Submission 48
102-108	Dünya ve Türkiye’de Keten (Linum usitatissimum L.) Üretimi	Özden Öztürk	Turkey	Submission 49
109-113	HT/HP Gaz Kondensat Karışımının Viskozitesini Hesaplayacak Model Denklemlerin Geliştirilmesi	İnci TÜRK TOĞRUL	Turkey	Submission 50
114-120	Doğal Gazın Viskozitesini Sıcaklık Ve Basınca Bağlı Olarak Hesaplayabilecek Model Denklemlerin Geliştirilmesi	İnci TÜRK TOĞRUL	Turkey	Submission 51
121-125	İNGİLİZCE ÖĞRETMENLİĞİ BÖLÜMÜ ÖĞRETMEN ADAYLARININ İSTİHDAM KAYGILARI	Yunus Emre Avcı, Ayhan Yavuz	Turkey, Turkey	Submission 52
126-131	ÖĞRETMEN İSTİHDAM POLİTİKALARI VE İSTİHDAM KAYGISI ÜZERİNE BİR DEĞERLENDİRME	Yunus Emre Avcı, Ayhan Yavuz	Turkey, Turkey	Submission 53
132-137	Comparative Analysis Of Sgdm And Adam Algorithms Using Covid 19 Images	Berrin AVUÇLU	Turkey	Submission 55
138-146	Experimental Determination of Spearmint Sorption Isotherms Using Salt Solutions	Nacer Chouchane, Hammam Chouchane	Algeria, Algeria	Submission 58
147-155	Fiber-Laser Square Texturing of AA2024-T3: Scale Factor and Scanning Speed Effects on Contact Angle and Surface Profilometry	Özer Coşkun, Sinan Fidan, Mustafa Özgür Bora, Satılmış Ürgün, Mehmet İskender Özsoy	Turkey, Turkey, Turkey, Turkey, Turkey	Submission 60
156-165	Parametric Study of Fiber-Laser Circular Microtextures on AA2024-T3: Influence of Scale Factor and Scan Speed on Wettability and Roughness	Özer Coşkun, Sinan Fidan, Mustafa Özgür Bora, Satılmış Ürgün, Mehmet İskender Özsoy	Turkey, Turkey, Turkey, Turkey, Turkey	Submission 61
166-171	Zararlılık etkisi yüksek kimyasalların depolama ve üretiminin yapıldığı tesiste risk analiz çalışma örneği	Zehra Gülten Yalçın	Turkey	Submission 62

172-178	Genomic Insights into Antimicrobial Resistance and Prophage Elements of <i>Lactiplantibacillus plantarum</i> TOS9 Isolated from the Honeybee Gut	Harun ÖNLÜ, Özlem OSMANAGAOGLU	Turkey, Turkey	Submission 65
179-187	Detection of Bone Fractures in X-ray Images with Machine Learning Methods Using InceptionV3 Deep Features	Mucahid Mustafa SARITAS, Ramazan KURSUN, Murat KOKLU	Turkey, Turkey, Turkey	Submission 81
188-192	Molecular Approaches to Determining Male Sterility in Carrots	Ünal KAL	Turkey	Submission 83
193-201	Machinery-Related Marine Casualties in European Waters: Insights from the EMSA 2024 Report	Bulut Ozan Ceylan	Turkey	Submission 84
202-215	REMARKS ON EXTENSION OF COMMON MODELS FOR STUDYING LEGISLATION COHERENCE AND EFFECTIVENESS	Alkida Llakaj, Dodë Prenga	Albania, Albania	Submission 86
216-222	Ablation-Driven Model Selection for Eating Disorder Prediction from Neurobehavioral Data	Halit Çetiner, Sedat Metlek	Turkey, Turkey	Submission 89
223-231	Euphorbia myrsinites'in Biyolojik Aktiviteleri ve Antidiyabetik Potansiyeli Üzerine Bir Yaklaşım	Muhammed Türkmen, Ömer Furkan Güverti, Sultan Pekacar, Didem Deliorman Orhan	Turkey, Turkey, Turkey, Turkey	Submission 98
232-241	Çamlıköy - Işıkdere Yöresi Kayaç ve Topraklarının Yerel Element Ortalama ve Zenginleşme Düzeyleri	Alaaddin Vural, Abdullah Kaygusuz	Turkey, Turkey	Submission 99
242-249	Genelleştirilmiş Berezin Sayısı Eşitsizliklerine Yeni Bakış Açılımları	Orçun Yücel, Mehmet Gürdal	Turkey, Turkey	Submission 104
250-260	Validating and modeling of metrics of micro turbojet engine by experimental and machine learning methods	Hakan Aygun, Kadir Donmez, Omer Osman Dursun, Suat Toraman, Oguzhan Sahin	Turkey, Turkey, Turkey, Turkey, Turkey	Submission 105
261-264	A Short Survey on Optimization in Engineering	Ali Mortazavi	Turkey	Submission 106
265-268	Uncertainty Quantification and Statistical Approaches in Engineering Design	Ali Mortazavi	Turkey	Submission 107
269-277	Kültivatör Uç Demirlerinin Laboratuvar Şartlarında Aşınma Davranışlarının İncelenmesi	Yusuf Dilay, Adem Özkan	Turkey, Turkey	Submission 109
278-286	ELEKTROOKSIDASYON YÖNTEMİ İLE REAKTİF BOYALARDAN RENK GİDERİMİNDE pH ve SICAKLIK ETKİSİNİN ARAŞTIRILMASI	Sermin GÜNASLAN, Deniz TOSUN, Baybars Ali FİL	Turkey, Turkey, Turkey	Submission 114
287-292	Predicting the Surface Roughness of Cu/B-CrC Metal Matrix Composites Using Artificial Intelligence Model	Üsâme Ali Usca, Serhat Şap, Ünal Değirmenci	Turkey, Turkey, Turkey	Submission 116
293-298	Purpose-Based Analysis of Domestic Tourism Demand in Türkiye: Travel, Overnight Stays and Indexing Approach for the Period 2009–2024	Ece ÖZGÖREN ÜNLÜ, Cengiz GAZELOĞLU	Turkey, Turkey	Submission 117
299-302	Serological evidence of Caprine Arthritis Encephalitis Virus (CAEV) in goats from the North-West region of Albania	Doriana Beqiraj, Brixhilda Qyra, Albana Munga, Majlind Sulçe, Enkelelda Ozuni, Gerald Muça	Albania, Albania, Albania, Albania, Albania, Albania	Submission 120
303-307	Prediction of Tribological Behavior of Powder Metallurgy Cu/B-CrC Hybrid Composites via LSTM Models	Üsâme Ali Usca, Ünal Değirmenci, Serhat Şap	Turkey, Turkey, Turkey	Submission 132
308-321	BIM Modelleri ile Gerçek İnşaat Verileri Arasındaki Metraj Uyuşmazlıklarının Analizi: Revit ile Sonradan Modelenmiş Yapı Elemanları Üzerine Bir Durum Çalışması	Dilara Aleyna Çapak, Gonca Özer Yaman, İsmail Vural	Turkey, Turkey, Turkey	Submission 133
322-330	Effect of Artificial Roughness Geometry on Heat Transfer Improvement in Flat-Plate Solar Air Collectors	Nacer Chouchane, Hammam Chouchane, Tesnim Chouchane	Algeria, Algeria, Algeria	Submission 137
331-335	SAHİPLİK YAPISININ AR-GE HARCAMALARI ÜZERİNDEKİ ROLÜ: BORSA İSTANBUL'DAN BULGULAR	Aysel Öztürkçü Akçay	Turkey	Submission 141
336-341	Tourism Expenditures in Türkiye: Trends, Seasonality, and Index Analysis (2012–2024)	Ece ÖZGÖREN ÜNLÜ, Cengiz GAZELOĞLU	Turkey, Turkey	Submission 142
342-351	Optimization of Exopolysaccharide Production by Lactic Acid Bacteria under Different Culture Conditions	Halil İbrahim UZUN, Harun ÖNLÜ	Turkey, Turkey	Submission 143
352-362	Deep Learning-Based Ensemble Model for Snake Species Classification	Mert Kodaman, Talha Akyl, Mustafa Yasin Erten, Hüseyin Aydılek	Turkey, Turkey, Turkey, Turkey	Submission 149
363-377	Comparative Study on the Applicability of Sulfur Polymer Concrete and Portland Cement Concrete in Structural Systems	Furkan Günday	Turkey	Submission 150
378-383	Performance Evaluation of Event-Based and RGB Cameras in Dynamic Scenes	Emin Güney	Turkey	Submission 152
384-389	Performance Analysis of Multiple Object Tracking Algorithms for Maritime Environments	Emin Güney, Cüneyt Bayılmış	Turkey, Turkey	Submission 156
390-395	Süreksizlik Noktası İçeren Sturm-Liouville Problemi İçin Green Fonksiyonunun Özfonksiyon Açılımı	Kadriye AYDEMİR, Oktay Sh. MUKHTAROV, Hayati OLGAR	Turkey, Turkey, Turkey	Submission 161
396-405	Kuzeydoğu Türkiye'de Avliyana (Gümüşhane)	Alaaddin Vural, Abdullah	Turkey, Turkey	Submission 162

	Sahası Topraklarındaki İz Elementlerin Jeokimyasal Zenginleşmesi/Kirlilik Düzeylerinin Tespiti	Kaygusuz		
406-415	The First Zagreb Index and First Leap Zagreb Index of Fibonacci Cubes	Özge Çolakoglu	Turkey	Submission 163
416-422	Soğuk İş Takım Çeliklerinin Tornalanmasında Kesme Hızı Değişiminin Kesme Kuvveti Üzerindeki Etkisinin İncelenmesi	Burhan Siper, Mustafa Kuntoğlu	Turkey, Turkey	Submission 164
423-430	Modbus-Based PID Position Control Simulation Using Outseal Nano and LabVIEW DSC Toolkit	Serhat Küçükdermenci	Turkey	Submission 165
431-435	BERLIN METROPOLITAN GOVERNANCE MODEL: A CASE STUDY IN CONTEMPORARY METROPOLITAN GOVERNANCE	Mustafa Demirkol	Turkey	Submission 169
436-442	COPENHAGEN METROPOLITAN GOVERNANCE MODEL: A CASE STUDY IN CONTEMPORARY METROPOLITAN GOVERNANCE	Mustafa Demirkol	Turkey	Submission 171
443-453	Mechanical And Morphological Properties Of Okro Bast Fibre/Rice Husk Particle Reinforced Unsaturated Polyester Hybrid Composites	Hindatu Idris Umar, Abdullahi Danladi, Nuhu Lawal, Auwal Salisu Yunusa, Umaru Semo Ishiaku, Muhammad Musa Bukhari, Jamila Baba Ali, Ashiru Abdullahi, Nuhu Adam Sulaiman	Nigeria, Nigeria, Nigeria, Nigeria, Nigeria, Nigeria, Nigeria, Nigeria, Nigeria	Submission 172
454-462	Frequency Analysis of Smart Sandwich Nanoplates Incorporating TPMS-Auxetic Core and PZT-4H Face Layers Under Thermal and Electromechanical Loads	Ali Kafali, Mehmet Tayyip Ozdemir, Mustafa Eroğlu, İsmail Esen	Turkey, Turkey, Turkey, Turkey	Submission 177
463-468	MASTEKTOMİ VE DİŞAVURUMCU SANAT TERAPİSİ	Ebru Akköse, Serap Güleç Keskin	Turkey, Turkey	Submission 59
469-476	Aerodynamic Perspectives on Tandem UAV Engines: A Comprehensive Review	Faiq Said, Zeeshan Khan, K. Sunil Kumar	Pakistan, Pakistan, India	Mail Submission 5
477-479	Existence Theorems for a System of Coupled Hybrid Fractional Differential Equations with Erdélyi-Kober Integral Boundary Conditions	Benia Kheireddine, Souid Med Said, Hallouz Ahmed	Algeria, Algeria, Algeria	Submission 10
480-483	Weak Solutions to Nonlinear Hybrid Fractional Differential Equations with Hadamard Integral Boundary Condition	Benia Kheireddine, Souid Med Said, Hallouz Ahmed	Algeria, Algeria, Algeria	Submission 11
484-488	Empathy in Action: Can Motivational Interviewing Improve Quality of Life in Substance Use Disorders ?	Sonila Bitri, Eliona Kulluri Bimbashi, Tea Bitri	Albania, Albania, Albania	Submission 101
489-496	İngilizce Öğretmenleri İçin Üretken Yapay Zekâ (ÜYZ) Okuryazarlığı Ölçeği: Geçerlik ve Güvenirlilik Analizi	Tuba Özgün Çoban, Mustafa Alpsülün, Müge Vuran, Hasan Celal Balıkcı	Turkey, Turkey, Turkey, Turkey	Submission 148
497-502	MİGREN VE OKSİDATİF STRES ARASINDAKİ İLİŞKİ	Kelimetullah GEÇER, Ayşe KESKİN GEÇER, Halit DEMİR	Turkey, Turkey, Turkey	Mail Submission 2
503-507	DİŞ ETİ İLTİHABI İLE OKSİDATİF STRES ARASINDAKİ İLİŞKİ	Kelimetullah GEÇER, Ayşe KESKİN GEÇER, Halit DEMİR	Turkey, Turkey, Turkey	Mail Submission 3
Content of Abstract Papers				
Page No	Title	Authors	Country	Submission ID
1	Isparta ili Keçiborlu ilçesinde oyuntu erozyonu görülen bir sahada mikroprofilmetre ölçüm yöntemi ile erozyonun belirlenmesi	İbrahim DURSUN, Hamza KELEŞ	Turkey, Turkey	Mail Submission 4
2	Insurance as a risk management tool: A study of a sample of Algerian insurance companies during the period 2010–2022	Hamza BACHIRI, Abdelghafour HERIZI, Riyadh ROUABHI	Algeria, Algeria, Algeria	Submission 1
3	Analysis of Host-Guest Interactions: Study of the Complexation of Tetrahydrocurcumin with Hydroxypropyl-β-Cyclodextrin through DFT, Molecular Dynamics, and Docking Techniques.	Mostefai Noria, Abdelkrim Guendouzi, Fatima Yahia Cherif	Algeria, Algeria, Algeria	Submission 2
4	Tensile Characteristics in Composites Laminated : Woven Glass and Woven Carbon Fiber Reinforcements	Adel Deliou, Taqiy Eddine Boukelia, Samir Djimli, Mohamed Kemiha, Khmissi Belkaid, Meriem Dehbi, Abdelkader Fidjah	Algeria, Algeria, Algeria, Algeria, Algeria, Algeria, Algeria	Submission 3
5	Regenerative Braking Optimization for Battery Longevity in Electric Drives	Toufik Sebbagh, Chahinez Beldjaat	Algeria, Algeria	Submission 4
6	A Mathematical Study of Chaotic Motion in the Double Pendulum	Kenza Zaibak, Ahlam Mraouefel	Algeria, Algeria	Submission 5
7	The factors affecting the critical temperature of the q-Bose-Einstein condensation	Lebba Ghenam	Algeria	Submission 7
8	Sensors in Modern Agriculture: Technologies, Applications, and Challenges	Bouthina Rechachi, Khaled Rezeg, Okba Kazar, Miled Zohra Rechachi	Algeria, Algeria, UAE, Algeria	Submission 8
9	Enhancement of Antioxidant Activity through Exogenous Application of Phytohormones: Focus on Indole-3-Acetic Acid (IAA)	BOUZIDI SOUMIA, BOUAMRANE ZINEB, DERBAL NEDJLA, HIMOUR SARAH,	Algeria, Algeria, Algeria, Algeria, Algeria, Algeria	Submission 12

		BELLATAR HAKIMA, YAHIA ABDELOUAHAB		
10	The influence of BAP on the biological activity of some spontaneous plant species	BOUZIDI SOUMIA, BOUAMRANE ZINEB, DERBAL NEDJLA, HIMOUR SARAH, BELLATAR HAKIMA, YAHIA ABDELOUAHAB	Algeria, Algeria, Algeria, Algeria, Algeria, Algeria	Submission 13
11	Enhanced Copper Ion Adsorption from Aqueous Solutions by Chitosan-Based Modification	Asmaa Habibia, Fatiha Zaoui	Algeria, Algeria	Submission 15
12	2-Stratified Cycle Domination in Prisms	Kerem Yamaç	Turkey	Submission 16
13	Blow-Up and Global Existence in a Nonlocal Reaction-Diffusion System	Salim Mesbahi, Samiha Djemai	Algeria, Algeria	Submission 20
14	MAMMALIAN BIODIVERSITY AND ECOSYSTEM HEALTH IN MILA, ALGERIA: INSIGHTS FOR WILDLIFE CONSERVATION AND ENVIRONMENTAL MANAGEMENT	REBBAH abderrauof chouaib, BOUZEGAG Abdelaziz, BOUCHAREB Nouredine, MENNOUR Hocine	Algeria, Algeria, Algeria, Algeria	Submission 21
15	Analysis of a Singular Degenerate Reaction-Diffusion Equation with Gradient Growth	Samiha Djemai, Salim Mesbahi	Algeria, Algeria	Submission 22
16	Enhancement of Uranium Dioxide (UO ₂) Properties through Gd and Ce Doping: A CASTEP First-Principles Study	Faiza Benlakhdar, Idris Bouchama, Mohand Tazerout	Algeria, Algeria, Algeria	Submission 25
17	Optimization of Energy Parameters in PV-Powered Urban Lighting Systems	Khammar farida, Boumous Samira, Boumous Zohir	Algeria, Algeria, Algeria	Submission 29
18	Electromagnetic Characterisation of Dielectrics by Permittivity Calculation	Samia Derbil	Algeria	Submission 33
19	First-Principles Investigation of Noble and Non-Noble Metal Adatoms on Graphyne	R. Masrour	Morocco	Submission 34
20	Mn- and Co-Based Full-Heusler Alloys: Structure, Properties, and Future Applications	R. Masrour	Morocco	Submission 35
21	Dynamic Phase Transitions in Ba ₂ NiWO ₆ Double Perovskites: A Monte Carlo and DFT Study	R. Masrour	Morocco	Submission 36
22	Investigating Task-Oriented Leader' Behavior in Public and Private Universities to Establish the Structure of Quality Improvement	Gulshan Fatima Alvi, Sehrish Khalid, Mahwish Safder	Pakistan, Pakistan, Pakistan	Submission 38
23	Duvar yönlendirme özelliğine sahip bir yanma odasında yakıt enjeksiyon konum açılarının araştırılması	İlker Temizer	Turkey	Submission 40
24	Examining the Relationship Between Principals' Supportive Work Environment Practices and Teacher Burnout in Pakistani Public Schools	Iram Muzzamil, Muqaddas Mehmood	Pakistan, Pakistan	Submission 46
25	CRISPR-Cas9n and Cas12a-Mediated EBNA1 Silencing: A Platform for Broader Microbial Applications	Reha Onur Azizoglu	Turkey	Submission 54
26	Performance of Sand and Activated Carbon in Vertical Flow Constructed Wetlands for Municipal Wastewater Treatment under Arid Conditions	Khouloud BELHADJ, Leila MIMECHE, Lynda HECINI	Algeria, Algeria, Algeria	Submission 56
27	Fuzzy Type-2 Feedback Linearization Control for DFIG-Based Wind Energy Conversion Systems	Kada Boureguig, Fayssal Ouagueni, Salah Soued	Algeria, Algeria, Libya	Submission 57
28	Étude du confinement de l'hydrogène et la fonctionnalisation des nanotubes de carbone	AWGNI Fatima, NASSER Hafida, Abdelhai Rahmani	Morocco, Morocco, Morocco	Submission 64
29	Investigation of LiScNiSi Heusler alloy's physical characteristics under pressure: Use in optoelectronics with the HSE06 hybrid function	Zakaria El Fatouaki, Othmane Zedouh, El Mustapha Hrida	Morocco, Morocco, Morocco	Submission 68
30	Controllability results for impulsive stochastic integro-differential inclusions with infinite delay	Oussama Melati	Algeria	Submission 69
31	Study of the effectiveness of the diisohexanizer and its impact on isomer quality at the Algiers refinery	Harche Rima, Laoufi Nadia Aicha	Algeria, Algeria	Submission 70
32	The Bosonic oscillator DKP in the context of MS noncommutative model	ASMA MERAD	Algeria	Submission 71
33	Comprehensive Energy Rehabilitation in Douirette: Improving Building Performance and Climate Impact	Bencheikroun Marwa, Dalel Kaoula, Baba Slimane Nour El Houda	Algeria, Algeria, Algeria	Submission 73
34	Mitigating Erosion in Cement-Mill Fans through Flow Regime and Blade Angle Optimization	Amour Aissa, Nouredine Aimeur	Algeria, Algeria	Submission 74
35	The Influence of Carbonation on Reinforced Concrete Structures	Ben Ammar Ben Khadda	Algeria	Submission 76
36	Computational Fluid Dynamics in Medicine: Current Applications and Future Perspectives	Mehmet Numan Kaya	Turkey	Submission 77
37	Sustainable Dye Removal with a Prickly Pear Seed Biosorbent: Process Optimization by RSM and a Comparative Outlook for Artificial Intelligence	Amel BELAYACHI-HADDAD, Nouredine BENDERDOUCHE, Benaouda BESTANI, Cherif HADDAD	Algeria, Algeria, Algeria, Algeria	Submission 79
38	Disformal Paths Beyond Horndeski: Frame Transformations and Stability	Fardouse Merzoug	Algeria	Submission 80
39	Aromatic and medicinal plants inventoried from	Nouar Belgacem, Berrabah	Algeria, Algeria, Algeria,	Submission 82

	the Nadhora forest (Tiaret-West Algeria)	Hicham, Maamar Benchohra, Saad Ahmed, Tir Elhadj, Aouadj Sid Ahmed, Rabah Hocine Fadlallah, Nouar Mohamed Amine	Algeria, Algeria, Algeria, Algeria, Algeria	
40	Adaptive Strategies of Vernacular Architecture in Arid Regions: A Sustainable Response to Environmental Stressors	Dalel Kaoula, Bencheikroun Marwa	Algeria, Algeria	Submission 85
41	Study of some physicochemical characteristics of two types of soils M'Ziraa and El-ghrous in the wilaya of Biskra (Algeria)	AISSAOUI Hichem, HIOUANI Fatima	Algeria, Algeria	Submission 88
42	Fırfırlı Kertenkele Optimizasyon Algoritması	Yasin BEKTAŞ	Turkey	Submission 90
43	Elimination of ETL/Perovskite Interface Defects and Charge Transfer Problems in Perovskite Solar Cells with CPTMS Modification	Murat EBIÇ	Turkey	Submission 94
44	Sharp estimates of solution of biharmonic problem on a family of open concave planar sectors	Abdelaziz DOUAH	Algeria	Submission 100
45	Numerical Investigation of the Influence of Angle of Attack on Hydrofoil Hydrodynamic Performance	Ouahrani Massinissa, Ben Amer Hamoudi	Algeria, Algeria	Submission 102
46	A New 4-D Four-Scroll chaotic System: Dynamics analysis, Multistability and Its Circuit Realization	Fareh Hannachi	Algeria	Submission 108
47	Bridging Quantum Mechanics and AI for Hydrogen Storage Innovations	NASSER HAFIDA, AWGNI FATIMA, FATTAH MOHAMED, CHADLI HASSANE	Morocco, Morocco, Morocco, Morocco	Submission 110
48	Tethered Drone Systems: The Critical Role of Electronic Control and Its Impact on Flight Stabilization under Heavy Cable Loads	Tark ÜNLER	Turkey	Submission 111
49	Enhanced Hydrogen Storage Capabilities and AIMD in Y-Decorated [NbS] ₂ TMDs : Insights from a DFT-D3 Computational Analysis	Radouane ASRI, Khuli Mohamed, Nejma Fazouan	Morocco, Morocco, Morocco	Submission 112
50	High-Efficiency Lead-Free NaSiCl ₃ Perovskite Solar Cells: Insights from DFT Calculations and SCAPS-1D Simulations	Selma Rabhi, Oualid Chinoune, Samia Fergani Ouanassa, Houssein Eddine El Yamine Sakhraoui, Yaacoub Ibrahim Bouderbala, Hadjer Bendjilali	Algeria, Algeria, Algeria, Algeria, Algeria, Algeria	Submission 115
51	Study of the inhibition of corrosion of mild steel in an acidic medium by a new synthesized heterocycle and evaluation of its biological activities	Berkane Alaeddine, Ouici Houari Boumediene, Guendouzi Abdelkrim	Algeria, Algeria, Algeria	Submission 118
52	A Numerical Modeling Approach For The Optimization Of Photovoltaic Installations	Khammar farida, Boumous Samira, Boumous Zohir	Algeria, Algeria, Algeria	Submission 119
53	Application of MBAL software for the development of condensate gas reservoir performance at the Oued Noumer field, Algeria	Zakaria Adjou, Djamil Boufades, Souad Hammadou née Mesdour	Algeria, Algeria, Algeria	Submission 122
54	A Hybrid DWT-DCT and Chaotic Filtering Approach for Robust Image Denoising	Boubakeur Latreche, Messaoud Linani, Imadeddin Djadour, Aboubakr Missaoui	Algeria, Algeria, Algeria, Algeria	Submission 123
55	Deep Learning for MRI-Based Medical Image Classification	Oussama Abda, Hilal Naimi	Algeria, Algeria	Submission 125
56	Synthesis, thermal analysis, biological assessment, and in silico studies of novel azo dye-based pyrazolone derivatives	ADDADI Rania, OUCI Houari Boumediene, GUENDOUZI Abdelkri	Algeria, Algeria, Algeria	Submission 126
57	Embedded AI-Powered System for Automated Cash Verification in Retail Operations	Messaoud Linani, Boubakeur Latreche, Said Terfaia, Aboubakr Missaoui, Imadeddin Djadour	Algeria, Algeria, Algeria, Algeria, Algeria	Submission 128
58	HQE in Building Design: Between Challenges and Reality	Baba Slimane Nour El Houda, Bencheikroun Marwa, Dalel Kaoula	Algeria, Algeria, Algeria	Submission 129
59	Dynamical analysis of the Impact of Deep Excavation on Railway Embankment Stability	Ayache RASSOUL, Rafik BOUFARH, Mohamed Lakhdar REDOUANE	Algeria, Algeria, Algeria	Submission 131
60	Reconnecting Education with Global Justice: Building Critical Awareness of Complicity, Power, and Resistance in Development Curricula	Sehrish Khalid, Gulshan Fatima Alvi, Mahwish Safder	Pakistan, Pakistan, Pakistan	Submission 135
61	Effect of irradiation source position and geometry on dose coefficients estimation in external irradiation by photon	Tarik EL GHALBZOURI	Morocco	Submission 140
62	Hydrodistillation Extraction and GC-MS Analysis of Algerian Cyperus rotundus L. Essential Oil	Chaima Belabbes, Farid Benkaci-Ali, Nadia Aicha Laoufi	Algeria, Algeria, Algeria	Submission 151
63	MMSE-Based Channel Shortening for F-OFDM under Extended Vehicular A Channel Conditions	Ouardas Asma, Lahcene Mohamed Rida, Bendjillali Ridha Ilyas, Mouradj Keltoum, Bendelhoum Mohammed Sofiane, Tadjeddine Ali Abderrazak	Algeria, Algeria, Algeria, Algeria, Algeria, Algeria	Submission 154
64	First-Principles Simulation of Hydrogen Storage in Two-Dimensional Materials	Said ELMOUSSAOUI, Mohamed KHULI, El Houssine ATMANI,	Morocco, Morocco, Morocco, Morocco	Submission 155

		Nejma FAZOUAN		
65	Risk-sensitive control problem under G-expectation	Meriyam Dassa	Algeria	Submission 159
66	The Supervisory Powers of the Supreme Authority for Transparency and the Prevention and Combating of Corruption..	taousse ben hamou	Algeria	Submission 160
67	Modeling and Simulation of DC Motor Speed PID Control Using Outseal with LabVIEW Integration	Serhat Küçükdermenci	Turkey	Submission 167
68	Therapeutic Effects of a Polyherbal Formulation on Diabetes-Induced Heart and Spleen Damage in Rats	Tahira Almas, Sajida Batool	Pakistan, Pakistan	Submission 168
69	Should the Posts of Rectors/Vice Chancellors of the Pakistani- Public-Sector Universities be Constitutional Posts?	Syed Arif Kamal	Pakistan	Submission 173
70	Comparing Additive and Multiplicative Attention in CNN-LSTM for Ictal Detection	Mustafa Erginli	Turkey	Submission 175
71	The Impact of Statistical Quality Control on Manufacturing Efficiency: A Conceptual and Empirical Overview	Ayşenur ERDİL	Turkey	Submission 176
72	Particle Breakage in Carbonate Sands: Multiscale Morphological Transformations and Their Geomechanical Implications under High Stress Conditions	Seyf Eddine MESSIOUD, Sadok FEIA, Abdelali DADDA	Algeria, Algeria, China	Submission 179
73	Design and Analysis of PBG Based Microstrip Patch Antennas on ISOLA ASTRA MT77 Substrate for Terahertz Applications	Hamed Abderrahime Bouzid	Algeria	Submission 180
74	Boundary value problems with Caputo Tempered fractional derivative and Infinite Delay in Banach Spaces	Wafaa Rahou	Algeria	Submission 181
75	Power Electronics Interface for Hydrogen Production Using Renewable Energy Sources	Abdelkader BRAHIMI, Mohamed ELBAR	Algeria, Algeria	Submission 184
76	Smart Power Conversion and Control Strategies for Renewable-Based Hydrogen Microgrids	Saliha BRAHIMI, Mohamed ELBAR	Algeria, Algeria	Submission 185
77	QUALITY OF THE NATURAL ENVIRONMENT AND HEALTH	Basti Asadova	Azerbaijan	Mail Submission 1
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79	Parallel Stacking of Quaterthiophene Chains: Impact on Charge Transport and Light Harvesting	Oumaima El ouardi, Brahim Fakrach, Hassane Chadli	Morocco, Morocco, Morocco	Submission 41
80	New lithostratigraphic column of the Pan-African terrains of Eastern Ouzellarh (High Atlas, Morocco)	Abdelfattah ABOULFARAJ, Latifa Aboukassim, Abdelhalim TABIT	Morocco, Morocco, Morocco	Submission 72
81	Adsorptive Removal of organic pollutants from industrial wastewater by adsorption using activated carbon made from sugarcane residue	DJEMMALI Badreddine, CHAABANE Toufik, DAHDOUH Nadjib, HAFSA Haroun	Algeria, Algeria, Algeria, Algeria	Submission 91
82	Evaluation of anti-arthritis potential of Guaiazulene alone and in combination with Methotrexate against adjuvant induced-arthritis and peripheral neuropathy in Wistar rats; A mechanistic approach	Ammara Saleem, Muhammad Furqan Akhtar	Pakistan, Pakistan	Submission 92
83	Fabricated microneedle patches mediated transdermal delivery of 4-methylesculetin for the treatment of adjuvant induced arthritis in Wistar rats; A novel approach	Ammara Saleem, Muhammad Furqan Akhtar	Pakistan, Pakistan	Submission 93
84	Existence and uniqueness for derivative nonlinear fractional integro-differential equations with caputo derivative	Iatime khadidja	Algeria	Submission 95
85	Physicochemical characterization and evaluation of the quality of thermo-mineral waters for irrigation : Case of Hammam Ouled Ali Guelma, North-East Algeria.	Abdelwaheb Benamara, Sihem Hedjal	Algeria, Algeria	Submission 97
86	A Review on Bio-Survival Toxins of Hymenoptera (Arthropoda: Insecta)	A.Kekillioglu	Turkey	Submission 178
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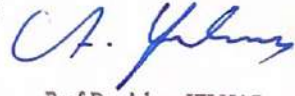
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Random Forest and Boosting Algorithm for Wildfire Prediction based on Time and Environmental Factors

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Abstract – This study comprehensively compares Random Forest and Boosting algorithms for wildfire prediction based on time (day and month) and environmental factors (temperature, relative Humidity, wind speed, precipitation). Both machine learning models were evaluated using various performance metrics (accuracy, precision, sensitivity, F1-Score, MCC, AUC) using the Algerian wildfire dataset. The results show that the Boosting algorithm exhibits a slight superiority in overall test accuracy (89.6%) and high sensitivity in fire class detection (93.3%). On the other hand, the Random Forest model stands out with a higher AUC value (0.978) in predicting fire-free days. The findings suggest that both models have the potential to be reliable components of an operational early warning system, suggesting that model selection will depend on the application's priorities.

Keywords – Wildfire Prediction, Machine Learning, Random Forest, Boosting Algorithm, Time and Environmental Factors

I. INTRODUCTION

Wildfires pose a significant and growing threat to ecosystems, biodiversity, human societies, and economic stability worldwide [1]. The increasing frequency and intensity of these disasters, exacerbated by climate change and human activities, highlight the urgent need for effective forecasting and early warning systems [2]. Accurately predicting fire outbreaks enables proactive resource allocation, timely evacuations, and strategic firefighting, ultimately reducing damage and saving lives. While useful, traditional fire risk assessment methods rely on static indices and may not fully capture the complex, nonlinear interactions among various environmental and temporal factors contributing to fire outbreak and spread. Consequently, there is an urgent demand for more dynamic, accurate, and reliable forecasting models that can process diverse data to provide timely warnings [3]. This study addresses this critical need by exploring the potential for predicting wildfire events using a combination of time-based variables and key environmental parameters.

In recent decades, machine learning has emerged as a powerful paradigm for addressing complex classification and prediction problems in diverse fields, from healthcare to finance [4]. Unlike traditional statistical models, which typically assume linear relationships, machine learning algorithms excel at identifying complex, nonlinear patterns and interactions within large, high-dimensional datasets [5]. Their ability to learn directly from data and make predictions has made them an ideal tool for modeling dynamic and uncertain systems where many factors converge, such as wildfire risk [6]. This flexibility and power have encouraged researchers to develop models beyond traditional indicators such as meteorological conditions, topographic features, and human factors. This study leverages this capacity of machine learning to explore the synergistic use of temporal and environmental data in fire prediction.

Wildfire prediction, at its core, is a classification problem that involves predicting a binary outcome of Fire or no fire [7]. In this context, machine learning offers exceptional value by being trained on historical fire records and critical variables that directly influence fire occurrence and behavior, such as

temperature, relative Humidity, wind speed, and precipitation [8]. These algorithms can learn complex thresholds and interactions that are not readily apparent to human analysis, such as how days with a combination of high temperature and low humidity increase fire probability [9]. They also integrate time-based models, such as seasonal and monthly variations, to enhance forecasts based on current weather conditions and the time of year [10]. This dynamic and multidimensional approach allows for more precise, localized, and timely fire risk assessments, providing actionable intelligence for firefighting organizations and paving the way for more efficient resource allocation [11].

While machine learning encompasses many algorithms, ensemble methods have consistently demonstrated high performance, particularly in forecasting tasks [12]. This study focuses on two of the strongest representatives of these methods: Random Forest and Boosting. Random Forest operates on the principle of bagging, generating multiple decision trees and combining the predictions of each tree to create an overall model [13]. This approach reduces overfitting and increases the model's stability and generalization. Conversely, Boosting follows a fundamentally different strategy: it sequentially trains weak learners (usually shallow decision trees), focusing on examples that the previous model misclassified at each step [14]. This sequential, error-driven learning process allows the model to perform increasingly well on challenging examples. Both algorithms can cope with challenges such as noisy data and complex relationships frequently encountered in wildfire data.

The primary objective of this study is to comprehensively evaluate and compare the performance of Random Forest and Boosting algorithms in wildfire prediction based on time (day and month) and environmental factors (temperature, relative Humidity, wind speed, precipitation). The study was conducted using the Algerian wildfires dataset [8]. The methodology section details the dataset's statistical properties, the variables' monthly change trends, and the theoretical foundations and specific parametric configurations of the applied Random Forest and Boosting algorithms. The results section presents a comprehensive performance comparison of the models using various metrics such as accuracy, precision, sensitivity, F1-Score, Matthews Correlation Coefficient (MCC), and Area Under the Curve (AUC). Complexity matrices and graphical analyses support this. Finally, the conclusion section provides an in-depth interpretation of the findings and discusses each model's strengths and potential applications in the context of practical applications.

II. MATERIALS AND METHOD

This study considered time-based day and month variables, along with environmental factors such as temperature, relative Humidity, wind speed, and precipitation, as independent variables for wildfire prediction. The dependent variable was fire status (Fire and not Fire) in forested areas. By coding the dependent variable as binary in the analyses, fire days were assigned a value of 1, and non-fire days were assigned a value of 0. The study data cover the year 2012 and were obtained from <https://archive.ics.uci.edu/dataset/547/algerian+forest+fires+dataset>. Year, location, and index data in the original data set are excluded from this study. Only June (6), July (7), August (8), and September (9) were considered as monthly data. **Table 1** presents descriptive statistics for the dependent and independent variables.

Table 1. Descriptive statistics of variables.

Outputs	Inputs	Valid	Mean	Variance	Skewness	Kurtosis	Range	Minimum	Maximum
Fire	Day	137	17.336	67.769	-0.145	-1.142	29.00	2	31
Not Fire		106	13.726	85.020	0.275	-1.161	30.00	1	31
Fire	Month	137	---	---	---	---	---	6	9
Not Fire		106	---	---	---	---	---	6	9
Fire	Temperature (C)	137	33.796	8.546	-0.028	-0.011	16.00	26	42
Not Fire		106	30.028	11.190	0.017	-0.125	17.00	22	39
Fire	Relative Humidity (%)	137	56.416	202.568	-0.103	-0.489	67.00	21	88
Not Fire		106	69.311	149.740	-0.236	-0.912	48.00	42	90
Fire	Wind speed (km/h)	137	15.321	5.323	-0.221	0.292	13.00	8	21
Not Fire		106	15.717	11.233	0.751	2.326	23.00	6	29
Fire	Rain (mm)	137	0.096	0.296	9.810	104.250	6.00	0	6
Not Fire		106	1.625	7.536	3.102	11.571	16.80	0	16.8

The descriptive statistics presented in **Table 1** show significant differences between wildfire and non-wildfire days. While the average temperature on wildfire days ($n=137$) was 33.8°C , this value decreased to 30.0°C on non-wildfire days ($n=106$). Similarly, the average relative Humidity increased from 56.4% on wildfire days to 69.3% . One of the most striking differences is seen in the precipitation data; the average precipitation on wildfire days was 1.63 mm , while on non-wildfire days it was only 0.10 mm . Mean wind speeds were similar in both cases (Fire: 15.32 km/h , No-Fire: 15.72 km/h). Examining the distributional characteristics of the variables, it is evident that the precipitation variable, in particular, exhibited extreme right skewness (skewness = 9.81) and sharpness (kurtosis = 104.25) on wildfire days. This suggests that there is mostly no precipitation on fire days, but occasional extreme precipitation events reach high values. The mean values and variances for the Day variable in the Fire and non-fire groups (17.3 and 13.7 , respectively) indicate that the data set is not homogeneously distributed over time.

Figure 1 shows the monthly average weather parameters changes for the four months examined (June-September). The first graph shows that monthly average temperatures start around 32°C in June, peak above 35°C in July and August, and then decline again in September. This coincides with periods of higher fire probability. The second graph shows the change in relative Humidity, with the lowest average humidity values (below 50%) recorded in July and August, when fire activity is highest. The third graph, showing the distribution of precipitation, shows a relative increase in June and September, but a significant decrease in precipitation in July and August. The final graph shows that wind speed follows a relatively more stable pattern across months, but shows a slight increase in August. The monthly changes in these parameters reveal that high temperatures, low Humidity, and low precipitation are critical factors that increase fire risk.

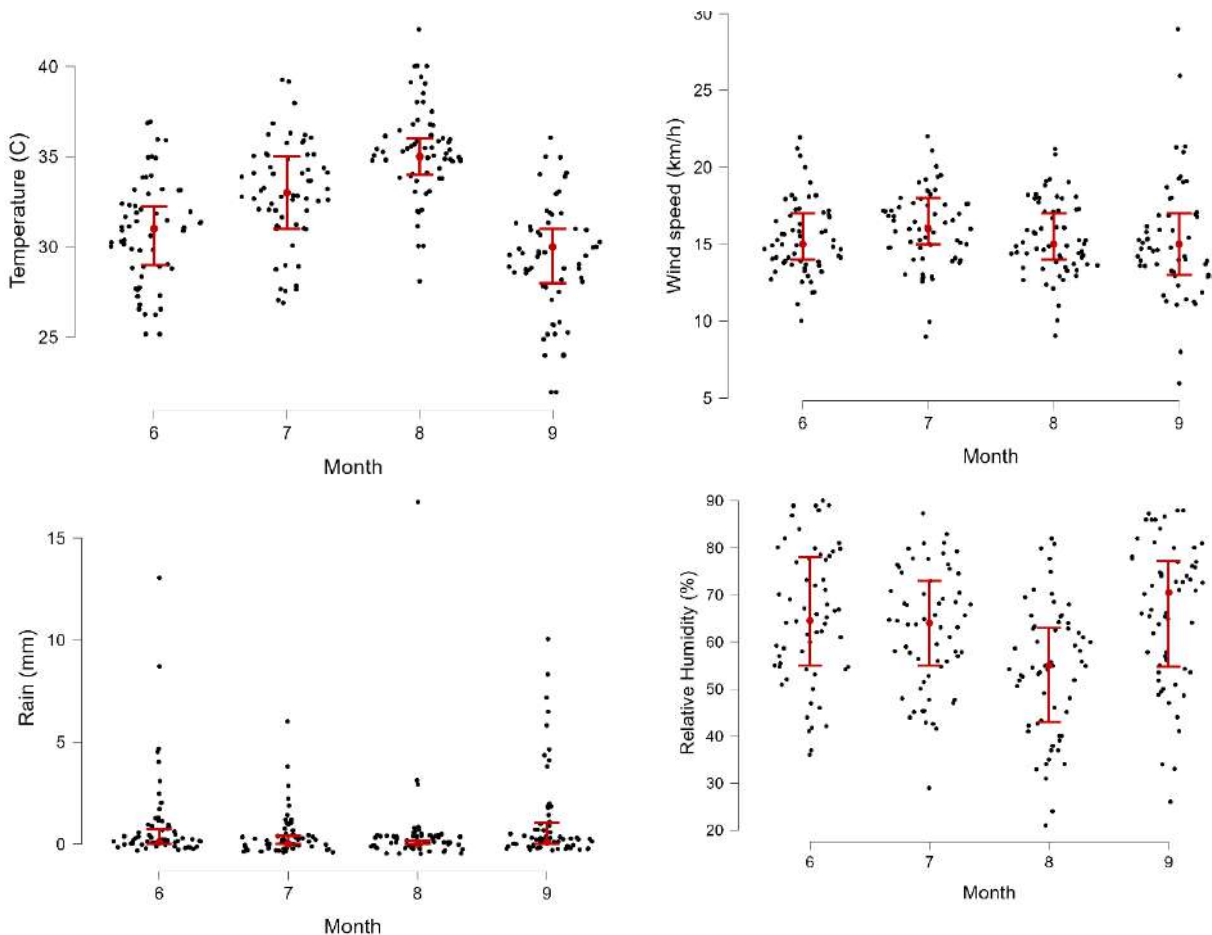


Figure 1. Changes in monthly weather parameters

Random Forest (RF) and Boosting algorithms, which are strong representatives of ensemble methods, were selected as machine learning models. Random Forest is a bagging method that creates multiple decision trees and combines the predictions of each tree [15]. This method uses random subsets and random feature selection to train each tree to reduce overfitting. It also provides a natural evaluation of model performance on an Out-of-Bag (OOB) dataset. This study optimized the model using 70 trees and considering two features at each split. The Boosting algorithm, on the other hand, is a method that sequentially trains weak learners (usually shallow decision trees) and focuses on the errors of the previous model at each step [16]. This allows the model to perform progressively better on complex examples. The boosting model used in this study was constructed using 15 trees, a 0.1 learning rate (shrinkage), and two features at each split.

The performance of the models was evaluated using various metrics, including accuracy, precision, recall, F1-Score, Matthews Correlation Coefficient (MCC), and Area Under the Curve (AUC). These metrics are important for measuring not only the overall accuracy of a model but also its reliability in cases of imbalance between classes. The AUC value, in particular, is a general measure of the model's ability to distinguish between positive and negative classes. Model training and calculating all these performance metrics were performed using JASP, a user-friendly statistical software program. Consequently, this section details the dataset used for wildfire prediction, the statistical properties of the variables, and their monthly change trends. The theoretical foundations of the Random Forest and Boosting algorithms applied in this study are explained, as are the specific parametric configurations. The following section presents and discusses the results obtained within the framework of this methodology.

III. RESULTS

The main objective of this study is to comprehensively evaluate and compare the performances of Random Forest and Boosting algorithms in wildfire prediction based on time and environmental factors. During the model development process, the dataset was divided into training (64%), validation (16%), and test (20%) subsets. Hyperparameter optimization of the models was performed based on Out-of-Bag (OOB) accuracy. This section presents a detailed comparison of both models based on their configuration parameters, classification performance metrics, complexity matrices, and graphical analyses, and discusses the findings in depth.

Table 2 summarizes both machine learning algorithms' optimized configurations and key performance results. The Random Forest model was built using 70 decision trees and two features per split, achieving a high OOB accuracy of 0.955. The Boosting algorithm was built using 15 trees, a 0.1 learning rate (shrinkage), and two features per split. In the performance comparison, the Boosting algorithm achieved a higher accuracy on both the validation set (0.872) and the test set (0.896) compared to Random Forest (0.821 and 0.875, respectively). These results show that Boosting has a slight superiority in overall classification performance.

Table 2. The features of ML algorithms

Features*	Random Forest	Boosting
Trees	70	15
Features per split	2	
Shrinkage		0.1
n(Train)	156	156
n(Validation)	39	39
n(Test)	48	48
Validation Accuracy	0.821	0.872
Test Accuracy	0.875	0.896
OOB Accuracy	0.955	

*The model is optimized with respect to the out-of-bag accuracy

Table 3 presents detailed performance metrics for the Random Forest model by class. The model produced near-perfect precision (precision = 1.000) for the No Fire (0) class, while this value was 0.806 for the Fire (1) class. Conversely, the model's recall was 1.000 for the Fire class and 0.739 for the No Fire class. This demonstrates that the model successfully detects fire days (True Positive Rate), but performs relatively poorly in identifying fire-free days (True Negative Rate). The model's F1-Score was 0.872, the Matthews Correlation Coefficient (MCC) was 0.772, and the Area Under Curve (AUC) was 0.978.

Table 3. The performance metrics values of Random Forest

Metrics	Not Fire (0)	Fire (1)	Average / Total
Support	23.000	25.000	48.000
Accuracy	0.875	0.875	0.875
Precision (Positive Predictive Value)	1.000	0.806	0.899
Recall (True Positive Rate)	0.739	1.000	0.875
False Positive Rate	0.000	0.261	0.130
False Discovery Rate	0.000	0.194	0.097
F1 Score	0.850	0.893	0.872
Matthews Correlation Coefficient	0.772	0.772	0.772
Area Under Curve (AUC)	0.986	0.970	0.978
Negative Predictive Value	0.806	1.000	0.903
True Negative Rate	1.000	0.739	0.870
False Negative Rate	0.261	0.000	0.130
False Omission Rate	0.194	0.000	0.097
Threat Score	2.833	2.083	2.458
Statistical Parity	0.354	0.646	1.000

Table 4 shows the performance metrics of the Boosting algorithm. Boosting exhibited a more balanced precision and sensitivity profile across classes than Random Forest. For the No Fire class, precision was 0.867 and sensitivity was 0.722; for the Fire class, precision was 0.848 and sensitivity was 0.933. This demonstrates that, unlike Random Forest, the Boosting model can predict the No Fire class with high accuracy and is also very strong at detecting the Fire class (0.933 recall). The model's overall F1-Score is 0.851, its MCC is 0.685, and its AUC is 0.957.

Table 4. The performance metrics values of the Boosting Algorithm

Metrics	Not Fire (0)	Fire (1)	Average / Total
Support	18.000	30.000	48.000
Accuracy	0.854	0.854	0.854
Precision (Positive Predictive Value)	0.867	0.848	0.855
Recall (True Positive Rate)	0.722	0.933	0.854
False Positive Rate	0.067	0.278	0.172
False Discovery Rate	0.133	0.152	0.142
F1 Score	0.788	0.889	0.851
Matthews Correlation Coefficient	0.685	0.685	0.685
Area Under Curve (AUC)	0.957	0.957	0.957
Negative Predictive Value	0.848	0.867	0.858
True Negative Rate	0.933	0.722	0.828
False Negative Rate	0.278	0.067	0.172
False Omission Rate	0.152	0.133	0.142
Threat Score	1.444	2.333	1.889
Statistical Parity	0.313	0.688	1.000

Table 5 presents the complexity matrices for both algorithms, clearly visualizing the class distribution of predictions. The Random Forest model correctly predicted 17 of 23 No Fire observations and incorrectly predicted 6; and correctly predicted all 25 Fire observations. The Boosting algorithm correctly predicted 13 of 18 No Fire observations and incorrectly predicted 5; and correctly predicted 28 of 30 Fire

observations and incorrectly predicted 2. These matrices numerically confirm that Random Forest has excellent sensitivity for the Fire class, while Boosting exhibits a more balanced error distribution for both classes.

Table 5. Confusion matrix of algorithms

Algorithms			Predicted	
			0 (Not Fire)	1 (Fire)
Random Forest	Observed	0 (Not Fire)	17	6
		1(Fire)	0	25
Boosting Algorithm	Observed	0 (Not Fire)	13	5
		1(Fire)	2	28

Figure 2 shows the models' Receiver Operating Characteristic (ROC) curves. Both curves are close to the upper left corner, thus confirming the high classification ability of both models. With an AUC value of 0.978, the Random Forest model achieved a slight advantage in this metric compared to the Boosting algorithm's 0.957. This result indicates the model's strength in distinguishing positive and negative classes.

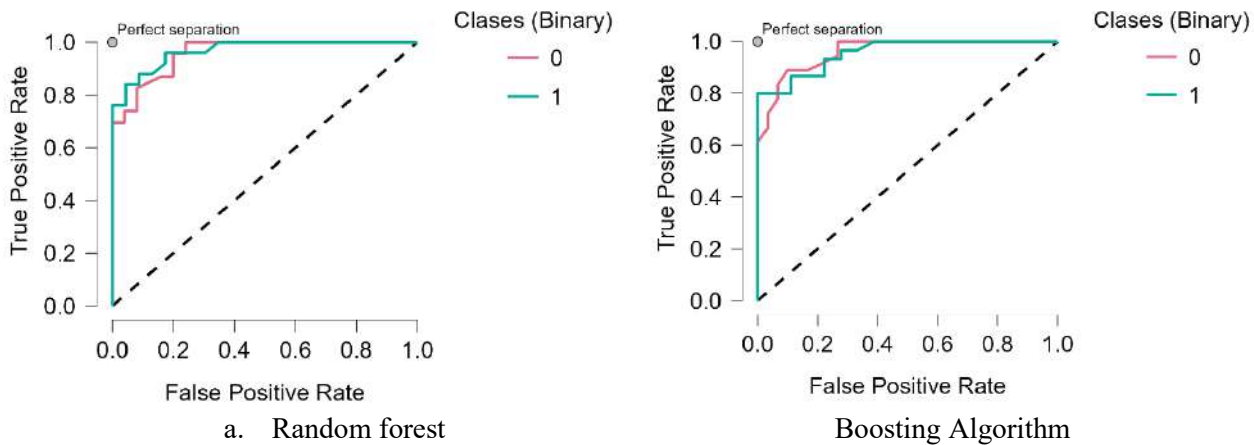


Figure 2. A receiver operating characteristic curve for algorithms

Figure 3 represents the improvement curves for the models' OOB errors. In the Random Forest model, the OOB error decreases rapidly as the number of trees increases, reaching a stable level after a certain point (approximately 20-30 trees). This indicates that the model converges well with 70 trees, and that additional trees will not contribute significantly. The Boosting algorithm, however, uses a smaller ensemble of 15 trees, and the error rate is observed to be similarly optimized.

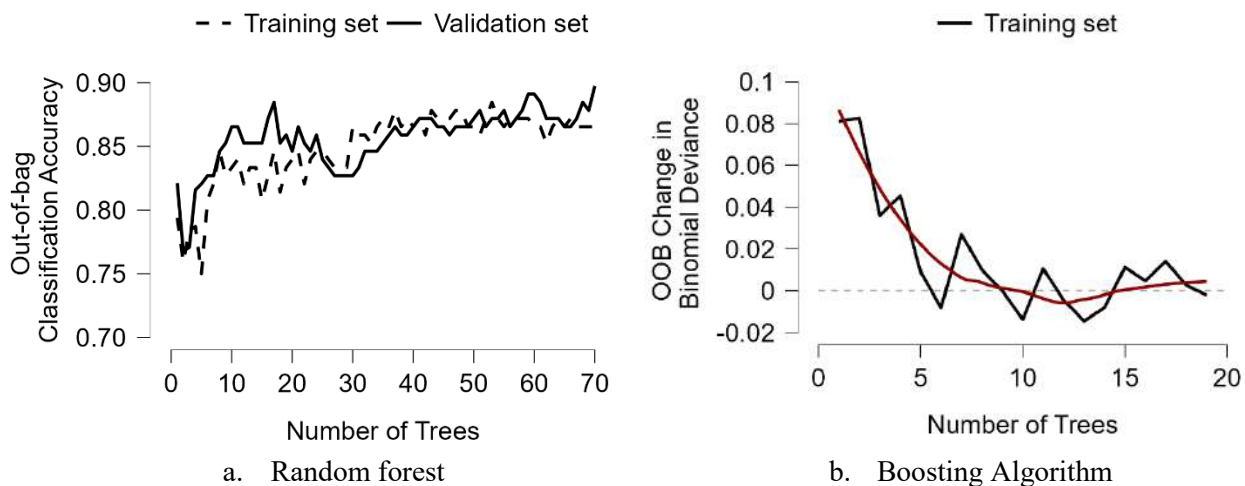


Figure 3. Out-of-bag Improvement Plot for algorithms

Overall, all the numerical findings and graphical analyses presented in this section support the position of both Random Forest and Gradient Boosting algorithms as highly effective tools for wildfire prediction. The Boosting algorithm stands out with its overall test accuracy and high sensitivity in detecting the Fire class. In contrast, the Random Forest model stands out with metrics such as higher AUC, superior precision in the No Fire class, and a more balanced MCC value. The model chosen will depend on the application's objectives: if the priority is to avoid fires as much as possible, Boosting may be a more suitable option, while if the priority is to reduce false alarm rates, Random Forest may be a more suitable option. Both models could be reliable components of an operational early warning system when using the available dataset and features.

IV. CONCLUSION

This study demonstrates the effectiveness of Random Forest and Boosting algorithms in wildfire prediction. The Boosting algorithm stands out in terms of its overall fire classification accuracy. In contrast, the Random Forest model stands out with its exceptional accuracy in identifying fire-free days and more balanced metrics. Model performance demonstrates that both methods can produce practically applicable, accurate, and reliable forecasts with the available dataset and selected features. The choice of model will depend on the specific objectives of the application: if the priority is to avoid missing fires as much as possible, Boosting may be a more suitable option, while if the priority is to minimize false alarm rates, Random Forest may be a more suitable option. This study contributes to developing machine learning-based fire prediction systems and lays the groundwork for future research.

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Aerodynamic Resistance in Land Vehicles: Comparative CFD and Experimental Analysis

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Abstract –This study investigates the effect of aerodynamic resistance on land vehicles and provides both numerical and experimental analyses. Two different vehicle prototypes were examined to evaluate their aerodynamic structures and drag forces under varying wind conditions. Computational Fluid Dynamics (CFD) simulations were carried out using ANSYS Fluent to calculate the drag force for each prototype. To validate the numerical results, a simple experimental setup was designed. A closed-section wind tunnel was constructed with plates and a volute fan, while load cell sensors integrated with an Arduino system were employed to measure the drag force acting on the models. The airflow velocity was calculated based on the volumetric flow rate and cross-sectional area of the tunnel, and the experimental results were compared with simulation outputs. The prototypes and several tunnel components were fabricated using PLA material on a 3D printer to reduce cost and ensure manufacturing feasibility. Additional equipment such as the fan, sensors, and electronic circuits were commercially sourced. The comparative analysis demonstrated significant differences between experimental and simulated values, highlighting challenges in scaling and accuracy when testing small prototypes. Nonetheless, the study emphasizes the importance of aerodynamic optimization in reducing drag forces, improving fuel efficiency, and enhancing vehicle performance. The findings contribute to the understanding of how simplified wind tunnel setups can complement CFD analyses in educational and research contexts, while also revealing limitations that must be considered in future work.

Keywords – Aerodynamics, Drag Force, Computational Fluid Dynamics, Wind Tunnel, Vehicle Design.

I. INTRODUCTION

Road vehicles are among the most widely used means of transportation and remain at the center of industrial and academic research. As vehicles move, they are subjected to various resistance forces, of which aerodynamic drag is one of the most significant. Aerodynamics, defined as the study of the interaction between air and solid bodies, plays a crucial role in determining vehicle performance, fuel consumption, stability, noise, and overall driving comfort. Reducing drag forces has become a primary objective for automotive manufacturers seeking to enhance energy efficiency and competitiveness in an increasingly demanding market.

Traditional methods for analyzing vehicle aerodynamics include road testing and wind tunnel experiments. While road testing offers realistic environmental conditions, it is often costly, time-consuming, and sensitive to uncontrollable external factors. Wind tunnel testing, on the other hand, provides a controlled environment but may require large-scale facilities and significant resources, particularly when testing full-scale vehicles. As a result, numerical approaches such as Computational Fluid Dynamics (CFD) have gained prominence. CFD tools allow researchers and engineers to evaluate air flow patterns, pressure distributions, and drag coefficients at lower cost and with greater flexibility, even before physical prototypes are built [1].

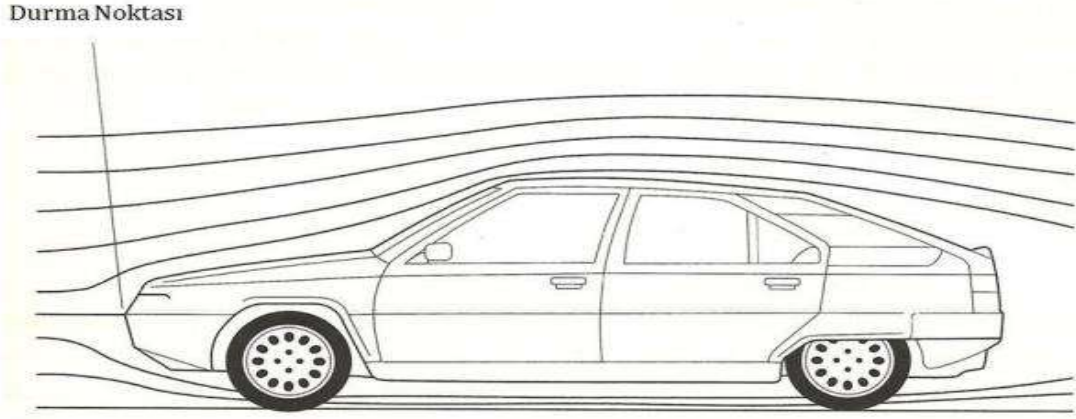


Fig. 1 Streamlines flowing around the car

Streamlines are diagrams that show the instantaneous directions of fluid motion throughout a flow field. They are quite useful in this regard. Regions of continuous circulation and separation of fluid from a solid wall can be easily identified using streamline patterns. The distance between streamlines reflects the airflow characteristics of the region in which they are located. This allows us to interpret regional velocity and pressure values (Figure 1).

This study focuses on analyzing the aerodynamic characteristics of two vehicle prototypes through both CFD simulations and simplified experimental validation. The objectives are to determine drag forces under different wind conditions, compare numerical and experimental outcomes, and highlight the potential and limitations of combining digital and physical approaches. The research also underscores how cost-effective, small-scale experiments can complement advanced simulations in both educational and industrial contexts [2].

II. MATERIALS AND METHOD

Two prototype vehicles, representing different geometrical configurations, were designed and analyzed to evaluate aerodynamic resistance. The study employed a dual methodology: computational simulations using ANSYS Fluent and experimental testing with a custom-built wind tunnel.

Prototype Design and Fabrication: The vehicle models were scaled down and fabricated using a 3D printer with polylactic acid (PLA) filament. This approach ensured cost efficiency, dimensional consistency, and the ability to quickly modify designs. Each prototype was designed to highlight distinct aerodynamic characteristics, allowing comparison between vehicle types [3].

Computational Simulations: CFD analyses were performed using ANSYS Fluent. The computational domain included a virtual wind tunnel setup where airflow velocities were varied to simulate different operating conditions. Boundary conditions were applied to replicate realistic flow behavior, and the drag coefficients (C_d) were extracted for both prototypes. Mesh sensitivity tests were conducted to ensure numerical accuracy [4].

Experimental Setup: A simplified wind tunnel was constructed using four plates to create a closed flow section. A volute (snail-type) fan was used to generate airflow. Load cells connected to an Arduino microcontroller were employed to measure the drag force exerted on the prototypes. The air velocity inside the tunnel was calculated based on the volumetric flow rate and tunnel cross-sectional area ($20 \text{ mm} \times 20 \text{ mm}$). This allowed direct comparison with the CFD-predicted velocities [5].

Measurement and Data Acquisition: The load cell system was calibrated using reference weights, ensuring accurate force measurements. The Arduino system collected data continuously, which was filtered and averaged to eliminate noise. The airflow velocity was cross verified by combining volumetric flow data with the tunnel's cross-sectional dimensions. Experimental drag forces were compared with CFD outputs to assess consistency and identify deviations [6].

Cost and Practical Considerations: Most of the wind tunnel structure and prototypes were 3D-printed to minimize cost and maximize flexibility in design modifications. Components such as fans, sensors, and electronic circuits were procured from commercial suppliers. This hybrid methodology enabled the study to maintain a balance between practicality and scientific rigor [7].

The combined computational and experimental approach provided a comprehensive understanding of aerodynamic resistance in simplified vehicle models, while also highlighting the limitations of small-scale experimental setups [8].

A. Experimental Setup

The experimental arrangement included two distinct vehicle models: a minibus prototype and a sports car prototype. These models were placed inside the custom-built mini wind tunnel, which consisted of four acrylic plates forming a rectangular test section. The volute fan provided steady airflow through the tunnel and drag forces acting on each prototype were measured using the Arduino–load cell system. This setup enabled direct observation of how geometric differences between a commercial-type minibus and a streamlined sports car influence aerodynamic resistance, See Fig. 2.



Fig. 2 Vehicle prototypes used in the experimental setup, mini wind tunnel (load cell setup) and snail fan

III. RESULTS

The experimental and computational analyses produced distinct outcomes for the two vehicle prototypes. The **minibus prototype**, characterized by its larger frontal area and less streamlined geometry, exhibited higher drag coefficients and greater measured drag forces. In contrast, the **sports car prototype**, with its aerodynamic design and reduced frontal area, showed significantly lower drag values in both CFD simulations and wind tunnel measurements.

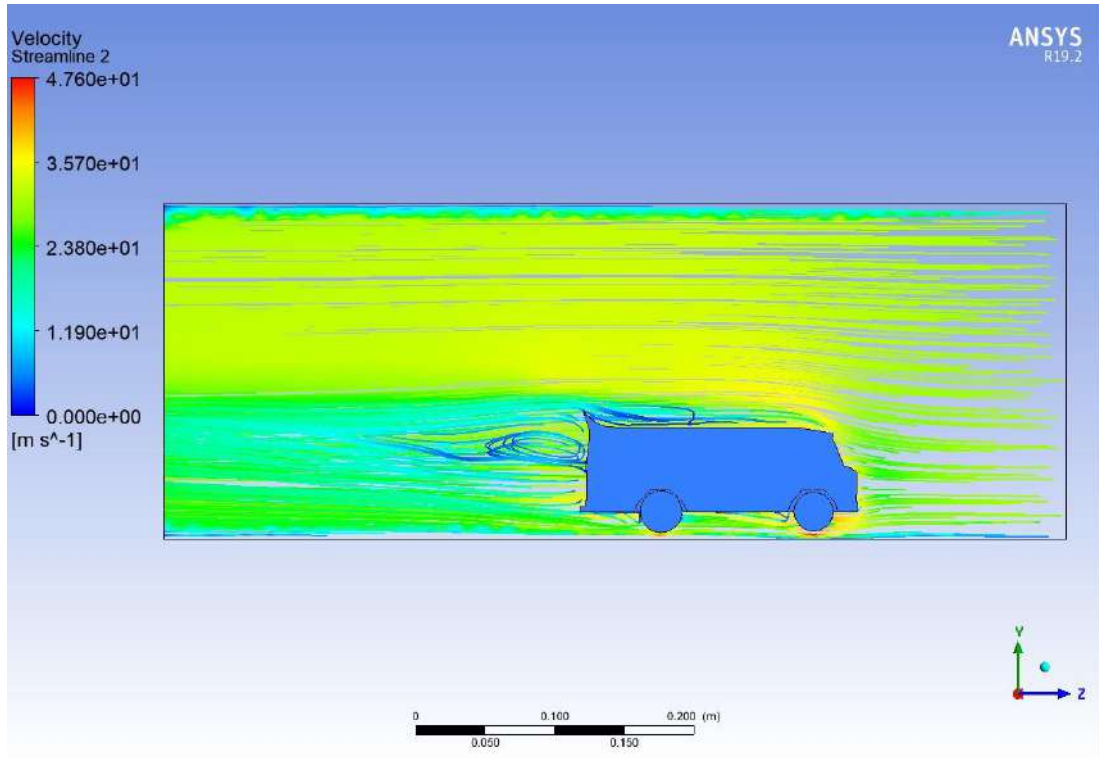


Fig. 3 Turbulence simulation resulting from minibus wind analysis

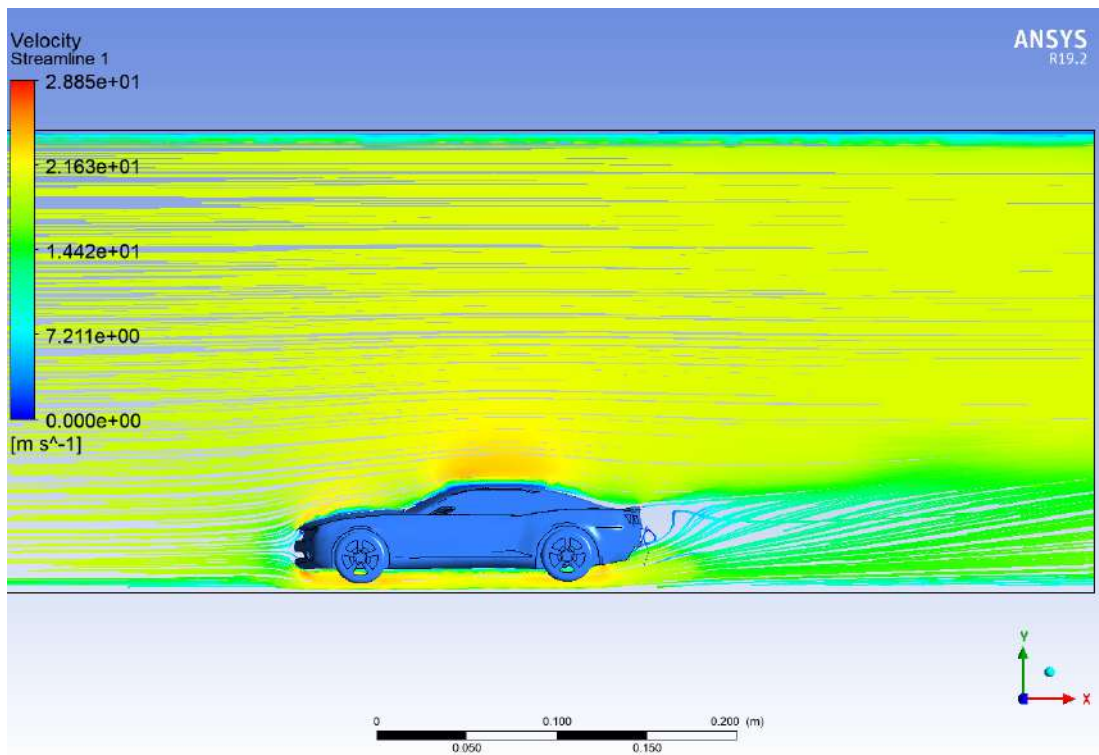


Fig. 4 Turbulence simulation resulting from sports car wind analysis

CFD simulations predicted drag coefficients of approximately $Cd = 0.86$ for the minibus model and $Cd = 0.36$ for the sports car model under similar flow conditions. Experimental results, however, revealed noticeable discrepancies compared to the simulations. While the sports car prototype demonstrated drag forces close to the predicted values, the minibus prototype showed larger deviations, highlighting the scaling limitations of the small wind tunnel setup.

The mini wind tunnel provided qualitative confirmation of the aerodynamic differences between the two prototypes, though absolute values were influenced by tunnel size, fan performance, and measurement sensitivity. Despite these limitations, the comparative analysis confirmed the expected trend: vehicles with streamlined geometries experience significantly reduced aerodynamic resistance compared to bulkier designs.

IV. DISCUSSION

The results demonstrate that vehicle geometry is the primary determinant of aerodynamic performance. The higher drag coefficient of the minibus prototype can be attributed to its box-shaped design and larger frontal area, which promote flow separation and turbulence. In contrast, the streamlined shape of the sports car prototype facilitated smoother airflow, resulting in reduced drag and more efficient aerodynamic behavior.

The discrepancies between CFD predictions and experimental measurements highlight the challenges of small-scale wind tunnel testing. Limitations such as restricted tunnel dimensions, fan-induced turbulence, and sensor sensitivity contributed to deviations in measured values. Nevertheless, the experiments effectively illustrate the relative differences between the two vehicle types, validating the overall trends predicted by CFD.

This combined approach reinforces the value of integrating computational tools with simplified physical models. While CFD provides detailed insights into flow characteristics, experimental setups allow students and researchers to visualize airflow phenomena and gain practical experience in aerodynamic testing. For industry applications, the findings underline the necessity of refining prototype testing methods and scaling considerations to achieve more accurate predictions.

Ultimately, the study emphasizes that reducing aerodynamic drag is crucial for improving vehicle performance, enhancing fuel efficiency, and supporting sustainability goals in the transportation sector.

V. CONCLUSION

This study evaluated the aerodynamic performance of a minibus and a sports car prototype through CFD simulations and small-scale experimental testing. The findings confirmed that streamlined vehicle geometries significantly reduce aerodynamic resistance compared to bulkier designs. Although discrepancies were observed between numerical and experimental results, the general trends were consistent, validating the complementary use of CFD and wind tunnel experiments.

The research highlighted the potential of low-cost, 3D-printed models and mini wind tunnel setups as effective tools for educational purposes and preliminary aerodynamic assessments. However, scaling effects and measurement limitations must be carefully addressed to improve experimental accuracy. Future studies could focus on enhancing tunnel design, employing advanced sensors, and expanding prototype diversity to strengthen the correlation between computational and experimental outcomes.

In conclusion, the integration of computational and experimental approaches provides valuable insights into vehicle aerodynamics, supports the development of more efficient vehicle designs, and contributes to broader efforts in energy conservation and sustainable transportation.

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Aluminum-Based Sandwich Structures in Aircraft

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Abstract – Aluminum-based sandwich structures have attracted significant attention in the aerospace industry due to their lightweight properties, high strength-to-weight ratio, and exceptional structural performance. This paper investigates the engineering advancements, design principles, manufacturing techniques, and applications of aluminum-based sandwich structures in aircraft construction.

Keywords – Aluminum Alloys, Sandwich Structures, Lightweight Materials, Aircraft Structures, Advanced Materials.

I. INTRODUCTION

Aluminum alloys and aluminum-based sandwich structures stand as indispensable components in modern aircraft design, embodying the pursuit of lightweight construction, structural integrity, and operational efficiency. As aerospace engineering continually evolves, the quest for materials that can withstand the rigors of flight while minimizing weight remains paramount. In this paper, we focus on a comprehensive exploration of aluminum alloys and aluminum-based sandwich structures, elucidating their pivotal roles, engineering principles, manufacturing techniques, properties, and diverse applications within the aerospace industry.

Aircraft design necessitates materials that exhibit a delicate balance of strength, stiffness, durability, and weight considerations. Aluminum alloys, renowned for their remarkable combination of properties, have emerged as primary contenders in the aerospace realm. These alloys, derived from aluminum as the base metal with the addition of alloying elements such as copper, magnesium, zinc, and silicon, offer exceptional strength-to-weight ratios, corrosion resistance, machinability, and weldability. Such attributes render aluminum alloys ideal for a multitude of aircraft components, ranging from fuselage structures and wing panels to engine components and landing gear assemblies [1].

In parallel, aluminum-based sandwich structures have revolutionized aircraft construction methodologies, embodying innovative engineering concepts to achieve optimal strength, stiffness, and weight reduction. Sandwich structures comprise thin face sheets bonded to a lightweight core material, facilitating a structural configuration that optimally distributes loads while minimizing weight. The core materials, which may include foam, honeycomb, or composite materials, provide internal support and stiffness, enhancing the overall structural integrity of the sandwich panel. The application of aluminum-based sandwich structures in aircraft design represents a paradigm shift in aerospace engineering, offering unparalleled advantages in terms of weight reduction, aerodynamic performance, fuel efficiency, and structural robustness. From wings and fuselage sections to interior partitions and flooring panels, aluminum-based sandwich structures permeate various facets of aircraft construction, contributing to enhanced operational capabilities, safety, and sustainability [1], [2].

As introducing with the aluminum alloys and aluminum-based sandwich structures, we uncover a myriad of engineering intricacies, manufacturing techniques, material properties, and design considerations that underscore their significance in contemporary aerospace engineering. From the inception of alloy development and material selection to the intricacies of manufacturing processes and structural analysis, the integration of aluminum alloys and sandwich structures embodies the synergy

between advanced materials science, engineering innovation, and aerospace technology. Moreover, the exploration of aluminum alloys and sandwich structures transcends mere technicalities; it embodies a testament to human ingenuity, perseverance, and the relentless pursuit of excellence in aerospace engineering. Through collaborative research endeavors, interdisciplinary collaborations, and technological advancements, the aerospace industry continues to push the boundaries of possibility, unlocking new horizons and ushering in an era of unprecedented innovation and exploration.

II. DESIGN PRINCIPLES AND MANUFACTURING TECHNIQUES

Aluminum-based sandwich structures consist of two thin aluminum face sheets bonded to a lightweight core material, forming a sandwich-like configuration. The core material, often made of foam, honeycomb, or composite materials, provides stiffness and strength while minimizing weight. The design principles aim to optimize the distribution of loads, enhance structural integrity, and maximize stiffness while minimizing overall weight. Fig. 1. Shows aluminum based sandwich structures with honeycomb cores.

Several manufacturing techniques are employed to produce aluminum-based sandwich structures, including adhesive bonding, vacuum bagging, and autoclave curing. Advanced manufacturing processes such as automated fiber placement (AFP) and resin transfer molding (RTM) enable precise control over material placement and composite properties, resulting in superior structural performance and dimensional accuracy [3].



Fig. 1 Aluminum based sandwich structures with honeycomb cores [4]

III. STRUCTURAL PROPERTIES AND APPLICATIONS IN AIRCRAFT CONSTRUCTION

Aluminum-based sandwich structures offer exceptional mechanical properties, including high stiffness, strength, and impact resistance. These structures exhibit excellent fatigue resistance and durability, making them suitable for aerospace applications where reliability and performance are paramount. The lightweight nature of aluminum-based sandwich structures contributes to fuel efficiency and operational cost savings while maintaining structural integrity and safety.

Aluminum-based sandwich structures find extensive use in aircraft construction, particularly in components such as wings, fuselage panels, floor panels, and interior partitions. These structures enable significant weight reduction without compromising structural integrity or safety standards. Additionally, aluminum-based sandwich structures contribute to improved aerodynamic performance, fuel efficiency, and overall aircraft performance [5], [6].

IV. CONCLUSIONS

Aluminum-based sandwich structures represent a significant advancement in aircraft construction technology, offering lightweight, durable, and efficient solutions for aerospace applications. The integration of advanced manufacturing techniques, innovative materials, and optimized design principles continues to drive the evolution of aluminum-based sandwich structures in aircraft engineering. By addressing current challenges and embracing emerging technologies, aluminum-based sandwich structures will play a pivotal role in shaping the future of aerospace innovation and sustainability.

Future research in aluminum-based sandwich structures aims to enhance manufacturing efficiency, develop novel core materials, and optimize structural designs for specific aerospace applications. Challenges include reducing production costs, improving material recyclability, and addressing

environmental concerns associated with manufacturing processes. Furthermore, advancements in computational modeling and simulation techniques facilitate the design optimization and performance prediction of aluminum-based sandwich structures.

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Laminated Composites in Aircraft Applications

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Abstract – The aerospace industry is constantly striving to identify and implement materials that deliver outstanding mechanical performance while simultaneously contributing to a reduction in the overall weight of aircraft structures. Among the most promising materials, laminated composite materials have become integral to modern aircraft design due to their high strength-to-weight ratio, corrosion resistance, and design flexibility. This paper overviews the fundamentals of laminated composites, discussing their material constituents, manufacturing processes, and current applications in aerospace structures.

Keywords – Laminated Composites, Polymeric Materials, Lightweight Structures, Aircraft Applications, Advanced Materials.

I. INTRODUCTION

The aviation industry is constantly striving to identify and implement materials that deliver outstanding mechanical performance while simultaneously contributing to a reduction in the overall weight of aircraft structures. Among the most promising solutions are laminated composites, which are engineered materials composed of multiple bonded layers of fiber-reinforced polymers (FRPs). These layered structures allow for a high degree of customization in terms of strength, stiffness, and resistance to environmental factors. By carefully selecting the type, orientation, and sequence of fiber layers, engineers can tailor the mechanical properties of laminated composites to meet the specific demands of various aircraft components. This unique ability to optimize material performance in targeted directions makes laminated composites particularly advantageous compared to conventional metallic alloys traditionally used in aerospace engineering [1].

Laminated composites have become key materials in the design and manufacture of both primary and secondary aircraft structures. Their applications span across critical components such as fuselage panels, wing skins, spars, and control surfaces, as well as non-structural elements including fairings, interior panels, and flooring systems. The integration of these advanced materials not only reduces fuel consumption through weight savings but also enhances the overall durability, corrosion resistance, and fatigue performance of modern aircraft, contributing significantly to improved efficiency and lower operating costs [2].

II. MATERIAL CONSTITUENTS

Laminated composites are composed of layers (plies) of fibers embedded in a polymeric matrix. The fibers, typically carbon, glass, or aramid, provide strength and stiffness, while the matrix binds the fibers and transfers loads between them. By orienting plies at different angles, designers can customize the in-plane and out-of-plane properties to meet specific structural requirements. Furthermore, the stacking sequence, ply thickness, and fiber volume fraction can be varied to optimize the laminate for factors such as buckling resistance, impact tolerance, and vibration damping, making laminated composites versatile and highly adaptable to demanding aerospace conditions.

Fibers provide the primary load-carrying capability of laminated composites. They offer high tensile strength and stiffness, which are essential for structural integrity in aircraft applications. Common fiber types include carbon, glass and aramid fibers. Carbon fibers are the most prevalent in aerospace structures due to their high stiffness, high strength-to-weight ratio, and good fatigue performance. They also exhibit excellent thermal stability. Used in some secondary structures or non-critical components, glass fibers are more economical than carbon fibers but offer lower strength and stiffness. Aramid fibers are sometimes used in areas requiring high damage tolerance, such as ballistic panels or fan containment rings due to their impact resistance and toughness [3]. The matrix binds the fibers together, transfers loads between them, and protects them from environmental damage and mechanical abrasion. Matrix materials in aerospace composites are typically polymers, which can be categorized as thermosetting and thermoplastic resins. Epoxy resins are the most widely used thermosetting matrices in aircraft structures due to their excellent mechanical properties, ease of processing, and good adhesion to fibers. Other thermosets include phenolic and bismaleimide resins, used where fire resistance or higher temperature performance is needed. Increasingly used in modern aerospace applications, thermoplastic matrices like polyether ether ketone (PEEK) or polyether ketone ketone (PEKK) offer advantages such as improved toughness, impact resistance, and the ability to be reheated and reshaped, which can simplify repair and recycling. In some cases, additives such as nano-fillers, rubber particles, or other toughening agents are incorporated into the matrix to improve impact resistance and reduce crack propagation, which is critical for damage tolerance in aircraft structures. Fig. 1 shows the material constituents in composite laminates [4].

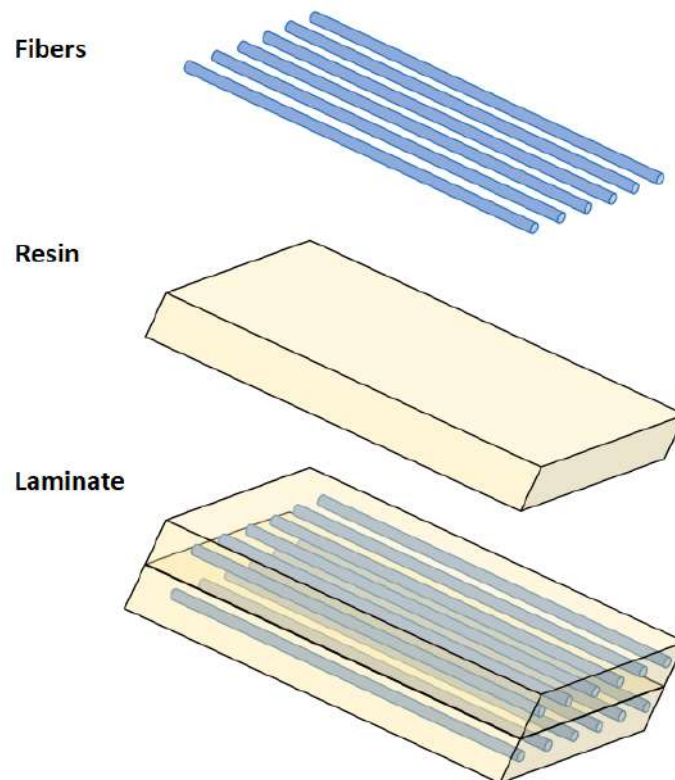


Fig. 1 Material constituents in composite laminates

III. MANUFACTURING PROCESSES

Common manufacturing techniques include autoclave processing, resin transfer molding, and automated fiber placement. Autoclave processing is one of the most widely used manufacturing techniques for producing high-quality laminated composites, particularly in the aerospace industry. In this method, layers of fiber reinforcements, usually pre-impregnated with resin (known as prepreg), are carefully laid up on a mold. The layup is then sealed with a vacuum bag and placed inside a large pressure

vessel called an autoclave. Inside the autoclave, high pressure and elevated temperature are applied simultaneously. This combination causes the resin to flow and fully cure while the pressure removes air pockets and voids, ensuring that the final laminate is dense, strong, and free from defects. This method is favored for critical aircraft structures like wings, fuselage panels, and control surfaces where maximum strength and reliability are essential. Another important manufacturing method is resin transfer molding, which is a closed-mold process suited for producing composite parts with complex shapes and smooth surfaces on both sides. In resin transfer molding, dry fiber reinforcements are placed inside a rigid mold cavity, which is then closed and sealed. Liquid resin is injected under pressure into the mold, where it thoroughly impregnates the fibers. Once the resin has filled the entire mold and wetted out the reinforcement, it is allowed to cure, forming a solid, durable composite part. Resin transfer molding is often used for medium to high production volumes because it offers good repeatability and can be partially automated. It is suitable for both structural and non-structural components, including aircraft fairings, interior panels, and some automotive parts. A more advanced technique, automated fiber placement, uses computer-controlled robotic machinery to precisely place narrow strips of fiber, called tows, onto a mold surface. The robot head moves along programmed paths, laying the fibers in specific orientations and patterns to build up the laminate layer by layer. This precise control over fiber placement allows engineers to tailor the strength and stiffness of a part exactly where it is needed, optimizing performance and minimizing excess weight. After the fiber placement is complete, the layup is typically cured in an autoclave. Automated fiber placement is especially valuable for manufacturing large, complex components such as fuselage sections, wing skins, and other high-performance structures that require accuracy and consistency while reducing material waste and labor costs [5].

IV. APPLICATIONS IN AIRCRAFT STRUCTURES

Laminated composites are extensively used throughout modern aircraft due to their exceptional strength-to-weight ratio, design flexibility, and resistance to fatigue and corrosion. In primary structures such as fuselage sections, aircraft like the Boeing 787 Dreamliner and the Airbus A350 rely heavily on carbon fiber-reinforced composites to construct large portions of the fuselage. By replacing traditional aluminum structures with advanced composite laminates, these aircraft achieve significant weight reductions, which translate to improved fuel efficiency and reduced operating costs. Similarly, laminated composites play a critical role in the construction of wings and control surfaces. High aspect ratio wings, which are designed to maximize aerodynamic efficiency and lift, benefit greatly from the use of lightweight composites that enable longer, more slender wing designs without compromising structural strength. This results in better aerodynamic performance, increased range, and lower emissions [6]. Beyond primary load-bearing structures, laminated composites are also widely used in interior components, including cabin panels, floor beams, seat frames, and partitions. These applications take advantage of the material's light weight to contribute to overall fuel savings, while also offering excellent resistance to corrosion and moisture damage, which helps maintain long-term durability and reduces maintenance costs. Together, these diverse uses highlight how laminated composites have become indispensable to the design and performance of next-generation aircraft, enabling manufacturers to meet strict efficiency, safety, and sustainability standards [7], [8].

V. CONCLUSIONS

The aerospace industry is constantly striving to identify and implement materials that deliver outstanding mechanical performance while simultaneously contributing to a reduction in the overall weight of aircraft structures. Among the most promising materials, laminated composite materials have become integral to modern aircraft design due to their high strength-to-weight ratio, corrosion resistance, and design flexibility. By enabling significant weight savings compared to conventional metallic materials, laminated composites play a crucial role in improving fuel efficiency, extending flight range, and lowering operating costs, all of which are vital in today's highly competitive and sustainability-focused aviation sector. In addition to their favorable mechanical properties, these materials allow

engineers to tailor structural components to meet specific performance requirements through careful selection of fiber orientations, layup sequences, and resin systems. This adaptability makes them suitable for a wide range of applications, from primary load-bearing structures such as fuselage sections and wing assemblies to secondary and interior components where weight reduction and durability are equally important. Advances in manufacturing technologies, including precision processes like autoclave curing, resin transfer molding, and automated fiber placement, have further enhanced the feasibility of producing large, complex composite parts with high consistency and minimal defects. This paper overviews the fundamentals of laminated composites, discussing their material constituents, manufacturing processes, and current applications in aerospace structures, while also highlighting the ongoing research that continues to expand their capabilities and drive the evolution of next-generation aircraft.

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The Use of Rosemary (*Rosmarinus officinalis* L.) in Cosmetic Products

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Abstract – Rosemary has a strong taproot, and its stem and shoots are green in the first year, becoming woody and turning brown from the second year onwards. The increasing demand for food worldwide has also led to a growing need for agriculture. In this regard, recycling waste to make it productive is extremely important. In today's world, where the population is rapidly increasing, waste generation is also increasing, and only a very small portion of this waste is used for recycling. Waste not only harms the environment but also causes health problems in humans. Recycling waste has become an important issue in order to reduce these problems. Rosemary oil is commonly used in products targeting skin conditions such as acne and psoriasis due to its antiseptic and anti-inflammatory properties. Rosemary is commonly used as a spice to alter or enhance food flavors, but it is also valued as a medicinal plant in folk medicine. Rosemary oil is an aromatic oil obtained from rosemary leaves, possessing strong antiseptic and antioxidant properties. Rosemary is used in the cosmetics industry, particularly in fragrance and aromatherapy products. It is known to have refreshing and relaxing effects in cologne, soap, and bath foam. The phenolic compounds found in rosemary extract are used in the chemical industry due to their high antioxidant and antimicrobial properties. It is frequently used in cosmetic products for its skin-regenerating effect, in the pharmaceutical industry for its medicinal properties, and in agricultural production applications for its plant growth-promoting effects.

Keywords – Rosemary, *Rosmarinus Officinalis*, Cosmetic, Essential Oil.

I. INTRODUCTION

This Rosemary is a perennial plant that can grow to a height of 50-100 cm, has needle-like leaves, does not shed its leaves in winter, and blooms with blue or purple flowers. Rosemary has a strong taproot, and its stem and shoots are green in the first year, becoming woody and turning brown from the second year onwards [1]-[3]. According to Baydar [4] the plant's blue flowers are located in the leaf axils as well as at the ends of the main stem and side branches. Furthermore, although the plant has a hermaphroditic flower structure, it is cross-pollinated by bees, and the flowering period is known to be in the spring and summer months [5],[6]. The increasing demand for food worldwide has also led to a growing need for agriculture. In this regard, recycling waste to make it productive is extremely important. In today's world, where the population is rapidly increasing, waste generation is also increasing, and only a very small portion of this waste is used for recycling. Waste not only harms the environment but also causes health problems in humans. Recycling waste has become an important issue in order to reduce these problems [7].

Rosemary oil is commonly used in products targeting skin conditions such as acne and psoriasis due to its antiseptic and anti-inflammatory properties [8]. Rosemary is commonly used as a spice to alter or enhance food flavors, but it is also valued as a medicinal plant in folk medicine. Rosemary oil is an aromatic oil obtained from rosemary leaves, possessing strong antiseptic and antioxidant properties [9]-[11].

N O	RetTime [min]	Compound Name	Cas No	%
1	2.14	Hexane	110-54-3	3.25
2	2.91	4-Acetylamidophenyl phenyldisulfone	NA	5.25
3	2.91	N-(Methoxymethoxy)-N'-phenyldiimide N'-oxide	NA	5.25
4	2.91	cis/trans-4-Iodomethyl-2-phenylsulfonyl- γ -butyrolactone	NA	5.25
5	4.78	Octane	111-65-9	0.46
6	4.78	Octadecane, 1-chloro	3386-33-2	0.46
7	4.78	Docosane	629-97-0	0.46
8	4.78	Hexane, 2,4-dimethyl	589-43-5	0.46
9	5.09	Cyclotrisiloxane, hexamethyl	541-05-9	0.87
10	7.20	2,6-Dimethyl-4-nitrosophenol	13331-93-6	1.17
11	10.55	Tricyclene	508-32-7	0.29
12	7.87	Delta.3-Carene	13466-78-9	0.29
13	8.18	cis-Ocimene	6874-10-8	1.69
14	8.18	α -Pinene	80-56-8	1.69
15	8.66	Camphene	79-92-5	1.18
16	9.47	2- α -Pinene	127-91-3	3.31
17	9.47	Linalylacetate	115-95-7	3.31
18	9.47	Sabinene	3387-41-5	3.31
19	11.10	1,8-Cineole	470-82-6	28.54
20	11.87	γ -Terpinene	99-85-4	5.30
21	12.23	2-(5-Chloro-2-Methoxyphenyl)Pyrrole	69640-07-9	0.26
22	12.83	Benzene, 2-ethenyl-1,3-dimethyl	2039-90-9	0.72
23	12.83	Benzene, 1-methyl-2-(2-propenyl)	1587-04-8	0.72
24	12.83	Benzene, 1-methyl-4-(1-methylethenyl)	1195-32-0	0.72
25	13.25	Nonanal	124-19-6	4.71
26	14.53	Bicyclo[2.2.1]heptan-2-one, 1,7,7-trimethyl-, (1S)	464-48-2	0.61
27	14.53	Camphor	76-22-2	0.61
28	15.28	1-Borneol	464-45-9	2.13
29	15.28	Borneol	10385-78-1	2.13
30	15.79	Butanoicacid, hexyl ester	2639-63-6	0.38
41	15.94	α FenchylAlcohol	470-08-6	1.10
42	15.94	α Terpineol	98-55-5	1.10
43	16.26	(+)-(1r,5r)-2(10)-Pinen-4-One	1196-01-6	1.43
44	17.46	1,6-Octadien-3-ol, 3,7-dimethyl-, 2-aminobenzoate	7149-26-0	2.31
45	17.46	LinalylAcetate	115-95-7	2.31
46	17.46	1,6-Octadien-3-Ol, 3,7-Dimethyl-, Acetate	115-95-7	2.31
47	18.37	Iso-MenthylAcetate	20777-45-1	0.54
48	18.37	Cyclohexanol, 5-methyl-2-(1-methylethyl)-, acetate	16409-45-3	0.54
49	18.37	1-Menthylacetate	2623-23-6	0.54
50	18.70	Anethole	104-46-1	20.89
51	18.70	Trans-Anethole	4180-23-8	20.89
52	18.70	Benzene, 1-methoxy-4-(1-propenyl)	104-46-1	20.89
53	19.14	Phenol, 5-methyl-2-(1-methylethyl)	89-83-8	4.33
54	19.14	Phenol, 2-methyl-5-(1-methylethyl)	499-75-2	4.33
55	20.08	Cyclohexanol, 5-methyl-2-(1-methylethyl)-, acetate	16409-45-3	0.62
56	20.86	Nerylacetate	141-12-8	0.17
57	21.34	Geranylacetate	105-87-3	0.88
58	21.34	LavandulylAcetate	25905-14-0	0.88
59	22.05	Dodecanal	112-54-9	0.10
60	25.13	(-)-Caryophylleneoxide	1139-30-6	1.07

ND: Not Detected; RT: Retention Time

Fig. 1 Example of an image Some volatile oil components of the rosemary (*Rosmarinus officinalis* L.) plant [12].

Rosemary oil is an essential oil obtained from the leaves and stems of the rosemary plant. It is primarily composed of monoterpene hydrocarbons, oxygen-free monoterpenes, and sesquiterpene compounds [12]. A recent study [12]. has revealed that rosemary essential oil contains important compounds. The compounds in the rosemary essential oil obtained in the study are shown in Figure 1.

Rosemary is used in the cosmetics industry, particularly in fragrance and aromatherapy products. It is known to have refreshing and relaxing effects in cologne, soap, and bath foam. The phenolic compounds found in rosemary extract are used in the chemical industry due to their high antioxidant and antimicrobial properties. It is frequently used in cosmetic products for its skin-regenerating effect, in the pharmaceutical industry for its medicinal properties, and in agricultural production applications for its plant growth-promoting effects. [11], [13].

II. RESULTS

The essential oil derived from the rosemary plant attracts attention with its wide range of uses. Its important components, in particular, demonstrate its significance for cosmetic products. The antioxidant and antimicrobial properties of rosemary oil provide a natural preservative effect that extends the shelf life of cosmetic products. This makes rosemary oil even more important for skin care products. In addition, rosemary oil's properties that promote hair growth and prevent hair loss demonstrate its potential for use in cosmetic products for hair care.

Considering all these areas of application and the natural properties of rosemary, it is thought that it will play an important role in the production of sustainable cosmetic products and that wider areas of application will emerge in line with increasing demand.

However, the applications of rosemary oil will not be limited to the cosmetics industry; its use is expected to expand into perfumery, aromatherapy, and even the pharmaceutical sector. The growing demand for natural and environmentally friendly compounds indicates that rosemary oil will be used more widely and has high potential as a raw material.

Considering the uses of the rosemary plant and its suitability for cultivation in Turkey's climate conditions, it is seen as an increasingly valuable plant. It is thought that it should be cultivated in wider production areas and that more comprehensive research should be conducted in this field.

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Design and Performance Evaluation of a 30 t/h Capacity Screw Conveyor System

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Abstract –Screw conveyors are widely employed in industrial sectors for transporting granular and powdered materials over short distances. In this study, the design of a screw conveyor with a capacity of 30 t/h was carried out, aiming to provide both transport and washing functionalities for grain materials. The system was modeled in SolidWorks, and detailed engineering calculations including shaft design, bearing and key selection, and coupling design were performed. Static strength analyses were conducted using ANSYS to verify the safety and durability of critical components under operational loads.

The results demonstrated that the proposed screw conveyor, manufactured from stainless steel (304 grade), offers high reliability, durability, and efficiency. In addition to its primary transport function, the design incorporates a perforated section enabling simultaneous washing and conveying of grains, which reduces operational costs and improves processing efficiency. A cost analysis was also performed, confirming the economic feasibility of the design.

In conclusion, the study presents an optimized screw conveyor system that can significantly contribute to time-saving, energy efficiency, and long-term sustainability in industrial applications. The findings provide practical insights for manufacturers and serve as a basis for future improvements in conveyor design.

Keywords – Screw Conveyor, Transport Systems, Grain Washing, Static Analysis, Cost Evaluation.

I. INTRODUCTION

Road Material handling systems play a crucial role in modern industry, where efficiency, reliability, and cost-effectiveness are primary concerns. Screw conveyors, also known as auger conveyors, are widely used for the transportation of dry and granular bulk materials due to their simple design, compact structure, and ability to operate in both horizontal and inclined positions. Beyond their common use in short-distance transportation, screw conveyors can also be adapted to perform additional functions such as mixing, feeding, or even washing of materials, depending on process requirements [1-4].

The primary aim of this study is to design a screw conveyor system with a capacity of 30 t/h, capable of transporting dry solid materials, particularly grains, while also enabling a washing function when needed. By integrating a perforated screw section, the system allows water to be added during the conveying process, ensuring both transportation and cleaning of grains in a single operation. This dual functionality reduces the need for separate systems, thereby minimizing operational costs and saving processing time.

Compared to other conveying systems such as belt or vibrating conveyors, screw conveyors offer significant advantages in terms of space efficiency, dust-free operation, and the ability to discharge materials at multiple points along the conveying path. However, they are generally limited to short conveying distances and moderate capacities. Therefore, the design must consider appropriate material selection, geometric parameters, and operational constraints to ensure efficiency and durability [5-8].

Previous studies in the literature highlight the classification of screw conveyors based on geometry and application. Common types include O-type, U-type, conical, and shaftless screw conveyors, with

applications ranging from food and chemical industries to cement and mining. In this project, an O-type stainless steel screw conveyor was selected for its suitability in handling lightweight grain materials [9-10]. Figure 1 illustrates the assembly of the designed conveyor system, which incorporates both transport and washing functionalities, representing an innovative approach to conventional screw conveyor design (Fig. 1).

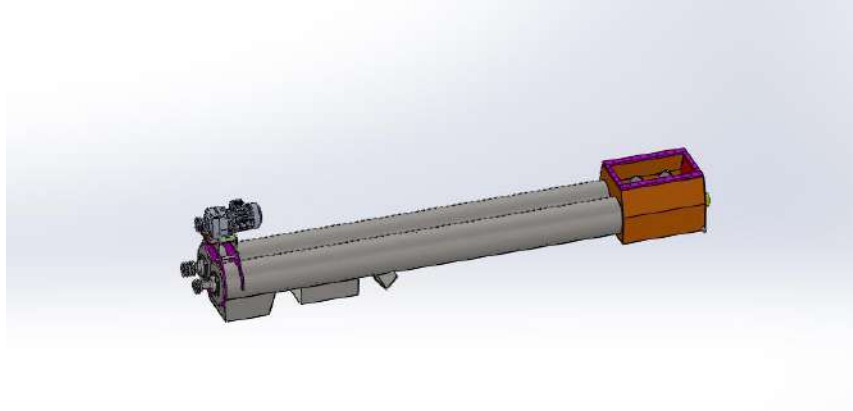


Fig. 1 Assembly drawing of the designed screw conveyor system, illustrating the main components and the integration of the transport and washing sections.

II. MATERIALS AND METHOD

Two The design and evaluation of the screw conveyor system were carried out through a systematic methodology involving material selection, engineering calculations, and numerical analyses. The aim was to ensure that the designed conveyor with a capacity of 30 t/h meets industrial requirements for durability, efficiency, and dual functionality (transport and washing).

A. Conveyor Design and Material Selection

The screw conveyor was designed to handle dry bulk materials, particularly grains, with the additional capability of washing the product during transport. Stainless steel (AISI 304) was selected as the primary material due to its corrosion resistance, mechanical strength, and suitability for food-related applications. The design included a screw diameter of 300 mm, a pitch equal to the diameter, and an overall length of 4.93 m, optimized for the desired capacity. Key components such as the shaft, bearings, keys, and couplings were dimensioned based on mechanical strength and fatigue criteria [11].

Fig. 2 shows the schematic representation of the horizontal screw conveyor, which formed the basis for the engineering calculations. The system geometry was modeled in SolidWorks, and the component dimensions were refined considering both standard design practices and application-specific constraints.

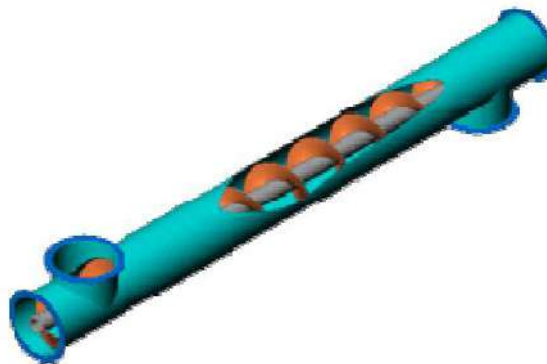


Fig. 2 Schematic view of the horizontal screw conveyor used as the basis for engineering calculations and design validation.

B. Engineering Calculations

The capacity of the screw conveyor was determined using conventional design equations that take into account the screw diameter, pitch, rotational speed, and loading efficiency. A design capacity of 30 t/h was targeted, with loading efficiency (ψ) values adjusted depending on the material flow characteristics. Torque and power requirements were calculated by considering friction between the material and the screw surface, as well as axial and radial forces acting on the shaft.

Shaft diameter was calculated under combined loading conditions (torsion, bending, and axial loads), and a diameter of 90 mm was found sufficient for safe operation. Bearing selection was performed using dynamic equivalent load and service life equations, ensuring operational reliability. Coupling dimensions were determined from torque transmission requirements, with a 140 mm coupling selected to withstand the calculated design moment.

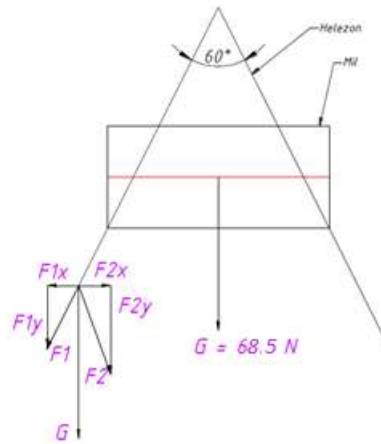


Fig. 3 Forces acting on a single helical blade, illustrating axial, radial, and tangential load components affecting the shaft and key connection.

Key selection was performed based on shear and surface pressure criteria. Fig. 3 illustrates the forces acting on a single helical blade, which were used to determine the loading conditions on the shaft and key connection. Fig. 4 presents the dimensional details of the key, where the selected size ($16 \times 6 \text{ mm}$, length 68 mm) satisfied both shear and contact pressure requirements.

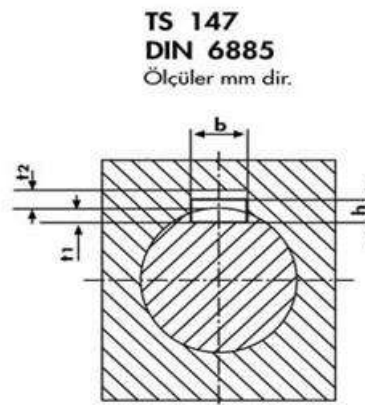


Fig. 4 Dimensional details of the key selected for shaft–coupling connection, showing width, height, and calculated length.

III. RESULTS

To validate the analytical design results, finite element analyses were conducted using ANSYS on the most critical components of the screw conveyor system. The numerical evaluation aimed to confirm that the selected materials and dimensions could withstand the expected operational loads.

Fig. 5 illustrates the screw conveyor gear system connected to the motor. Initial analyses with stainless steel 304 revealed that the stresses around the keyway exceeded allowable values, indicating a risk of deformation. To overcome this limitation, the gear material was changed to 16MnCr5 case-hardened steel, which provided a higher yield strength ($\sigma_y = 635$ MPa). The new analysis confirmed that the maximum stress (328 MPa) remained below the material's yield limit, thus ensuring safe operation.

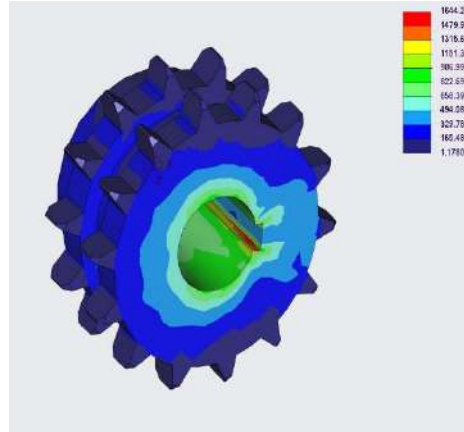


Fig. 5 Screw conveyor gear system (14-tooth double-row gear) connected to the motor, showing stress distribution and material analysis results.

A similar approach was applied to the tail shaft, which is subject to significant radial and axial loads due to bearing contact. As shown in Fig. 6, the stainless steel 304 material exhibited deformation risks in the press-fit region of the bearing seat. After replacing it with 16MnCr5, the maximum stress (30 MPa) was found to be far below the yield limit, with a safety factor greater than 2, confirming the suitability of the new material selection.

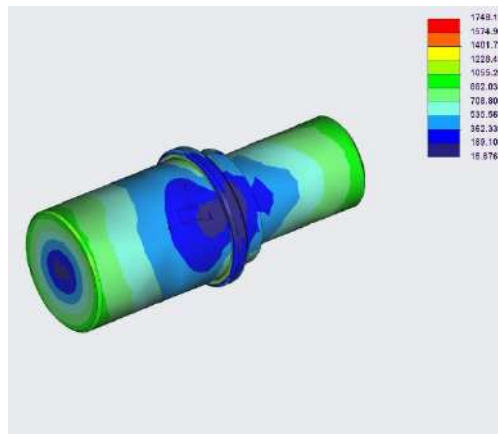


Fig. 6 Tail shaft of the screw conveyor, illustrating the critical bearing seat region and the effects of applied radial and axial loads.

Finally, the motor shaft connected to the coupling was analyzed (Fig. 7). The stainless steel 304 design again showed excessive stress in the keyway section, potentially leading to premature failure. With 16MnCr5 material, the maximum stress decreased to 548 MPa, which is below the yield strength. This ensured that the shaft can safely transmit the required torque without structural failure.

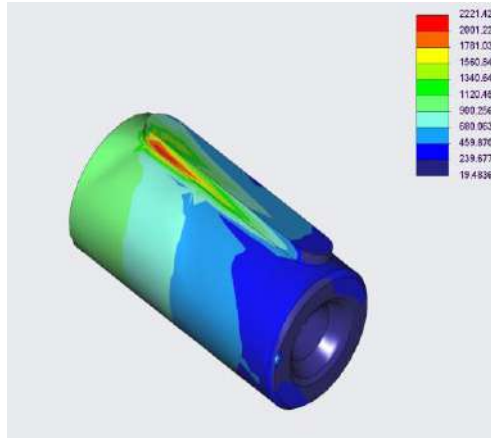


Fig. 7 Motor shaft of the screw conveyor (4 kW, 90 rpm), highlighting the coupling connection and stress concentration around the keyway section.

Overall, the numerical analyses demonstrated that replacing the initially selected stainless steel 304 with 16MnCr5 significantly improved the safety margins of the gear, tail shaft, and motor shaft. These results validated the analytical calculations and confirmed that the redesigned conveyor system is structurally reliable for continuous operation.

IV. DISCUSSION

The design and analysis of the screw conveyor system highlight the importance of integrating analytical calculations with numerical validation to achieve reliable and efficient performance. The proposed system, designed for a capacity of 30 t/h, not only fulfills the conventional role of transporting granular materials but also introduces a washing function, offering additional flexibility compared to standard screw conveyors. This dual functionality demonstrates the potential of screw conveyors to be adapted for multipurpose industrial applications, especially in the food and agricultural sectors where both transport and cleaning are required.

The results of the **static and numerical analyses** confirmed that the initial selection of stainless steel 304 for certain critical components was insufficient to ensure long-term durability under combined torsional, bending, and axial stresses. By substituting these components with **16MnCr5 case-hardened steel**, the system achieved higher safety factors, ensuring operational reliability. The comparative stress distributions observed in Figures 5–6 clearly demonstrate the advantages of this material substitution. This finding emphasizes the necessity of considering alternative material choices during the design stage to prevent premature failures.

Another critical aspect is efficiency. The optimized screw diameter, pitch, and rotational speed parameters improved transport performance, raising the hourly capacity from approximately 25 t/h to 30 t/h. Additionally, by incorporating a perforated screw section, the system enabled simultaneous washing and conveying of grains, which reduces operational time and eliminates the need for separate washing units. This innovation increases overall productivity and offers significant cost savings for industrial users.

The cost analysis supported the technical findings, showing that the conveyor could be manufactured at an economically feasible level. When combined with the verified structural safety and extended service life, the design becomes a strong candidate for industrial-scale implementation. However, it should be noted that screw conveyors are inherently limited in terms of transport distance and are less efficient for highly abrasive or sticky materials. These operational boundaries must be considered when deploying the system in different sectors.

In summary, the discussion indicates that the integration of advanced material selection, analytical design, and numerical validation can significantly enhance the reliability and performance of screw

conveyors. The presented design not only meets industrial requirements but also contributes to broader goals of **energy efficiency, cost-effectiveness, and sustainability**.

V. CONCLUSION

This study presented the design, analysis, and validation of a screw conveyor system with a capacity of 30 t/h, developed to address both transport and washing functions for granular materials. The integration of a perforated screw section provided an innovative solution that enabled simultaneous conveying and cleaning of grains, thereby improving efficiency and reducing the need for separate processing equipment.

Analytical calculations were performed to determine the shaft dimensions, bearing and coupling selection, and torque requirements, while finite element analyses were conducted to validate the structural integrity of the key components. The results demonstrated that stainless steel 304, although commonly used, was insufficient under combined loading conditions. Replacing critical components with 16MnCr5 case-hardened steel ensured higher safety factors and improved long-term durability, as confirmed by the stress distributions shown in the numerical analyses.

The optimized screw geometry and operational parameters enhanced transport efficiency, increasing the throughput from 25 t/h to 30 t/h. A detailed cost analysis indicated that the design is economically feasible, offering an effective balance between performance and manufacturing expenses.

In conclusion, the proposed screw conveyor system provides significant advantages in terms of reliability, dual functionality, and cost-effectiveness. The findings underline the importance of combining **analytical design, material optimization, and numerical validation** in engineering practice. Future studies may focus on extending the design for larger capacities, incorporating smart sensor systems for operational safety, and investigating performance with different bulk materials.

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Design and Analysis of a Tennis Ball Launcher for Standard Court Applications

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Abstract –The aim of this study is to design and evaluate a tennis ball launcher suitable for use in an international standard tennis court. Different launching principles were reviewed, including wheel-driven systems, pneumatic launchers, spring mechanisms, and catapult systems. After a comparative evaluation based on efficiency, cost, adjustability, and ease of integration, the wheel-driven system was selected as the optimal solution due to its ability to impart both topspin and backspin to the ball.

The launcher was designed using SolidWorks, and detailed engineering calculations were conducted for ball acceleration, wheel rotation, motor power, and shaft dimensions. Critical parameters such as ball deformation, Magnus effect, and drag force were incorporated into the theoretical modeling. Motor and shaft designs were analyzed to ensure sufficient torque, speed, and structural stability. The maximum output velocity was targeted at 80 km/h to ensure cross-court ball delivery, considering aerodynamic losses during flight.

Simulation studies were carried out to validate theoretical calculations. Both static and motion analyses revealed that the launcher design met the required performance criteria, although shaft deflection was identified as a weak point. Cost analysis indicated that the system could be manufactured within the range of 1000–1500 TL, making it economically feasible.

In conclusion, the study demonstrates that wheel-based tennis ball launchers can provide a practical and cost-effective solution for training and practice sessions. The design not only achieves the required ball velocity and spin but also ensures mechanical simplicity, portability, and adaptability for future improvements.

Keywords – Tennis Ball Launcher, Wheel-Based Mechanism, Magnus Effect, Design Analysis, Simulation.

I. INTRODUCTION

Tennis is one of the most popular sports worldwide and requires extensive training to develop technical skills, reaction time, and physical endurance. Consistent practice often demands a partner or coach to feed balls at controlled speeds, angles, and spins. To overcome the limitations of manual training, tennis ball launchers have been developed as mechanical devices capable of delivering balls with adjustable parameters, providing players with realistic practice scenarios without the need for a partner [1-3].

The primary objective of this study is to design and analyze a cost-effective and portable tennis ball launcher that can meet the requirements of a standard tennis court. The system is intended to achieve variable ball velocities, simulate different spin conditions (topspin, backspin), and ensure stable operation under repetitive use. By combining theoretical modeling with computer-aided design and simulation tools, the study aims to validate the feasibility of the proposed design both in terms of mechanical performance and economic efficiency [4-5].

The scope of the project covers the investigation of different launching mechanisms and the selection of the most suitable system. Alternative methods such as pneumatic launchers, spring-based mechanisms,

and catapult systems were reviewed, each offering unique advantages and disadvantages. Among these, wheel-based launching systems were identified as the most practical due to their controllability, ability to generate spin, and relatively simple construction. The design process involved solid modeling, material selection, torque and power calculations, and structural analyses. In addition, manufacturing feasibility and cost evaluation were included to ensure real-world applicability [6].

A review of the literature reveals that tennis ball launchers have been widely studied from both mechanical and biomechanical perspectives. Researchers have highlighted key physical factors such as the Magnus effect, drag force, and ball deformation during launch, which directly affect ball trajectory and spin (Fig. 1).

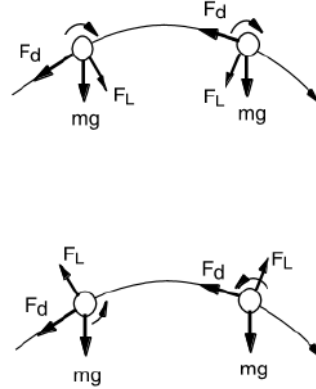


Fig. 1 Illustration of the Magnus effect and aerodynamic drag acting on a spinning tennis ball during flight [7].

Wheel-driven systems in particular have been shown to replicate realistic ball motions by controlling rotational speed differences between the wheels, making them suitable for training purposes. Previous works also emphasize the importance of safety, energy efficiency, and adaptability of such devices in sports engineering [8].

Recent studies further categorize launchers into different types. Pneumatic systems provide high initial velocity but lack fine spin control; spring-based mechanisms are compact but offer limited velocity ranges; catapult systems can produce strong launches but require complex structures. In contrast, wheel-based mechanisms stand out for their versatility, allowing precise control of velocity and spin while remaining mechanically simple. This literature review justifies the focus of the present study on developing a wheel-driven tennis ball launcher that balances performance, cost, and portability.

II. MATERIALS AND METHOD

A. Design Concept and Mechanism Selection

The design process began with an evaluation of different ball launching mechanisms, including pneumatic, spring-based, catapult, and wheel-driven systems. After a comparative assessment, the wheel-driven mechanism was selected due to its simplicity, controllability, and ability to generate both topspin and backspin by adjusting the relative wheel speeds. The system was designed to achieve an exit velocity of up to 80 km/h, sufficient for cross-court ball delivery under standard playing conditions.

B. Theoretical Calculations

The launching dynamics of the tennis ball were analyzed by considering both translational and rotational motion. The Magnus effect and aerodynamic drag were incorporated into trajectory calculations (Figure 1). The trajectory of the ball, including its curved descent onto the court due to spin, is shown in Fig. 2.

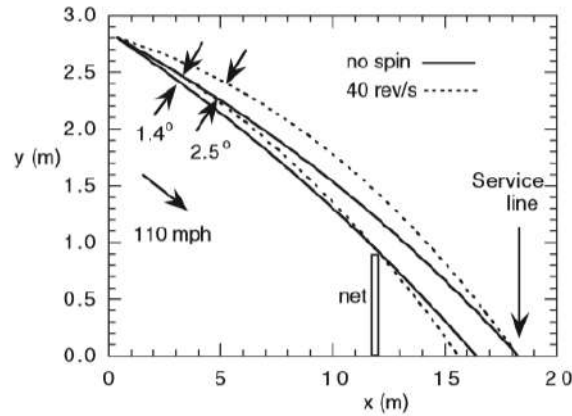


Fig. 2 Trajectory of a tennis ball affected by the Magnus effect, illustrating its curved flight path and descent onto the court [9].

Key design parameters included:

- **Ball velocity (V):** Determined using Newton's second law, considering wheel tangential speed and frictional contact.
- **Wheel rotation speed (N):** Calculated from $v = \pi d N / 60$, where d is wheel diameter.
- **Motor power (P):** Estimated using $P = T \cdot \omega$, with torque values obtained from resistive forces during launch.
- **Shaft diameter (d):** Determined using combined torsional and bending stresses, applying von Mises criteria [10].

The calculations confirmed that a shaft diameter of 12 mm and a motor capacity of approximately 250–300 W were sufficient to achieve the desired performance.

C. Motor and Shaft Selection

Two DC motors were selected to drive the wheels independently, enabling precise spin control. Each motor was rated at 24 V and capable of reaching 5000 rpm, delivering sufficient torque for continuous operation. The shafts connecting the motors to the wheels were supported by ball bearings to minimize friction and ensure stability. Shaft deflection was also analyzed, revealing the need for a safety factor greater than 2 under repeated loading conditions.

D. SolidWorks Modeling and System Layout

A complete 3D model of the launcher was developed in SolidWorks, incorporating the frame, wheel assembly, ball feeding mechanism, and electronic control components. The model emphasized portability and lightweight design, enabling the launcher to be used in training sessions without significant setup effort. Figure 3 shows the general view of the SolidWorks assembly model of the tennis ball launcher.

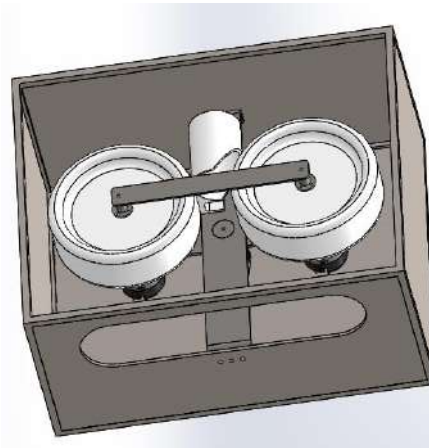


Fig. 3 Internal view of the ball launching mechanism enclosed within the system body.

E. Numerical Analyses

Finite element analyses (FEA) were performed to verify the structural safety of the shaft and wheel assembly. Static stress analyses indicated that maximum stresses occurred at the shaft–wheel connection due to torque transfer. Modal analysis confirmed that the operational frequency of the system was below resonance limits, ensuring vibration safety. Motion simulation was also conducted to observe the ball's acceleration and release, validating the theoretical trajectory predictions.

F. Cost Evaluation

A cost analysis was performed to assess the economic feasibility of the design. The estimated manufacturing cost was between 1000 and 1500 TL, including motors, electronic control units, shafts, and frame materials. This cost level makes the system affordable compared to commercial tennis ball launchers, which are significantly more expensive.

III. RESULTS

The results obtained from theoretical modeling, CAD-based design, and numerical simulations confirmed the feasibility and efficiency of the proposed tennis ball launcher.

A. Trajectory and Aerodynamic Effects

The aerodynamic behavior of the launched tennis ball was modeled by considering the Magnus effect and drag forces. As illustrated in Figure 4, the Magnus effect produces a lift force perpendicular to the direction of motion, altering the flight path of the spinning ball. This effect becomes especially evident in topspin shots, where the ball dips sharply after crossing the net. Figure 5 shows the simulated trajectory of a ball launched with backspin, where the Magnus effect increases lift and extends the flight distance. These results demonstrate that the designed launcher can replicate different spin conditions, ensuring realistic training scenarios.

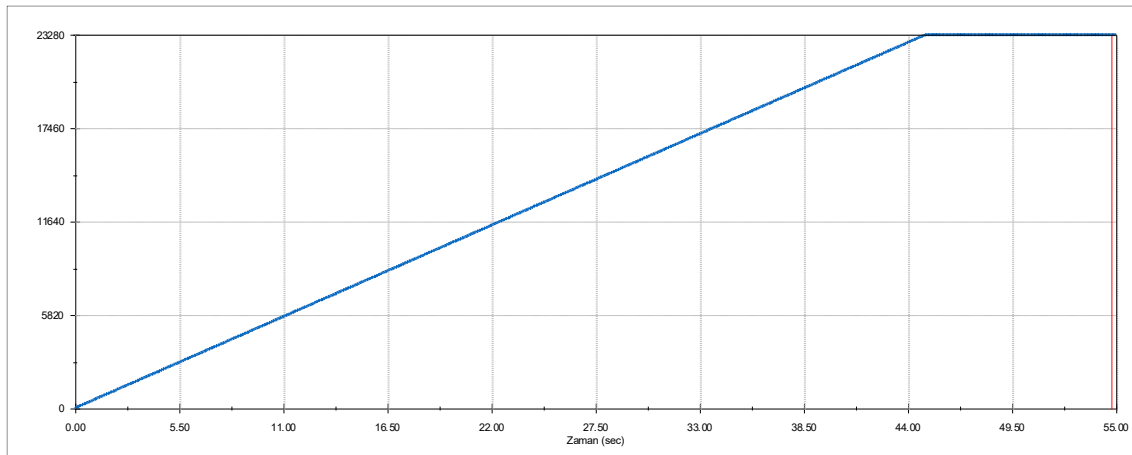


Fig. 4 Acceleration of the motor during operation, showing the variation of rotational speed over time.

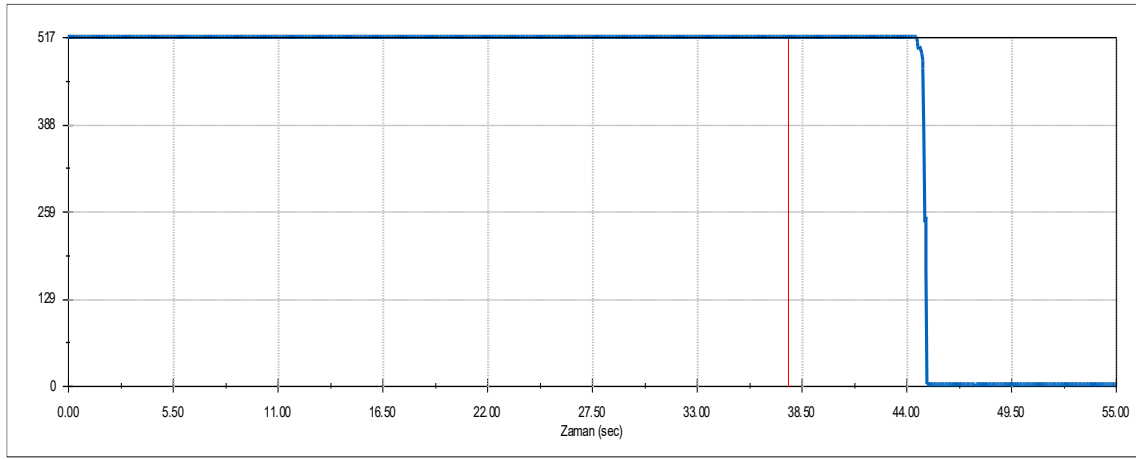


Fig. 5 Motor acceleration characteristics, illustrating the change in angular velocity with respect to time.

B. Structural Layout and Assembly

The SolidWorks model of the launcher emphasized compactness and portability. Figure 6 presents the general assembly of the launcher, including the dual-wheel system, shaft connections, and support frame. The arrangement ensures mechanical stability and balanced weight distribution. Figure 7 shows the exploded view of the assembly, highlighting the modular design that simplifies maintenance and part replacement. The placement of the motors, shafts, and control units within the body is further illustrated in Figure 26, which demonstrates the efficient use of internal space.

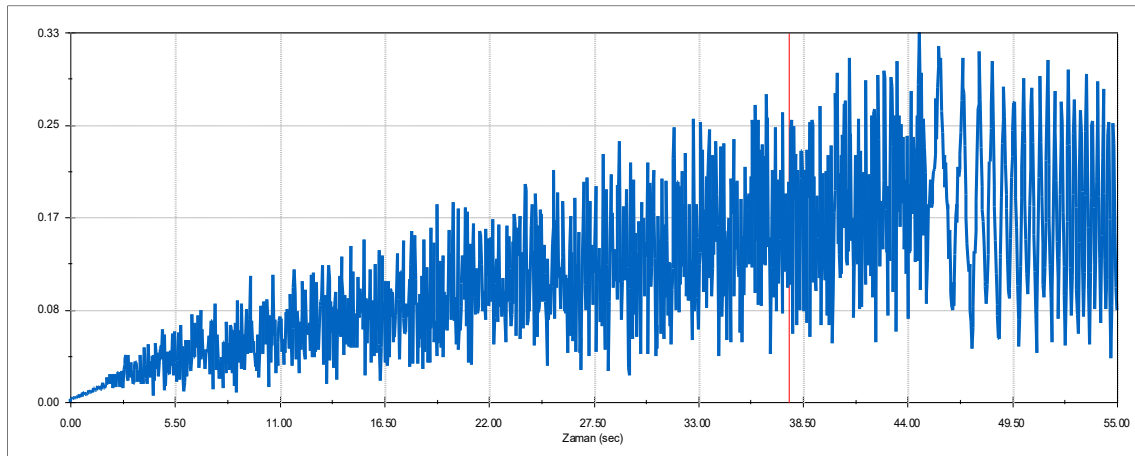


Fig. 6 Torque applied by the motor during operation, illustrating the variation of output torque over time.

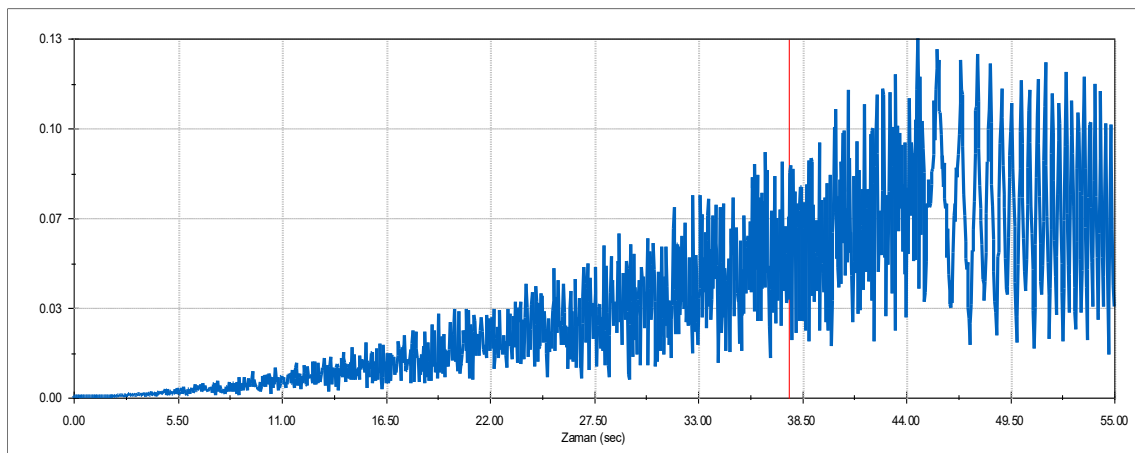


Fig. 7 Power consumption of the motor during operation, showing the variation of output power over time.

C. Shaft and Stress Analysis

Finite element analyses (FEA) were conducted to validate the structural strength of the shaft and wheel system. Figure depicts the stress distribution on the motor shaft under operating torque. The maximum stress remained below the yield strength of the selected material, ensuring a safety factor greater than 2. Fig. 8 shows the deflection analysis of the shaft, where the maximum displacement was found to be within acceptable limits. These results confirm that the shaft design can withstand repetitive launching without structural failure.

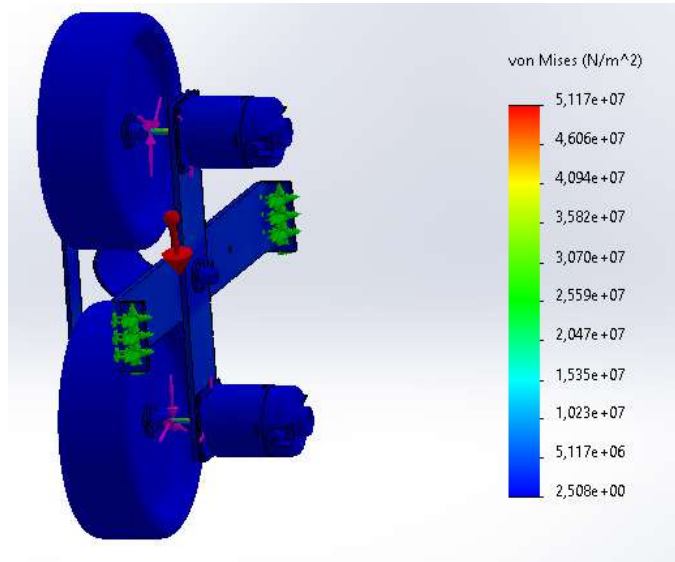


Fig. 8 Stress distribution on the launcher system under operational loading conditions.

D. Dynamic Simulation of the Launch

The dynamic simulation of the launching mechanism was performed to validate ball acceleration and release behavior. Fig. 9 illustrates the motion analysis of the ball being compressed and accelerated between the rotating wheels. The simulation confirmed that the launcher can deliver the ball at velocities up to 80 km/h, while allowing adjustments in spin by varying wheel speeds. The observed motion closely matched the theoretical predictions of trajectory and spin, confirming the accuracy of the design approach.

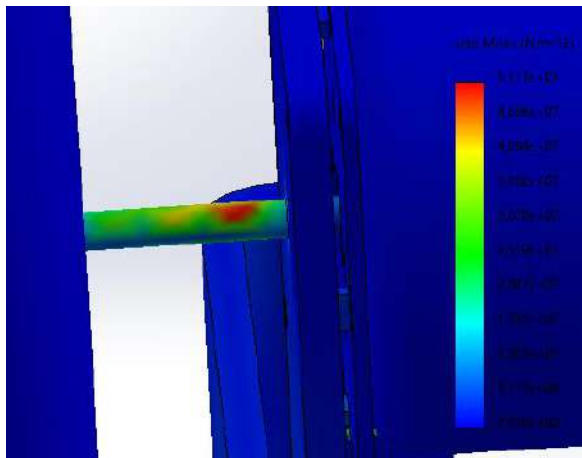


Fig. 9 Stress distribution on the shaft, illustrating maximum stress regions under applied torque and bending loads.

E. Cost and Practical Feasibility

In addition to mechanical and aerodynamic performance, a cost evaluation was carried out. The estimated production cost of 1000–1500 TL makes the launcher an economically viable alternative to commercial products. Combined with its compact design and ease of transport, the system provides both affordability and functionality for training purposes.

IV. DISCUSSION

The study demonstrates that the designed tennis ball launcher successfully meets the performance requirements of velocity, spin control, and structural stability. The integration of theoretical modeling, mechanical design, and numerical analysis provided consistent results that validate the overall feasibility of the system.

The analysis of motor behavior confirmed that the selected drive units can rapidly reach the necessary rotational speeds, ensuring continuous and reliable operation. Torque and power evaluations further indicated that the motors function within safe operational limits, delivering sufficient energy for ball acceleration without exceeding rated capacities. This shows that the launcher design achieves both energy efficiency and mechanical effectiveness.

From a structural perspective, stress and deflection analyses highlighted that the shaft and supporting components can withstand the applied loads while maintaining a sufficient safety margin. Although localized stress concentrations were observed at connection points, they remained within acceptable limits, indicating that the design is reliable under repeated loading conditions.

The aerodynamic modeling of ball trajectories confirmed that the launcher is capable of reproducing realistic topspin and backspin effects, which are essential for effective training scenarios. This strengthens the practical value of the system by enabling players to practice with conditions that closely mimic real matches.

In terms of cost, the estimated production expense between 1000 and 1500 TL places the launcher as an affordable alternative compared to commercial products, which are significantly more expensive. Its compact and portable design further enhances usability, particularly for training centers and individual athletes.

Despite these strengths, some limitations exist. The relatively small shaft diameter may be vulnerable to fatigue under prolonged operation, and performance could be influenced by external factors such as ball wear, wheel friction, and environmental conditions. Future work should address these aspects by incorporating durability testing, optimizing material choices, and developing more advanced control systems for adjustable launching parameters.

In conclusion, the discussion confirms that the proposed wheel-based tennis ball launcher is technically reliable, economically viable, and practically useful, with the potential to serve as a low-cost training aid while also providing a strong foundation for future improvements.

V. CONCLUSION

This study presented the design, analysis, and evaluation of a tennis ball launcher intended for training applications on a standard court. The system was developed using a wheel-based launching mechanism, chosen for its simplicity, controllability, and ability to reproduce both topspin and backspin effects.

Theoretical calculations, CAD modeling, and numerical analyses confirmed that the launcher can deliver balls at velocities up to 80 km/h, meeting the requirements for cross-court training exercises. Structural analyses demonstrated that the shaft and supporting components provide sufficient strength and durability under operational loads, while motor performance evaluations indicated efficient power usage and reliable acceleration behavior.

In addition to technical performance, the launcher was designed with cost-effectiveness and portability in mind. The estimated manufacturing cost of 1000–1500 TL makes it significantly more affordable than commercial alternatives, offering accessibility for training academies and individual players.

Overall, the study concludes that the proposed tennis ball launcher is a **technically reliable, economically feasible, and practically applicable** solution. Future work should focus on long-term durability testing, optimization of wheel materials, and integration of advanced control systems to further enhance performance and adaptability.

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VisionGuard: Hybrid Deep Ensemble Feature Fusion for Robust Malware Detection Across Mobile and Desktop Platforms

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Abstract – Malware remains a significant and evolving threat, compromising a wide spectrum of devices and operating systems, and causing substantial operational and financial disruptions across industries. In today's interconnected digital landscape, the need for robust and adaptable detection frameworks is more urgent than ever. To address this challenge, we present VisionGuard, a hybrid deep learning-based malware detection model designed for both Android and desktop environments. The proposed approach integrates seven pre-trained convolutional neural networks (CNNs)—VGG16, VGG19, Xception, ResNet50, EfficientNetV2B0, MobileNetV2, and ConvNeXtLarge—into a unified ensemble, enhanced by an autoencoder block to improve feature refinement. The model is trained on grayscale image representations of malware binaries, derived from 8-bit vectorized formats. Its performance was evaluated on two distinct classification tasks: binary classification using an Android malware dataset, and multi-class classification across 25 desktop malware families. In both scenarios, the model demonstrated exceptional accuracy, exceeding 99%. Specifically, it misclassified only 2 out of 1,200 Android samples and 3 out of 9,339 desktop samples, despite the class imbalance. These results highlight the effectiveness, adaptability, and real-world applicability of the proposed approach in modern malware detection systems.

Keywords – Malware Detection, Pre-trained CNN Models, Android Operating System, Malware Visualization.

I. INTRODUCTION

With the widespread integration of smart devices into everyday life, these technologies have increasingly become prime targets for cybercriminals. One of the primary vectors used to compromise systems is malicious software, commonly known as malware. According to AVTEST, a prominent independent institution in IT security, over 100 million new malware instances were detected in 2020 alone [1]. Another report highlights that approximately 15.37% of internet-connected systems globally encountered at least one malware incident during that year [2]. Given the rapid evolution and emergence of new malware variants, researchers have turned to deep learning and machine learning as promising solutions for cybersecurity challenges. These techniques, already proven effective in other domains, offer adaptability and reliability, making them particularly suitable for identifying and categorizing malware. Differences among existing models often stem from the choice of data representation and classification techniques. Common representations include raw binary data, embedded features, image-based visualizations, and extracted descriptors. Additionally, by converting malware into visual formats, these methods contribute to better computational efficiency in terms of speed and memory usage. Malware analysis can also be conducted through static or dynamic approaches. Static analysis involves inspecting the code structure and control flow without executing the program, although it may be less effective against obfuscated or encrypted malware due to its dependency on unpacked binaries. Conversely, dynamic analysis observes the program's behaviours during execution in a controlled environment. While more resistant to obfuscation, this approach requires considerable resources and may miss malicious

behaviours that is not triggered during execution. In this study, we introduce an advanced method for analysing and classifying malware. Executable malware files can be transformed into binary sequences composed of 0s and 1s, which can be reshaped into image matrices for visual interpretation. We noticed that these images exhibit similar patterns for malware samples from the same family. Leveraging this observation, we adopted a transfer learning-based strategy and constructed a hybrid model by combining seven pre-trained convolutional neural networks (CNNs), aiming to achieve high performance in malware classification.

1.1.NOVELTY

A key innovation of our study lies in the versatility and robustness of the proposed model, which has been thoroughly evaluated across different types of classification tasks and computing environments. Unlike many existing approaches that focus exclusively on either binary or multi-class classification, our model has been designed and validated to perform effectively in both scenarios. Specifically, the architecture integrates multiple pre-trained convolutional neural network (CNN) models and incorporates an autoencoder block to enhance feature extraction and reduce redundant or noisy information. To assess the generalizability of our method, we utilized two distinct datasets representing malware threats in Android and desktop systems. The first dataset consists of grayscale image representations generated from the binary files of Android applications. This dataset supports a binary classification task where samples are labelled as either malicious or benign. The second dataset includes grayscale visualizations derived from the binary content of desktop malware and spans 25 distinct malware families, presenting a significantly imbalanced distribution across classes. This second dataset served as the basis for a challenging multi-class classification task. Our model demonstrated consistently high performance on both datasets, indicating its adaptability to different data distributions and classification demands. Its successful application to both mobile and desktop platforms highlight its potential as a generalized malware detection framework. Leveraging the power of transfer learning, the model effectively captures transferable features from pre-trained CNNs and applies them to the malware domain, thereby reducing the need for extensive task-specific training data while maintaining accuracy and efficiency in diverse testing conditions.

II. RELATED WORKS

Over the years, a wide range of approaches have been proposed to enhance the accuracy and efficiency of malware detection systems. Among the traditional methods, signature-based detection remains one of the earliest techniques, which relies on identifying predefined patterns or signatures associated with known malware strains [3]. Heuristic-based methods offer a more flexible alternative by using rule-based systems to detect abnormal or suspicious behaviours, enabling the identification of previously unseen threats [4]. Despite their merits, both approaches often struggle to keep up with the rapid evolution and obfuscation tactics employed by modern malware. In recent years, deep learning has emerged as a powerful solution capable of adapting to new and complex malware variants. Researchers have explored a wide spectrum of deep learning architectures—ranging from basic neural networks to sophisticated hybrid models—to boost detection performance and minimize false positive rates. Furthermore, innovative concepts such as binary visualization and multi-layered fusion of analytical techniques have demonstrated substantial improvements in detection accuracy and resilience [5]. Several notable studies have introduced advanced techniques for malware classification. In [6], a system was developed using over 200 features derived from both dynamic and static analysis. This system utilized a Deep Belief Network (DBN), which was trained in two phases: initially in an unsupervised manner using Restricted Boltzmann Machines (RBMs), followed by supervised fine-tuning. In [7], the researchers extracted Application Programming Interface (API) calls from Smali code and grouped them into blocks based on their associated methods. These blocks were then used as input to a DBN for Android malware classification, with evaluations conducted using real samples from the Comodo Cloud Security Centre.

Another significant contribution, presented in [8], involves converting Android application bytecode into RGB colour images to facilitate feature extraction. A CNN was trained on a balanced dataset of one million benign and one million malicious samples using these encoded images. Similarly, the authors of [9] proposed a hybrid detection model that integrates a CNN with a deep Autoencoder (AE), wherein the AE was used to pre-train the CNN for improved performance. The study in [10] focused on extracting raw API call sequences from .dex assembly code and converting them into vectors suitable for CNN training. Their architecture included a convolutional layer with ReLU activation, a max-pooling layer, a fully connected layer with dropout and batch normalization, and a final output layer designed for dual-task classification. A different approach, COPYCAT, was introduced in [11] to create adversarial samples specifically aimed at malware detection systems. COPYCAT includes two attack strategies: AE padding for untargeted attacks and sample injection for targeted classification outcomes, both designed to preserve the executability of the malware. The authors reported high misclassification rates—98.9% for Windows and 96.5% for IoT binaries. In another study [12], malware samples were treated as images, and a Support Vector Machine (SVM) was employed for multi-class classification. The researchers utilized texture feature extraction techniques such as Discrete Wavelet Transform, Gabor Wavelets, and GIST. Using the Maling dataset comprising 12,470 samples, they trained and tested their model across eight malware families. Visual similarity techniques were explored in [13], where opcode sequences were translated into RGB matrices, allowing for malware classification based on image similarity. Dynamic execution traces were also incorporated, enabling analysis of packed malware samples. Building on opcode sequence analysis, [14] introduced a method to assess the importance of opcode frequencies by assigning weights to sequences, enhancing classification performance for known malware families. The study in [15] proposed a transfer learning-based approach using CNNs to classify Android malware images. Their model effectively distinguished malicious samples from benign ones through the use of pre-trained CNN layers. Lastly, in [16], a VGG16-based deep neural network was adapted for malware classification by representing malicious executables as grayscale images. The original VGG16 layers were retained (frozen), while the final layers were modified to enable classification into malware families. A comparative summary of these studies and their methodologies is presented in Table 1.

Table 1. Some state of the Art Studies on Malware Detection Using Different Techniques and Approaches

Work	Year	Method	Performance
Day et al.[17]	2023	Metaheuristic Based Ensemble Feature Selection	99.41%
Srinivasan et al. [18]	2023	Ensemble Classification Based Machine Learning	94.08%
Fast & Furious[19]	2023	Data Stream and ML Based	98.15%
[20]	2023	Deep Stacked Ensemble Methods	99.1%
DL-Droid[21]	2020	Deep Learning Model	97.8%
Kim et al.[22]	2018	Multimodal Deep Learning Model	98%
MalDozer[23]	2018	Deep Learning Techniques	96–99%
DroidCat[24]	2018	ML Multi-Class Classifier	97%
Rana et al.[25]	2018	Tree-Based Machine Learning Classifiers	97.24%
AndMFC[26]	2019	Machine Learning Based	>96%
EntropLyzer[27]	2021	Entropy-Based Behavioural Analysis	98.4%
DeepAMD[28]	2021	Deep learning Techniques Based	93.4%
GDroid[29]	2021	Graph Convolutional Network (GCN)	97%
VisDroid [30]	2021	Image features and ML Based	97.94%
DeepVisDroid[31]	2021	Image features and DL Based	98%

III. MATERIALS AND METHOD

3.1. DEEP NEURAL NETWORKS

Deep learning has become increasingly prominent in recent years, primarily due to its ability to achieve high accuracy when trained on large-scale datasets. It encompasses a wide array of models, including perceptrons, Hopfield networks, Boltzmann machines, fully connected networks, convolutional neural networks (CNNs), recurrent neural networks (RNNs), long short-term memory (LSTM) networks,

autoencoders, deep belief networks (DBNs), and generative adversarial networks (GANs), among others. These models generally rely on the backpropagation algorithm for training, allowing them to adjust internal parameters by minimizing error through gradient descent. Deep neural networks consist of layers filled with computational units known as neurons, which are interconnected by weighted edges. These connections enable the flow of information across layers, facilitating complex feature learning. Due to their strong generalization capabilities and ability to learn high-level representations, deep learning techniques have become particularly effective in malware detection tasks.

3.2. TRANSFER LEARNING

While traditional machine learning methods have shown considerable success across various domains, their effectiveness is often limited by the need for extensive labeled training data that matches the distribution of the test set. Acquiring such data can be both costly and time-consuming. Although semi-supervised learning helps alleviate this dependency by leveraging a small amount of labeled data alongside a larger pool of unlabeled data, it still requires access to suitable datasets. Transfer learning offers a compelling alternative by enabling knowledge gained from one domain to be reused in another. This approach allows models trained on a source dataset to be adapted for new, but related, tasks or datasets—often with minimal retraining. By reusing feature representations learned from large-scale benchmark datasets, transfer learning significantly reduces the effort needed to build high-performance models for target tasks. A visual representation of this concept is illustrated in Figure 1.

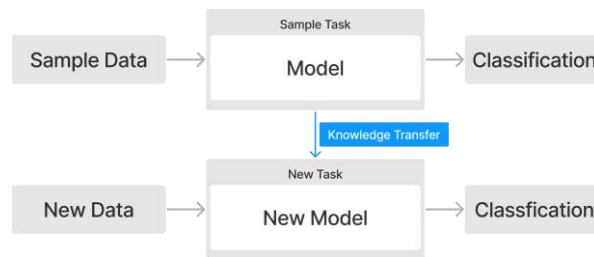


Figure 1. Visualization of Transfer Learning Approach

3.3. CONVOLUTIONAL NEURAL NETWORKS

Convolutional Neural Networks (CNNs) are a specialized type of deep learning architecture widely used in computer vision and pattern recognition tasks. Unlike traditional neural networks, where each neuron in one layer connects to every neuron in the next, CNNs utilize a local connectivity pattern by applying shared weights in the form of convolutional filters. This significantly reduces the number of parameters and allows the network to learn spatial hierarchies of features effectively. The core operation in a CNN is the convolution, a mathematical function that combines two sets of information—typically, a filter (or kernel) and a small region of the input. This process results in a feature map that highlights patterns such as edges, textures, or shapes. These features become progressively more abstract in deeper layers of the network. In image processing tasks, 2D convolutions are commonly used to capture spatial relationships between pixels. This architecture is particularly well-suited for malware detection when malware binaries are visualized as grayscale images. The shared weights and hierarchical feature extraction make CNNs highly efficient at identifying patterns and anomalies that distinguish malicious from benign code, even in complex visual representations.

3.3.1 PRETRAINED CNN MODELS

Pre-trained convolutional neural networks (CNNs) have become foundational tools in deep learning, particularly for tasks involving image recognition and classification. These models are initially trained on extensive and diverse datasets—such as ImageNet—which enables them to learn intricate and generalizable patterns. When applied to new domains, pre-trained models offer a significant advantage by

reducing the need for large task-specific datasets and extensive computational overhead. In this study, we adopted a transfer learning strategy that leverages these pre-trained networks to develop an effective malware classification framework. By reusing their learned feature representations, we accelerated training and enhanced accuracy, even with relatively limited malware-specific data. As outlined in Table 2, our model integrates several state-of-the-art pre-trained CNN architectures—including VGG16, VGG19, Xception, ResNet50, EfficientNetV2B0, MobileNetV2, and ConvNeXtLarge. The combination of these models allows for comprehensive and multi-scale feature extraction, making our approach a powerful solution for detecting malicious patterns across varied digital environments.

Table 2. The pretrained CNN models adopted in this study

Model	Size (MB)	Accuracy in ImageNet Dataset	Number of Parameters
VGG16	528	71.3%	138.4M
VGG19	549	71.3%	143.7M
Xception	88	79.0%	22.9M
ResNet50	98	74.9%	25.6M
EfficientNetV2B0	29	78.7%	7.2M
MobileNetV2	14	71.3%	3.5M
ConvNeXtLarge	1310	86.7%	350.1M

3.4 AUTO ENCODERS

In the context of image classification, incorporating an autoencoder-decoder structure at the end of a CNN model can significantly enhance the system’s effectiveness and resilience. Autoencoders are a type of neural network designed to compress input data into a lower-dimensional latent space and then reconstruct it, thereby learning essential data representations. When integrated with convolutional neural networks, this structure acts as a refinement layer that enhances the quality of feature extraction by filtering out noise and irrelevant details. This refinement process supports better generalization and leads to higher classification accuracy, as the model becomes more adept at identifying and focusing on the most informative aspects of the input.

3.5 DATASETS

Evaluating a deep learning model across varied scenarios and datasets is essential to verify its applicability in practical, real-world settings. In this research, we developed and tested our proposed malware detection model using two separate datasets representing different computing environments: Android and desktop operating systems. These datasets were selected to assess the model’s performance in both binary classification (malware vs. benign) and multi-class classification (across multiple malware families). This dual testing strategy provides a more thorough understanding of the model’s adaptability, reliability, and overall effectiveness in diverse threat detection tasks.

3.5.1. ANDROID DATASET

The Android malware dataset utilized in this study was previously introduced in our earlier work [32]. It comprises a total of 6,000 samples, equally divided into 3,000 malicious and 3,000 benign grayscale images, as summarized in Table 3. Each image was generated by visualizing the binary contents of APK files (details in Section 3.6). The malicious samples were randomly selected from reputable Android malware databases such as Malgenome and Drebin, ensuring diversity in malware behavior and structure. The benign samples were collected using the APKPure downloader tool, targeting legitimate applications from the official Google Play Store. In our previous project, we also developed an automated script to facilitate the retrieval of application package names directly from Google Play, which was instrumental in constructing this dataset. As shown in Figure 2, our Android dataset is structured with examples of both malware and benign instances.

Table 3 Sample distribution of Android dataset according to categories

Category	Number of Sample
Malware	3000
Benign	3000

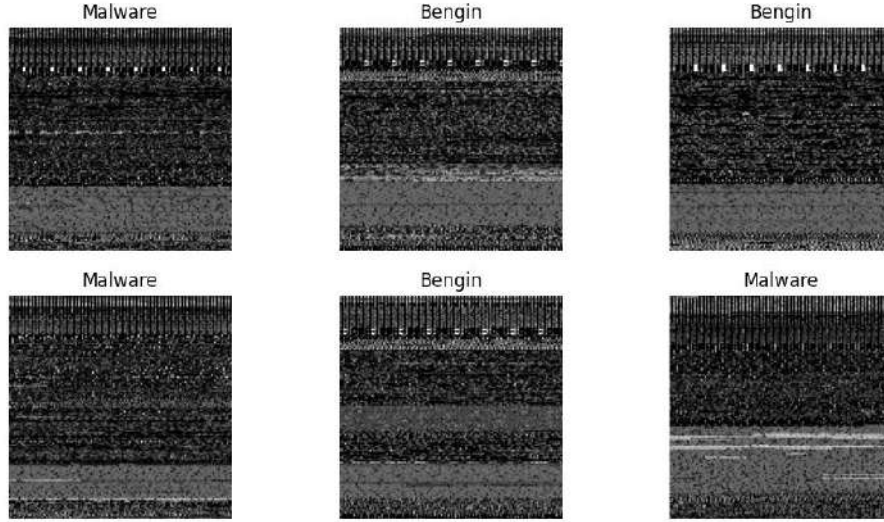


Figure 2. Sample records from the used the Android dataset

3.5.2. DESKTOP DATASET

The second dataset utilized in this research represents malware samples that target desktop-based operating systems. Originally introduced in [33], this dataset consists of 9,339 grayscale images, each derived from the binary structure of malware files and visualized as described in Section 3.6. The dataset spans 25 distinct malware families but exhibits a significantly imbalanced class distribution, where some categories contain far more samples than others. This imbalance, illustrated in Figure 3, poses challenges for traditional machine learning models, which may struggle to accurately classify underrepresented classes. Rather than applying data balancing techniques such as under sampling or oversampling, we chose to retain the dataset's original distribution. This decision aligns with the goal of simulating real-world conditions, where data often reflects natural imbalances. Our objective was to evaluate the model's ability to generalize and perform accurately under such constraints, thereby demonstrating its robustness and practical applicability in real deployment scenarios. As seen in Figure 4 the malware examples in our dataset have been converted to grayscale images.

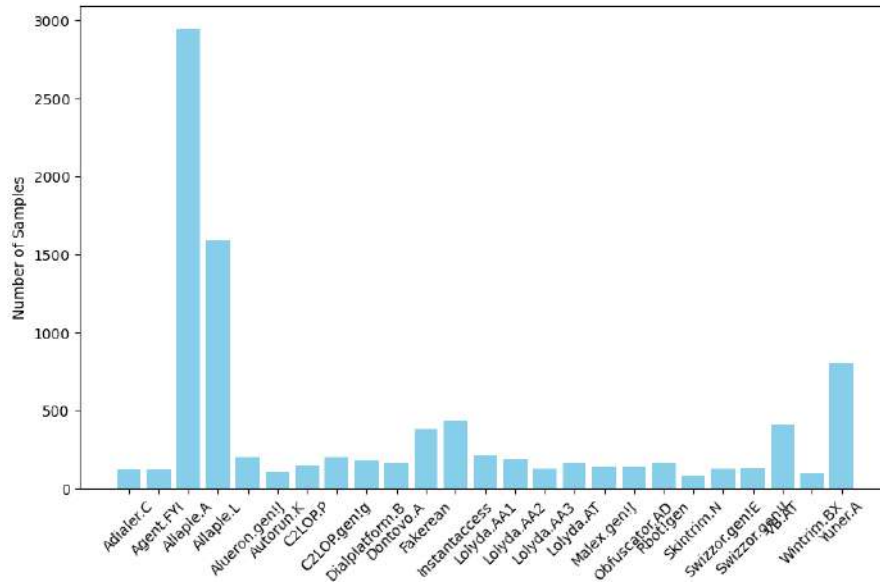


Figure 3. Number of samples per malware family in the used Desktop dataset

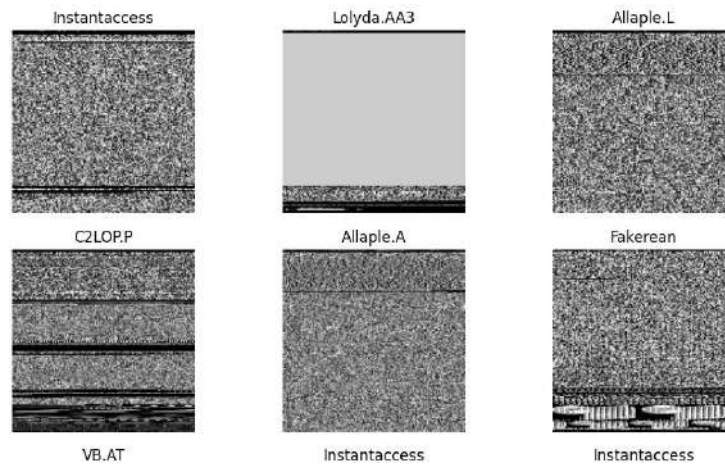


Figure 4. Sample records form malware families in the desktop dataset

3.6. DATA VISUALIZATION

A malware binary is processed by converting it into a vector of 8-bit unsigned integers. This vector is then arranged into a 2D array, which can be visualized as a grayscale image with pixel values ranging from 0 to 255, where 255 denotes white pixels and 0 indicates black pixels. This method allows for visual analysis and processing of malware data, as depicted in Figure 5.

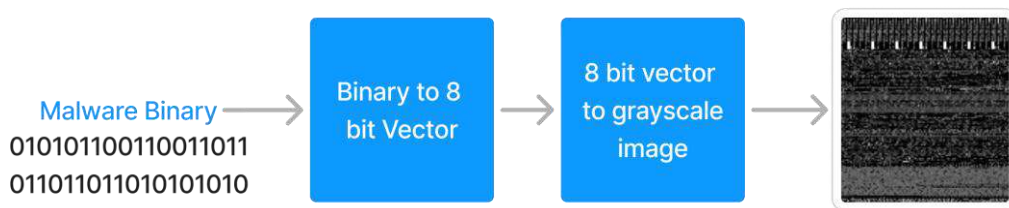


Figure 5. Transformation of malware binary data into a grayscale image.

3.7. PROPOSED MODEL

In this work, we introduce a novel malware detection framework that leverages visual representations of binary files and fuses the strengths of multiple advanced convolutional neural network (CNN) architectures. As illustrated in Figure 6, the process begins with the conversion of raw malware binaries into 8-bit binary vectors. These vectors are subsequently reshaped into grayscale image matrices, making them suitable for image-based processing. The grayscale images are then passed in parallel through seven pre-trained CNN models—VGG16, VGG19, Xception, ResNet50, EfficientNetV2B0, MobileNetV2, and ConvNeXtLarge. Rather than fine-tuning these models end-to-end, we extract their high-level feature outputs from the final convolutional layers and flatten each output into a one-dimensional vector. These vectors are concatenated to form a unified feature representation that captures multi-scale characteristics of the malware samples. To further improve feature compactness and remove redundancies, the concatenated vector is passed through an Autoencoder block. This block consists of symmetrical encoder and decoder dense layers with 512 and 256 neurons, respectively, using ReLU as the activation function. The encoder compresses the data into a latent space, while the decoder attempts to reconstruct the original feature set, enhancing the feature robustness before final classification. Depending on the task type, the processed features are directed to a classification head optimized for either binary or multi-class output. For binary classification (malware vs. benign), the model uses a sigmoid activation function with binary cross-entropy loss. For multi-class classification (identifying specific malware families), a softmax activation function and sparse categorical cross-entropy loss are employed. Both setups use a fixed learning rate of $1e-5$. No additional hyperparameter tuning was performed beyond these core settings. This architecture not only consolidates the advantages of several state-of-the-art CNNs but also benefits from an intermediate compression step through the autoencoder, making it well-suited for detecting a wide variety of malware threats across platforms.

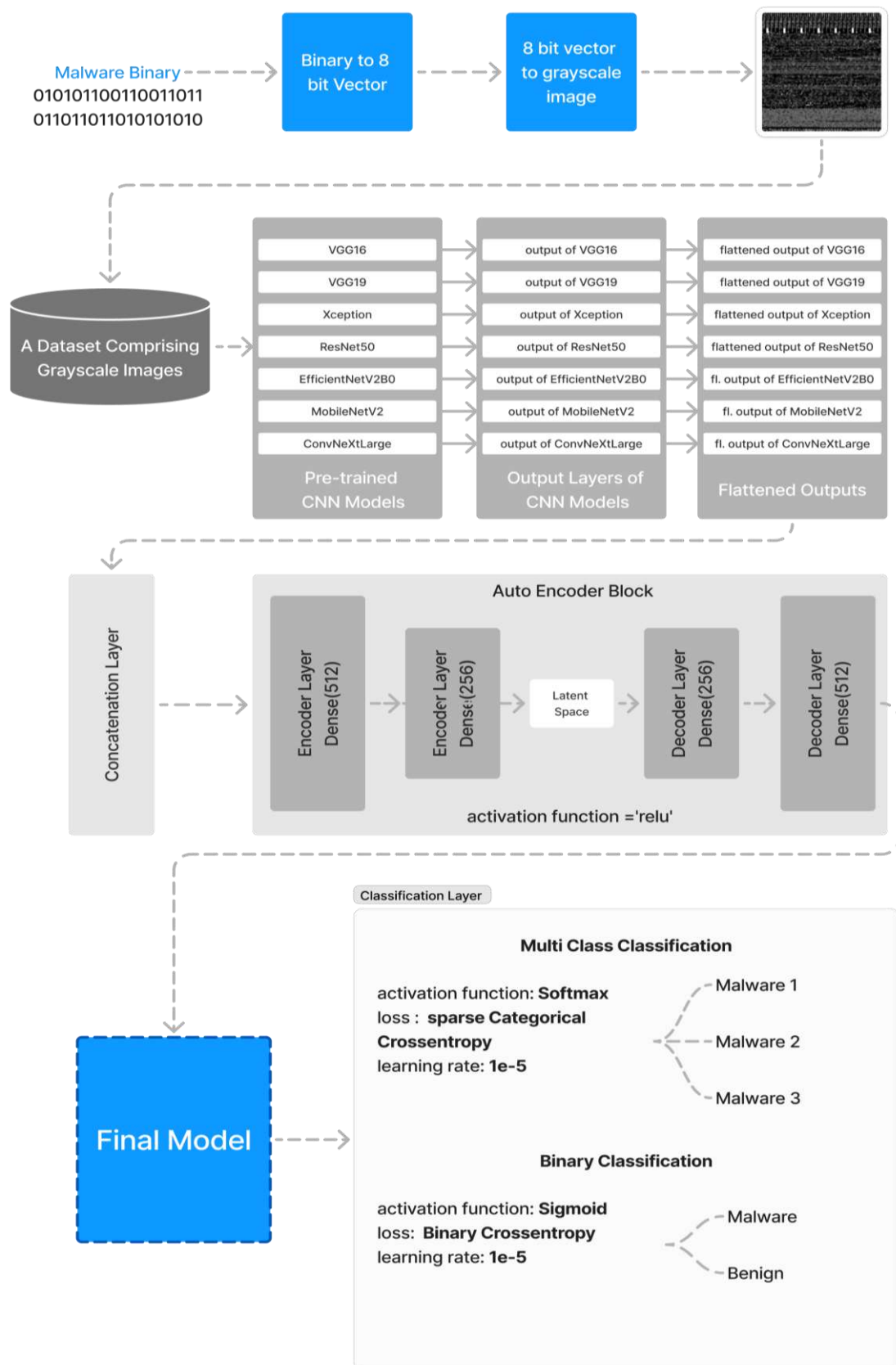


Figure 6. Visualization of our proposed model

IV. RESULTS

4.1. EXPERIMENT SETUP

In this study, multiple experiments and evaluations were conducted on a range of deep learning and machine learning models. The testing environment consisted of a machine configured with an Intel i7 12th generation processor and 32 GB of RAM, which provided sufficient computational power for executing the tasks efficiently. All deep learning-related experiments were implemented using the TensorFlow framework. This hardware-software setup proved to be effective for running our proposed model, offering fast execution and streamlined analysis without the need for high-end or specialized computing infrastructure typically required for deep learning workloads.

4.2. OBTAINED RESULTS

4.2.1. DESKTOP DATASET WITH MULTI CLASS CLASSIFICATION TASK

To evaluate the effectiveness of our proposed model in a multi-class classification scenario, we conducted experiments using the desktop malware dataset. The dataset was split into 80% training and 20% testing portions. Following the model architecture discussed earlier, the ReLU activation function was applied across all dense layers, and the training process was carried out over 20 epochs. This setup was consistent for all model variations to maintain comparability. Table 5 provides a detailed summary of the training progress across epochs. A consistent and steep decline in training loss is observed, accompanied by a corresponding rise in training accuracy. By the 12th epoch, the model achieved perfect training accuracy (100%). However, more importantly, the validation accuracy also continued to improve and remained high throughout, peaking at 99.83% by the 20th epoch. This indicates that the model not only learned the training data well but also generalized effectively to previously unseen samples. As visualized in Figure 7, the training and validation loss curves decrease rapidly, with validation loss stabilizing at very low levels early in the training process. Meanwhile, the accuracy curves reflect steady improvement with minimal fluctuation, showing the model's stability and robustness during training.

To further analyze the model's classification ability, a detailed performance report is presented in Table 6. The model achieved an overall accuracy of 99.84%, with a macro-average F1 score of 0.9943. This indicates consistently high precision and recall across the 25 malware classes, despite the dataset's significant class imbalance.

Table 4. Output of Multi-Class Classification for Our Proposed Model Over 20 Epochs

Loss	Accuracy	Validation Loss	Validation Accuracy
0.059402	1.000.000	0.007986	0.998393

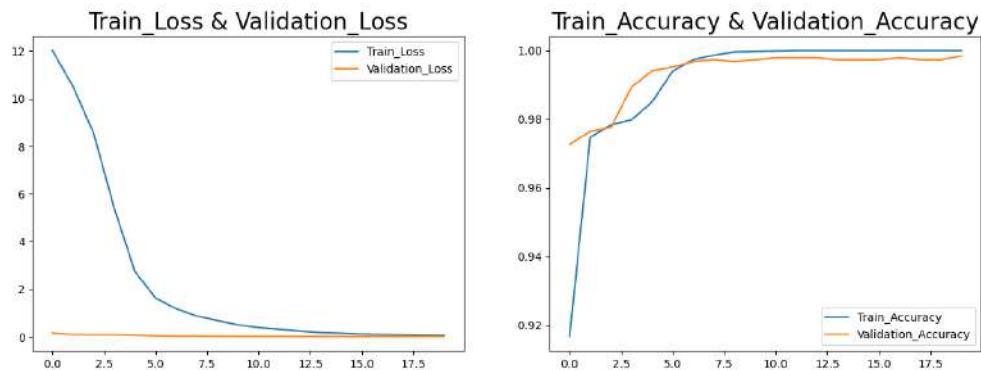


Figure 7. Visualization of our proposed model's outputs over multi-class classification task

Table 5. Classification Report over Multi Class Classification

Metric	Precision	Recall	F1 Score	Support
accuracy	0.9984	0.9984	0.9984	0.9984
macro	0.9946	0.9941	0.9943	1867
weighted	0.9984	0.9984	0.9984	1867

Confusion Matrix Heatmap

A confusion matrix heatmap, shown in Figure 8, provides a visual breakdown of the model’s predictions across all malware classes. It reveals that only 3 misclassifications occurred out of 1,867 test samples, demonstrating the model’s remarkable accuracy and reliability. Despite the presence of severely imbalanced class distributions, the model maintained exceptional performance, accurately classifying instances from both frequent and rare malware families. This performance is a testament to the model’s ability to extract meaningful and discriminative features from grayscale malware images using a combination of CNN architectures and autoencoder enhancement.

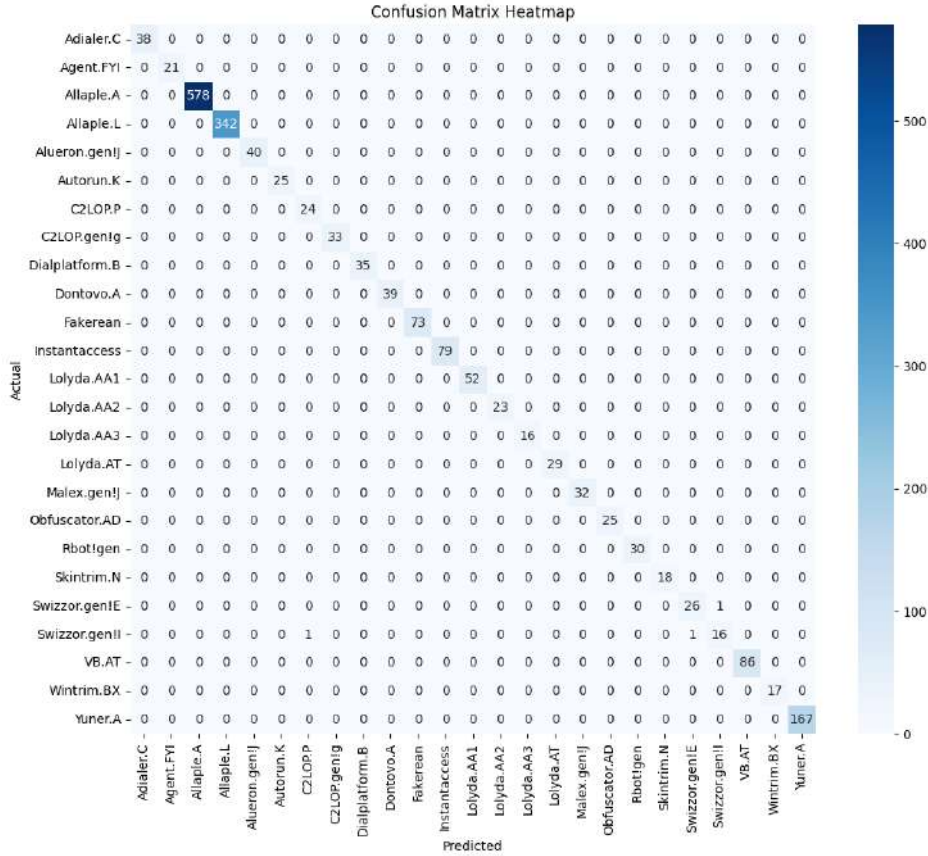


Figure 8. Confusion Matrix Heatmap for Multi-class classification in desktop environment

4.2.2. ANDROID DATASET WITH BINARY CLASSIFICATION TASK

Following the successful evaluation of our model on the multi-class classification task using the Desktop dataset, we extended our experiments to a different context to further validate its versatility. Specifically, we tested the model’s performance on a binary classification task using the Android malware dataset, previously described in Section 3.5.1. The dataset was partitioned in the same manner as before, with 80% used for training and the remaining 20% reserved for validation. The training configuration remained consistent with the prior experiment: ReLU activation was applied across all dense layers, and a fixed learning rate of 1e-5 was used. The model was trained over 20 epochs. Although this task involved

only two output classes (malicious vs. benign), the model demonstrated strong learning behavior and achieved highly effective classification performance—underscoring its adaptability across varying malware detection scenarios.

Table 8. Output of Binary Classification for Our Proposed Model Over 10 Epochs

Epoch	Loss	Accuracy	Validation Loss	Validation Accuracy
20	0.006215	0.986733	0.009306	0.998333

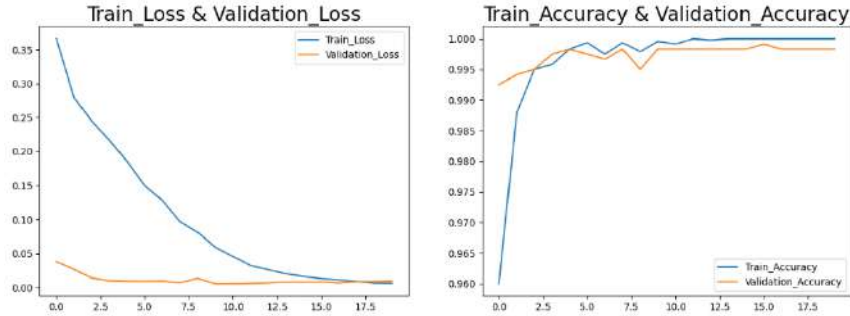


Figure 9. Visualization of our proposed model's outputs over binary classification task

The performance of our proposed model on the Android binary classification task yielded exceptional results, as reflected in Table 8, Table 9, and Figure 9. The model achieved a validation accuracy of 99.83%, indicating its strong ability to generalize to unseen Android samples. The training process spanned 20 epochs, during which both training and validation accuracy showed a consistent upward trend, while loss values steadily declined. As observed in Tab, the training loss decreased from 0.3657 in the first epoch to just 0.0062 by the final epoch. Concurrently, training accuracy improved from 96% to 100%, with full accuracy being achieved by the 12th epoch. The validation loss also dropped substantially—from 0.0376 initially to a low of 0.0054, while validation accuracy increased and stabilized near 99.83% from the 5th epoch onward. Though minor fluctuations were noted in the loss and accuracy curves, particularly between epochs 7 and 13, the overall trajectory clearly demonstrates the model's ability to learn efficiently and maintain high generalization performance. The line plots in Figure 9 further reinforces these observations. The training and validation loss curves both trends downward, converging at minimal loss values by the end of training. Likewise, the accuracy curves display rapid convergence toward optimal performance, with only negligible divergence between training and validation sets, signifying low overfitting and robust learning behavior. The classification report presented in Table 9 highlights balanced and high-performance metrics across both classes—malicious and benign. The model achieved precision, recall, and F1-scores of 0.9983 for each class, demonstrating a near-perfect classification ability. Moreover, the macro and weighted averages further confirm the consistent accuracy across the entire dataset of 1,200 samples. Taken together, these results validate the model's effectiveness not only in multi-class scenarios (as shown with the desktop dataset) but also in binary classification settings. This adaptability across distinct datasets and classification tasks illustrates the robustness and practical applicability of the proposed architecture in real-world malware detection.

Table 9 Classification Report over Binary Classification

	Precision	Recall	F1 Score	Support
benign	0.9979	0.9981	0.9985	594
malware	0.9982	0.9985	0.9983	606
accuracy	0.9983	0.9983	0.9983	0.9983
macro average	0.9983	0.9983	0.9983	1200
weighted average	0.9983	0.9983	0.9983	1200

Confusion Matrix Heatmap

The confusion matrix heatmap depicted in Figure 10 provides a clear and detailed assessment of the model's performance on the binary classification task using the Android dataset. Out of a total of 1,200 test samples, the model accurately identified 593 out of 594 benign samples, misclassifying only a single instance as malware. Similarly, it correctly predicted 605 out of 606 malware samples, with just one sample incorrectly labeled as benign. This results in only two misclassifications across the entire test set, highlighting the model's excellent discriminative capability. The balance between true positives and true negatives demonstrates not only high overall accuracy but also a strong ability to minimize both false positives and false negatives—an essential requirement in security-critical applications like malware detection. These findings further validate the robustness and reliability of our proposed hybrid model in real-world binary classification scenarios.

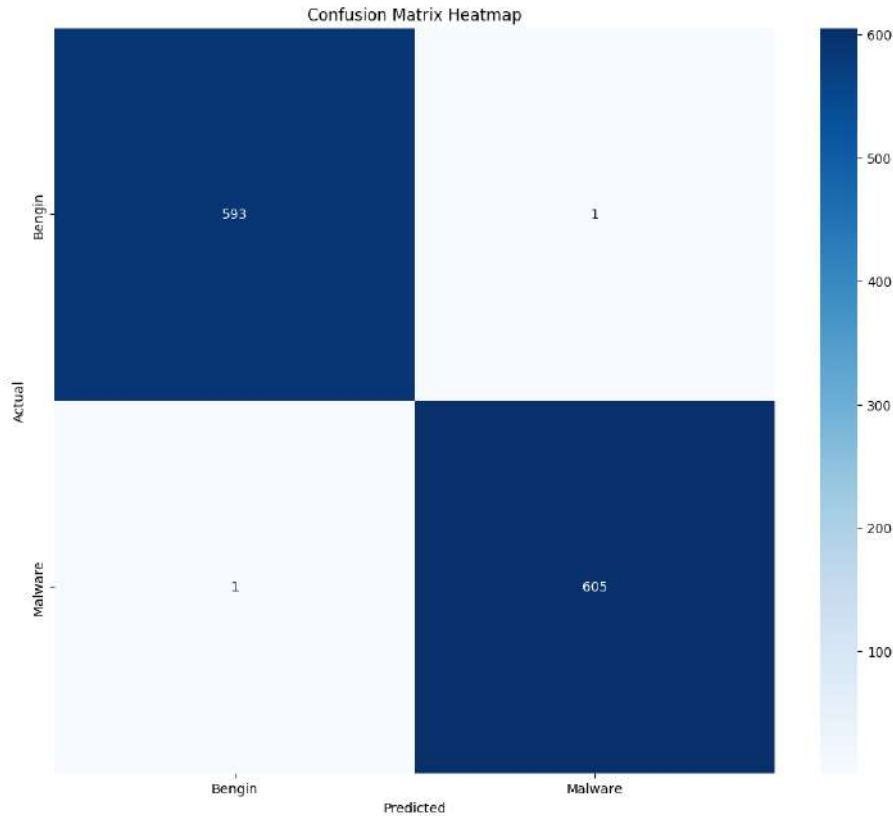


Figure 10. Confusion Matrix Heatmap for Binary classification

V. CONCLUSION

In this study, we introduced a comprehensive malware detection framework based on an ensemble of pre-trained convolutional neural network (CNN) architectures. The proposed model was designed to operate on grayscale visual representations of malware binaries, allowing for efficient pattern recognition through deep feature extraction. We rigorously evaluated its effectiveness using two distinct datasets: one targeting Android malware for binary classification and another focused on desktop malware for multi-class classification involving 25 different malware families. The experimental results clearly demonstrate the model's high performance, achieving validation accuracies exceeding 99.8% in both classification tasks. Notably, only three misclassifications were observed in the multi-class setting, despite significant class imbalance. Additionally, we showed that the dense feature representations extracted by our model could be successfully reused by a variety of traditional machine learning classifiers, which consistently yielded near-perfect results. This highlights the strength and versatility of our hybrid approach in enabling both deep and classical models to work synergistically. While the current model excels in controlled settings, a critical challenge remains—code obfuscation, a widely used evasion technique in modern

malware. Obfuscation complicates static and visual analysis by distorting or encrypting the original binary content, reducing detection accuracy and model robustness.

To overcome this limitation, our future work will explore the integration of Visual Transformers and Generative Adversarial Networks (GANs) into the current architecture. Visual Transformers, with their global attention mechanisms, are expected to enhance the model's ability to capture long-range dependencies and subtle patterns in obfuscated malware images. Meanwhile, GANs will be used to synthetically generate obfuscated malware variants, expanding the training dataset with more diverse and challenging examples. This will allow the model to generalize better and detect even the most sophisticated forms of evasion. By incorporating these advanced deep learning strategies, we aim to build a more adaptive, resilient, and intelligent malware detection system. The enhanced model will not only address existing vulnerabilities related to obfuscation but also serve as a valuable contribution to the field of cybersecurity—paving the way for real-world deployment in malware analysis platforms, intrusion detection systems, and endpoint protection solutions.

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Conflict of interest

The authors declare that they have no conflict of interest.

Data availability statement

The datasets generated during and/or analysed during the current study are available from the authors on reasonable request.

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VIS-NIR Spektroskopi ve Hiperspektral Görüntüleme Teknolojilerinin Gıda, Tarım ve Biyomedikal Alanlardaki Uygulamaları

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Özet – Görünür (VIS, 400–700 nm) ve yakın kızılötesi (NIR, 700–2500 nm) dalga boyları, malzemelerin optik özelliklerini anlamak ve içerik analizleri gerçekleştirmek açısından kritik öneme sahiptir. Günümüzde, hızlı ve numuneye zarar vermeden yapılan ölçümlere duyulan ihtiyaç, VIS-NIR spektroskopisi ile hiperspektral görüntüleme yöntemlerinin kullanımını yaygınlaştırmıştır. VIS-NIR spektroskopisi, tek bir noktadan alınan spektral veriler aracılığıyla bileşim bilgisi sunarken; hiperspektral görüntüleme, geniş alanlardan hem spektral hem de uzamsal verileri eş zamanlı toplayarak daha detaylı analiz imkânı sağlamaktadır. Bu çalışmada, iki teknolojinin temel çalışma prensipleri, avantajları, dezavantajları ve uygulama örnekleri sistematik bir yaklaşımla karşılaştırılmıştır. Özellikle gıda kalitesi, tarımsal üretim, tıbbi görüntüleme, çevre izleme ve uzay araştırmaları gibi farklı alanlardaki kullanımları değerlendirilmiştir. Ayrıca, veri işleme tekniklerindeki gelişmelerin ve yapay zekâ uygulamalarının bu teknolojilerin gelecekteki gelişim potansiyeline etkileri tartışılmıştır. Çalışmanın amacı, farklı araştırma ve uygulama ihtiyaçlarına uygun yöntem seçimi konusunda literatüre katkı sağlamaktır.

Anahtar Kelimeler – VIS NIR, Hiperspektral, Gıda, Yakın Kızılötesi, Veri İşleme.

I. GİRİŞ

Elektromanyetik spektrumun görünür (VIS: 400–700 nm) ve yakın kızılötesi (NIR: 700–2500 nm) bölgeleri, madde ve ışık etkileşimlerinin anlaşılmasında önemli bir yer tutmaktadır [1,2]. Bu spektral bantlar, organik ve inorganik maddelerin fiziksel ve kimyasal özellikleri hakkında değerli bilgiler sunmaktadır [3]. Özellikle son yıllarda, hızlı, hassas ve tahribatsız analiz ihtiyacının artmasıyla birlikte VIS-NIR spektroskopisi ve hiperspektral görüntüleme (hyperspectroscopy) teknolojileri ön plana çıkmıştır [4,5,6]. VIS-NIR spektroskopisi, belirli bir noktadan elde edilen spektral verilerle numunelerin bileşim analizinin gerçekleştirilmesine olanak tanırken, hiperspektral görüntüleme, hem spektral hem de uzamsal bilgileri birleştirerek yüzeyin her bir pikseline ait spektral verileri sunmaktadır [7,8,9]. Bu yöntemler, özellikle gıda güvenliği, tarımsal üretim, biyomedikal görüntüleme, çevresel izleme ve uzay araştırmaları gibi birçok kritik alanda uygulama potansiyeline sahiptir [10,11,12].

Bu çalışmada, VIS-NIR spektroskopisi ve hiperspektral görüntüleme teknolojileri kapsamlı bir şekilde ele alınacak; teknik özellikleri, avantajları ve dezavantajları karşılaştırmalı olarak incelenecektir. Ayrıca, her iki yöntemin farklı uygulama alanlarındaki etkinliği değerlendirilecek ve gelecekteki gelişim yönelimleri tartışılacaktır. Böylece, farklı araştırma ve endüstri ihtiyaçları doğrultusunda hangi yöntemin daha uygun olduğuna yönelik bir bakış açısı kazandırılması amaçlanmaktadır.

II. VIS-NIR SPEKTROSKOPISI

VIS-NIR (Görünür-Yakın Kızılötesi) spektroskopisi, elektromanyetik spektrumun 400 nm ile 2500 nm arasındaki dalga boylarında gerçekleştirilen optik ölçümleri ifade etmektedir [13]. Bu teknik, numuneye gönderilen ışığın bir kısmının soğurulması, yansımaları veya iletilmesi prensibine dayanmaktadır [14]. Elde edilen spektral bilgi, numunenin kimyasal bileşimi, yapısal özellikleri ve fiziksel durumu hakkında önemli ipuçları sağlamaktadır.

VIS-NIR spektroskopisinde temel olarak bir ışık kaynağı, numune bölgesi ve bir dedektör sistemi bulunmaktadır [13]. Numuneden geçen veya numune tarafından yansıtılan ışık, dedektör tarafından ölçülür ve belirli dalga boylarındaki absorptans veya reflektans değerleri kaydedilmektedir. Bu ölçümler, çeşitli analitik yöntemlerle işlenerek numunenin özellikleri hakkında kantitatif ve kalitatif bilgi elde edilmektedir.

2.1 Avantajları

- **Hızlı ve Tahribatsız Analiz:** Ölçüm süresi saniyeler içinde tamamlanabilir ve numuneye zarar verilmez.
- **Düşük Maliyetli Sistemler:** VIS-NIR spektroskopik cihazlar, hiperspektral görüntüleme sistemlerine göre daha ekonomik çözümler sunmaktadır.
- **Basit Veri Yapısı:** Noktasal veri elde edildiği için veri boyutu küçük ve işleme süreci hızlıdır.
- **Taşınabilirlik:** Portatif spektrometre sistemleri sayesinde sahada anlık analiz yapılabilmektedir.

2.2 Dezavantajları

- **Uzamsal Bilgi Eksikliği:** Ölçüm yalnızca tek bir noktadan yapılır; numunedeki heterojenlikler göz ardı edilebilmektedir.
- **Numune Hazırlık Gereksinimi:** Heterojen örneklerde doğru sonuçlar alabilmek için örnek hazırlama işlemleri gerekebilmektedir.
- **Sınırlı Görselleştirme:** Spektral veriler doğrudan görsel bilgi sağlamaz; sadece spektrumlar elde edilmektedir.

VIS-NIR spektroskopisi, özellikle homojen numunelerde içerik analizleri için oldukça etkili bir yöntemdir. Ancak, karmaşık yapıya veya heterojen dağılıma sahip numunelerde, tek nokta ölçümünün sınırlamaları göz önünde bulundurulmalıdır.

III. HIPERSPEKTRAL GÖRÜNTÜLEME (HYPERSPPECTROSCOPY)

Hiperspektral görüntüleme (HSI: Hyperspectral Imaging), hem spektral hem de uzamsal bilgi içeren verilerin eşzamanlı olarak elde edilmesini sağlayan güçlü bir teknolojidir. Bu yöntem, bir sahnenin veya nesnenin her pikseli için geniş bir spektral bant aralığında ölçümler gerçekleştirilerek, her pikselin bir spektral imzasını oluşturmaktadır. Böylece, hem görüntü hem de spektrum verileri aynı anda analiz edilebilmektedir. Hiperspektral sistemler, genellikle **pushbroom** (satır taramalı), **whiskbroom** (noktasal taramalı) veya **snapshot** (anlık görüntüleme) teknikleriyle çalışmaktadır. Pushbroom sistemler, bir satır boyunca tüm spektral bilgiyi toplarken, whiskbroom sistemler belirli bir noktayı tarayarak veri toplamaktadır. Snapshot sistemler ise tek bir görüntüde tüm sahneyi spektral olarak kaydedebilir, ancak çözünürlükleri genellikle sınırlıdır.

3.1 Avantajları

- **Spektral ve Uzamsal Bilginin Birleşimi:** Her pikselin spektral içeriği kaydedildiğinden, yüzeydeki homojenlik, doku farklılıkları ve bileşen dağılımları detaylı şekilde analiz edilebilmektedir.
- **Heterojen Numunelerde Üstün Performans:** Homojen olmayan örneklerde bile yüksek doğrulukla karakterizasyon yapılabilmektedir.
- **Çoklu Analiz İmkânı:** Aynı veri seti üzerinden farklı parametreler (örneğin nem oranı, içerik analizi, hastalık tespiti) için eşzamanlı analiz yapılabilmektedir.

- **Yüzey Haritalama:** Numunelerin fiziksel ve kimyasal özellikleri, uzamsal haritalar şeklinde görselleştirilebilmektedir.

3.2 Dezavantajları

- **Yüksek Veri Hacmi:** Elde edilen veriler çok büyük boyutludur ve işlenmesi ciddi hesaplama kaynakları gerektirir.
- **Yüksek Maliyet:** Hiperspektral sistemlerin kurulumu ve bakımı, VIS-NIR spektroskopisine göre oldukça pahalıdır.
- **Veri İşleme Zorluğu:** Gelişmiş analiz teknikleri (örneğin boyut indirgeme, sınıflandırma algoritmaları) gerektirir.
- **Ölçüm Süresi:** Büyük veri hacmi nedeniyle, veri toplama ve analiz süreci, noktasal ölçüm sistemlerine kıyasla daha uzun olabilmektedir.

Hiperspektral görüntüleme, özellikle karmaşık, heterojen veya yüzey özellikleri bakımından değişken numunelerin analizinde büyük avantajlar sunmaktadır. Uzamsal ve spektral bilgilerin birleşimi sayesinde, geleneksel spektroskopi yöntemleriyle elde edilemeyen ayrıntılı bilgiler ortaya çıkarılabilmektedir.

IV. TEKNİK KARŞILAŞTIRMA

VIS-NIR spektroskopisi ve hiperspektral görüntüleme sistemleri, farklı teknik özelliklere ve kullanım alanlarına sahiptir. Aşağıdaki tabloda iki yöntem arasındaki temel farklılıklar özetlenmiştir:

Tablo 1: VIS-NIR Spektroskopisi ve Hiperspektral Görüntüleme Sistemlerinin Teknik Özellikler Açısından Karşılaştırılması

Özellik	VIS-NIR Spektroskopisi	Hiperspektral Görüntüleme
Veri Tipi	Noktasal spektral ölçüm	Piksel bazlı spektral veri (görüntü)
Uzamsal Bilgi	Yok	Var (yüksek çözünürlükte)
Veri Hacmi	Düşük	Çok yüksek
Cihaz Maliyeti	Düşük-Orta	Yüksek
Ölçüm Süresi	Hızlı (saniyeler)	Görece daha uzun (tarama gerekebilir)
Veri İşleme İhtiyacı	Az	Fazla (yüksek işlem gücü gerekir)
Numune Homojenlik Gereksinimi	Yüksek	Düşük (heterojen numunelerde etkili)
Taşınabilirlik	Yüksek (portatif cihazlar mevcut)	Sınırlı (genellikle sabit sistemler)
Uygulama Alanları	Gıda analizi, tarım, biyomedikal	Tarım, çevre izleme, biyomedikal, uzay araştırmaları

VIS-NIR spektroskopisi, özellikle homojen yapıdaki numuneler için hızlı ve düşük maliyetli analizler sunarken, hiperspektral görüntüleme hem homojen hem de heterojen numunelerde çok daha ayrıntılı bilgiler elde edilmesine olanak tanır. Ancak, hiperspektral sistemlerin yüksek veri hacmi ve maliyet gibi önemli sınırlamaları bulunmaktadır. Uygulama ihtiyacına ve projenin bütçesine göre yöntem seçimi yapılmalıdır.

V. UYGULAMA ALANLARI VE ÖRNEKLER

VIS-NIR spektroskopisi ve hiperspektral görüntüleme teknolojileri, farklı sektörlerde geniş uygulama alanlarına sahiptir. Seçilecek yöntem, analiz edilmek istenen numunenin özelliklerine, uygulama ortamına ve ihtiyaç duyulan veri derinliğine göre değişiklik göstermektedir.

5.1 Gıda Kalite Kontrolü

VIS-NIR spektroskopisi:

- Gıda ürünlerinde nem, yağ, protein ve şeker oranlarının hızlı ve tahribatsız bir şekilde belirlenmesi için yaygın olarak kullanılmaktadır.

- Örneğin, süt, et, tahıl ve meyve örneklerinde içerik analizi VIS-NIR spektroskopisi ile başarılı şekilde gerçekleştirilmektedir.

Hiperspektral görüntüleme:

- Ürün yüzeyindeki küf, çürüme, renk değişimi gibi kalite kusurlarının hem spektral hem de uzamsal olarak haritalanmasına imkân tanımaktadır.
- Özellikle meyve ve sebze gibi heterojen yapıya sahip ürünlerde, kalite sınıflandırması ve kusur tespiti için tercih edilmektedir.

5.2 Tarım ve Bitki Sağlığı İzleme

VIS-NIR spektroskopisi:

- Bitkilerde su stresi, klorofil içeriği ve besin durumu gibi parametrelerin hızlı tespiti için kullanılmaktadır.

Hiperspektral görüntüleme:

- Tarımsal arazilerde hastalık tespiti, bitki türü ayrımı ve verim tahmini gibi uygulamalarda öne çıkmaktadır.
- Drone tabanlı hiperspektral sistemler, geniş alanların spektral haritalarını oluşturarak hassas tarım uygulamalarına katkı sağlamaktadır.

5.3 Biyomedikal Görüntüleme

VIS-NIR spektroskopisi:

- Doku analizi, kan glikoz ölçümü ve cilt hastalıklarının tespiti gibi alanlarda kullanılmaktadır.
- Hızlı ölçüm kabiliyeti sayesinde klinik öncesi taramalarda tercih edilmektedir.

Hiperspektral görüntüleme:

- Kanserli doku tespiti, yara iyileşme izleme ve cerrahi rehberlik gibi ileri biyomedikal uygulamalarda kullanılmaktadır.
- Yüksek çözünürlükte spektral veriler sayesinde patolojik değişimler detaylı şekilde haritalanabilmektedir.

5.4 Çevresel İzleme ve Uzay Araştırmaları

VIS-NIR spektroskopisi:

- Toprak örneklerinde nem ve organik madde analizi için kullanılmaktadır.
- Su kalitesi parametrelerinin (örneğin çözünmüş oksijen, bulanıklık) tespiti için de uygulanabilmektedir.

Hiperspektral görüntüleme:

- Orman yangını izleme, petrol sızıntısı tespiti, su kirliliği izleme ve toprak haritalama gibi çevresel izleme uygulamalarında kritik rol oynamaktadır.

Ayrıca uydu tabanlı hiperspektral kameralar, dünya yüzeyinin detaylı spektral analizini sağlayarak jeolojik araştırmalar ve doğal kaynak yönetimi için kullanılmaktadır

VI. SONUÇLAR

Görünür ve yakın kızılötesi spektroskopisi ile hiperspektral görüntüleme, farklı ölçeklerde bilgi sağlayarak birbirini tamamlayan iki yöntem olarak öne çıkmaktadır. Noktasal ölçüm temelli VIS-NIR spektroskopisi, hızlı ve taşınabilir çözümler sunarken; hiperspektral sistemler geniş veri kapsamı ve uzamsal detaylarıyla özellikle heterojen numunelerde üstünlük sağlamaktadır. Bu karşılaştırma, yöntem seçiminde yalnızca cihaz maliyeti ve veri boyutu gibi teknik faktörlerin değil, aynı zamanda uygulama ortamının özelliklerinin de belirleyici olduğunu göstermektedir.

Gıda kalite kontrolünde içerik doğrulama, tarımsal üretimde stres ve hastalık izleme, biyomedikal alanda doku analizi ve cerrahi destek, çevresel gözlemlerde ise toprak, su ve atmosfer parametrelerinin değerlendirilmesi gibi örnekler, bu teknolojilerin disiplinler arası yaygın kullanım potansiyelini ortaya koymaktadır. Ayrıca, uzay araştırmalarında jeolojik yapıların ve yüzey kompozisyonlarının incelenmesi, söz konusu yöntemlerin küresel ölçekteki önemini artırmaktadır.

Gelecekte yapay zekâ ve ileri veri işleme tekniklerinin entegrasyonu, her iki yaklaşımın sınırlılıklarını azaltarak daha güvenilir ve hızlı analizlerin önünü açacaktır. Özellikle derin öğrenme tabanlı modeller, yüksek boyutlu spektral verilerin anlamlandırılmasında kritik bir rol üstlenebilir. Bunun yanında, taşınabilir hiperspektral sistemlerin geliştirilmesi, saha uygulamalarında daha geniş erişim sağlayacaktır.

Sonuç olarak, VIS-NIR spektroskopisi ve hiperspektral görüntüleme, gıda güvenliğinden sağlık teknolojilerine, çevresel izlemeye kadar geniş bir yelpazede stratejik katkılar sunmaktadır. Bu çalışmanın ortaya koyduğu değerlendirmeler, yöntem seçiminde araştırmacılar ve endüstri paydaşları için yol gösterici nitelikte olup, ilerleyen yıllarda daha entegre ve akıllı sistemlerin geliştirilmesine zemin hazırlamaktadır.

KAYNAKLAR

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Entropy Generation Analysis of a Microchannel Heatsink

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Abstract – Microchannel heat sinks (MCHSs) are pivotal cooling devices designed to efficiently dissipate heat from electronic components and high-heat-flux applications by utilizing an array of micro-scale channels through which a coolant flows. This study investigates the entropy generation in a multi-branch MCHS with various fin configurations under laminar flow conditions using numerical simulations. The governing equations for mass, momentum, and energy conservation are solved under steady-state assumptions, focusing on the impacts of fin orientation on temperature distribution, heat transfer performance, and entropy production. Results reveal that fins arranged perpendicular to the main flow induce vortices that enhance heat transfer while increasing fluid friction entropy, yet overall reduce thermodynamic irreversibility. The entropy generation criterion (N_a) identifies this configuration as optimal among the studied cases, implying improved hydrothermal efficiency and lower system irreversibility. These findings offer insights into microchannel design optimized for entropy minimization to enhance thermal management in compact electronic devices.

Keywords – Heat Transfer, Microchannel Heatsink, Entropy Generation.

I. INTRODUCTION

MCHSs are advanced cooling systems that drain heat from electronic components and high-heat-flux devices using minuscule channels. Due to the increased surface area and decreased thermal resistance between the coolant and the heat source, they enable rapid heat transfer rates [1]. They are made up of a series of thin, parallel channels through which coolant, typically a liquid like water, is driven. Microelectronic cooling, laser diode arrays, high-energy laser mirrors, and power electronic devices, where heat flux levels can range from tens to thousands of W/cm², are among the many applications for this technology [2]. MCHSs are crucial for current high-performance electronics and photonics cooling because of their efficiency and compactness, which enable them to sustain modest temperature increases even under extreme heat dissipation demands [3]. Depending on their flow regimes and structural design, MCHSs come in different varieties. Two-phase microchannel heat sinks, which use latent heat and boiling to get even greater heat transfer coefficients, and single-phase MCHSs, in which the coolant stays liquid throughout, are the most popular varieties [4]. Microchannels can be either wavy or straight structurally; undulating designs can improve heat transmission and turbulence, while straight versions are more straightforward and prevalent. Plate-fin, pin-fin, and cold plate MCHSs are other varieties that vary in fin configurations and shapes to maximize thermal efficiency for certain uses. Two-phase MCHSs, despite their complexity, employ phase change to lower coolant flow rates and maintain consistent temperatures [5].

Jung et al. [6] examined analytical solutions for the entropy production rate distribution related to fluid friction and heat transmission in MCHSs. MCHSs were conceptualized as fluid flowing through a porous medium. The velocity and temperature distributions of MCHSs, which were based on the two-equation model for heat transfer and the modified Darcy model for fluid flow, were used to provide analytical

solutions. The entropy production of MCHSs was determined using the analytical solution. Thermal optimization of the MCHSs was carried out, and the effects of height, channel width, and fin thickness on the entropy production rate were examined. Khan et al. [7] optimized the overall performance of MCHSs using an entropy generation minimization approach. By using mass, energy, and entropy balances and taking into account a suitable control volume, new general formulations for the entropy generation rate were created. The slip flow region's entropy production rate was examined in relation to the channel aspect ratio, fin spacing ratio, heat sink material, Knudsen numbers, and accommodation coefficients. Heat transfer and friction coefficients were correlated analytically and empirically, and the hydraulic diameter of the channel was determined by the characteristic length.

Peter and Balasubramanian [8] used DI water and microencapsulated phase change slurry (MPCMS) to investigate the thermofluidic properties and entropy production in three different microchannel configurations: straight, segmental, and rib-groove. The study investigated operational factors such as fluid velocity, heat flux, and MPCM volume fractions by numerical analysis. The findings showed that while MPCM improves thermal performance more successfully in straight and rib-groove channels, segmental channels lower wall temperature by 29.7% and 26.3%, respectively, as compared to straight and rib-groove channels. Overall, total entropy was decreased in segmental channels due to increased frictional entropy and lower thermal entropy formation. Gupta and Subbarao [9] utilized DI water and water/alumina nanofluids at low Reynolds numbers to assess exergy and entropy production in a stainless steel MCHS. The results demonstrated that for $Re=40$, a 4% concentration of nanoparticles results in a 56% increase in exergy gain over DI water. At $Re=10$, DI water exhibited the maximum second law efficiency at 7.2%, while nanofluids displayed 5.9%.

The application of symmetrical ogive-shaped ribs in MCHS to improve thermal performance with little pressure drop was examined by Akhtar et al. [10]. Ribs on all walls, side walls, and bottom walls were the three configurations that were analysed. Heat transport and flow parameters were evaluated numerically using a laminar conjugate heat transfer model. According to the results, symmetrical ribs enhanced the Nusselt number by 13–50% when compared to smooth MCHS in the 100–1000 Reynolds number range. They also showed a 58% decrease in overall entropy generation. Abbassi [11] employed an analytical method to investigate entropy formation in a uniformly heated MCHS. The forced convection issue was solved using a porous medium model based on a two-equation model for heat transfer and an expanded Darcy equation for fluid flow. The governing equations were solved analytically after being converted into dimensionless form. Expressions for the local and average entropy generation rates in dimensionless form were obtained by doing a second law analysis based on velocity and temperature fields.

The present work assessed the entropy generation in an MCHS by estimating the entropy generation due to the friction and pressure and calculating the entropy generation number. Fig. 1 depicts a schematic of the proposed MCHS.

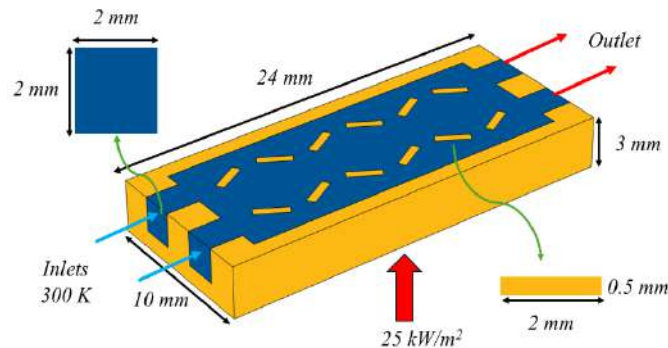


Fig. 1 Schematic of the proposed MCHS and its dimensions.

II. NUMERICAL METHOD

To calculate the hydrothermal performance of the current multi-branch MCHS, it is needful to solve the governing equations numerically in both the fluid and solid regions. The subsequent analyses are based on the following assumptions that contribute to the formulation of the governing equations: The thermophysical properties of the solid and cooling fluid are considered as constant values and independent of temperature variation on the cooling action. A stationary method is employed in which the temperature and velocity are constant. The fluid flow is assumed to be laminar and incompressible, and the effect of gravity and free convection on the fluid region is neglected. A stable heat flux is applied to the bottom wall of the MCHS, and radiative heat transfer in both the solid and fluid regions is neglected. Given these assumptions, the conformance formulation for the governing equations in the stationary case can be expanded. The mass conservation equation is as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (1)$$

The momentum equations in the specified three-dimensional region can be expressed as follows:

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = -\frac{1}{\rho_f} \frac{\partial p}{\partial x} + \frac{\mu_f}{\rho_f} \left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right] \quad (2)$$

$$u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} = -\frac{1}{\rho_f} \frac{\partial p}{\partial y} + \frac{\mu_f}{\rho_f} \left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right] \quad (3)$$

$$u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} = -\frac{1}{\rho_f} \frac{\partial p}{\partial z} + \frac{\mu_f}{\rho_f} \left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right] \quad (4)$$

The energy equation for the fluid area is given by:

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} = \frac{k_f}{\rho_f c_{pf}} \left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right] \quad (5)$$

For stationery conditions, the energy equation in the solid domain is defined as follows:

$$k_s \left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right] = 0 \quad (6)$$

The overall rate of entropy generation follows the following formula [1, 2]:

$$S_g = S_{g,\Delta p} + S_{g,\Delta T} \quad (7)$$

$$S_{g,\Delta p} = \frac{\dot{m} \Delta p}{\rho_m T_a} \quad (8)$$

$$S_{g,\Delta T} = \frac{Q_{base}(T_{base,avg} - T_a)}{T_{base,avg} T_a} \quad (9)$$

In the current study, $S_{g,\Delta T}$ signifies the entropy created by heat transfer, while $S_{g,\Delta p}$ shows the entropy generated by fluid flow. $\dot{m}$ denotes the fluid's mass flow rate, and T_a is the inlet fluid temperature, which is acquired to be $T_{f,in}$ for the purpose of this study.

The goal of the evolving entropy generation value $N_{s,a}$ is to make the expressionist simpler to evaluate the irreversibility of microchannels. The explanation for this factor is [1]:

$$N_{s,a} = S_g / S_{g,0} \quad (10)$$

where $S_{g,0}$ is the entropy generation rate of the base case in the current work. According to the second law of thermodynamics, if the amount of $N_{s,a}$ is less than 1, the included case has better efficiency due to a decrease in irreversibility in the heat transfer process and fluid flow.

III. RESULTS

In the studies conducted, it is observed that by using fins in different arrangements and layouts (cases 1 to 4), the temperature distribution pattern significantly improved compared to the base case (Fig. 2). This improvement is due to the increased contact area and more efficient heat conduction within the heat sink structure. Additionally, the results showed that as the angle of the fins relative to the main flow path of the fluid increases, heat transfer from the solid section to the fluid environment is intensified due to the formation of vortices and swirling flows in the fluid passage area. As a result of this process, the heat

dissipation rate increased, and the overall temperature of the heat sink experienced a significant decrease compared to the baseline state.

The results obtained from the simulations show that as the Reynolds number increases, the amount of entropy generated due to fluid flow follows an upward trend. This is justifiable due to the increased pressure drop intensity and, consequently, the increased energy losses in the fluid flow system. Comparing different cases with the baseline indicates that all proposed fin arrangements result in higher entropy production compared to the baseline case. Among these cases, case number 4 has the highest amount of entropy generated by the fluid flow; a situation where the fins are perpendicular to the main flow direction of the fluid. Such a configuration causes vortices to form in the channel and ultimately maximizes the entropy production rate in the system (Fig. 3a).

Fig. 3b shows the changes in entropy production due to the heat transfer process in the Reynolds number range of 400 to 1200 for the proposed cases. As the results indicate, as the Reynolds number increases, and consequently the inlet flow rate increases, the rate of energy exchange between the fluid and the solid region intensifies. In these conditions, the fluid gains a greater ability to absorb heat from the heat sink, resulting in a decrease in the overall temperature of the sink. Reducing the heat sink temperature directly affects the amount of entropy produced by reflected heat transfer, leading to a noticeable decrease. Comparing different cases shows that among all configurations, case 4, which includes fins perpendicular to the fluid flow direction, has the lowest amount of entropy generated due to heat transfer. This indicates the better performance of this arrangement in reducing thermodynamic losses caused by the heat transfer process.

To make the final comparison between the proposed cases, the Na criterion can be used as a general indicator of entropy production. In this criterion, the total entropy generated by fluid flow and the entropy generated by heat transfer are considered, and the value for the base case is selected as a reference against which other cases are evaluated. Analysis of the results obtained shows that case number 4, although it produces the highest amount of entropy due to fluid flow, ultimately has the lowest value of Na due to lower values of entropy caused by heat transfer. This clearly indicates that Case 4, from the perspective of the principle of entropy production, performed better than the other configurations and can be presented as the best option among the designs studied.

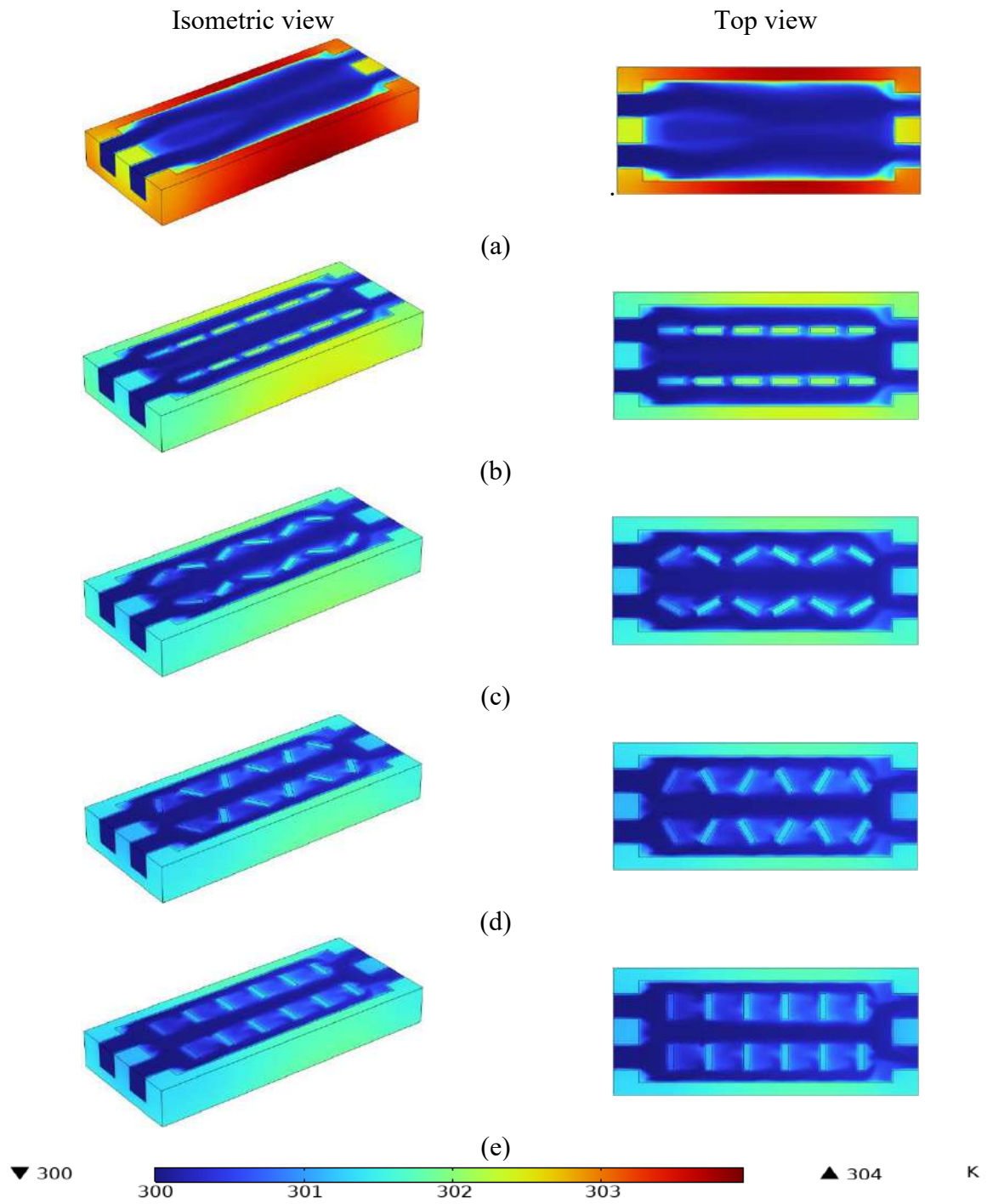


Fig. 2 Temperature contours along the MCHSs at $Re = 800$ for (a) base case, (b) case 1, (c) case 2, (d) case 3, and (e) case 4.

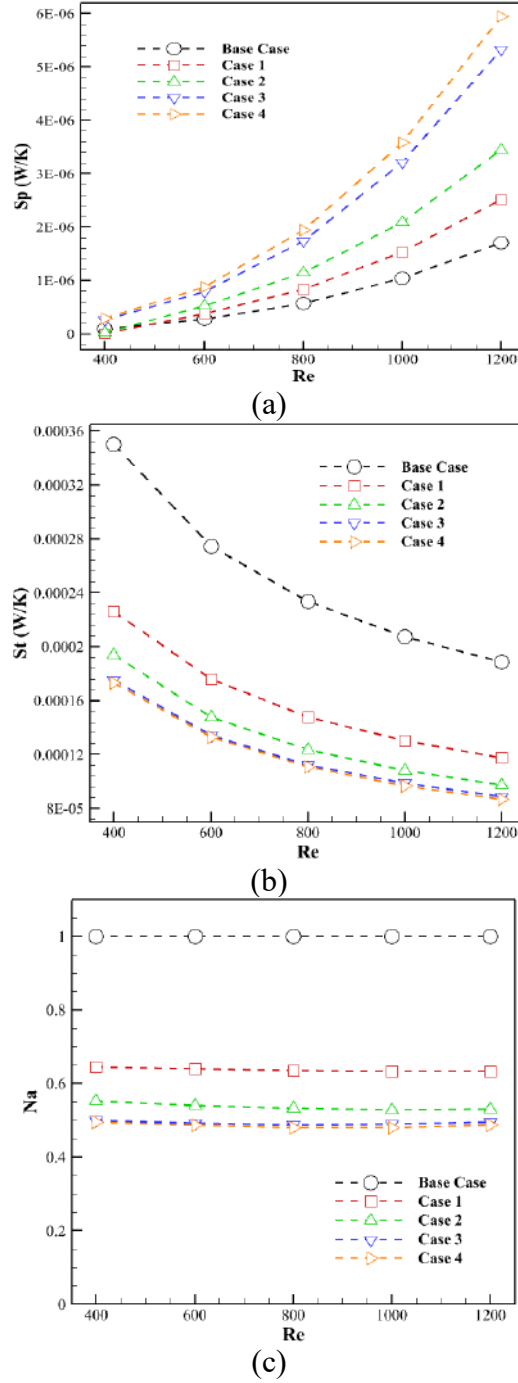


Fig. 3 Variations of (a) S_p , (b) S_t , and (c) N_a in terms of Re for various MCHS configurations.

IV. CONCLUSION

The numerical analysis of entropy generation in the proposed multi-branch microchannel heat sink demonstrates that the arrangement of internal fins significantly affects the device's thermal and thermodynamic performance. Perpendicular fin orientation to the flow path enhances heat transfer due to vortex formation, resulting in a pronounced decrease in heat sink temperature and entropy generation from heat transfer processes. Although this configuration increases entropy due to friction, the combined entropy generation criterion confirms its superior overall performance in reducing irreversibility compared to other fin layouts and the baseline. This study highlights the importance of optimizing fin geometry and orientation to balance fluid flow resistance and thermal enhancement in microchannel heat sinks, providing a practical approach to designing highly efficient cooling solutions for high-performance electronic systems.

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Pseudo Random Number Generator Based on Hash Algorithm and Chaotic map

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Abstract – Random numbers are needed in many areas today. One of the most important of these is undoubtedly security applications. The need for fast and secure random number generators for use in these applications is increasing daily. This study demonstrates that effective random numbers can be generated using the output of hash algorithms. The proposed approach first takes a word from the user. This word is passed through any hash algorithm, and the resulting bits are recorded. To generate the desired number of bit sequences, it is necessary to provide another input to the hash algorithm. Chaotic maps are utilized for this purpose. The bits obtained with the chaotic map are XORed with the bits obtained in the hash output and are then provided as input to the algorithm. Using the chaotic map here, the randomness of the algorithm is increased and made more secure. In this study, the MD5 algorithm is used for hashing, and the logistic map is used as the chaotic map. In this way, two bit sequences containing 1 million bits were generated. The resulting bit sequences successfully passed all NIST tests. This demonstrates that hash algorithms can generate secure random numbers. Additionally, the large number of chaotic maps and hash algorithms in the literature provides significant motivation for future studies.

Keywords – PRNG, Hash, Chaotic Map, Logistic Map, MD5.

I. INTRODUCTION

Random number generators [1] are frequently used in many fields, such as finance, game development, prediction applications, and cryptography. This study focuses on generating random numbers that can be used in cryptography. Cryptography is one of the most effective ways to protect data from unauthorized parties. In cryptography, data is generally protected from attackers using digital signatures [2], hash functions [3], and encryption algorithms [4,5]. Random numbers are needed in almost all of these applications. These random numbers, whether used as keys or for other purposes, must be obtained securely. Otherwise, the algorithm can be vulnerable to attackers. Random number generators are basically classified into two types. The first is true random number generators. These generators generally utilize real sources such as keyboard and mouse movements, electromagnetic waves, and processor activity [6]. The data obtained from these sources is processed and converted into real numbers. The numbers obtained in this way are secure. However, such processes are often both time-consuming and difficult. In other words, obtaining true random numbers is difficult. Another approach is pseudorandom number generators [7]. This method typically utilizes an algorithm or mathematical equations to generate random numbers [8]. Since there's no real source, generating numbers this way is often quite quick and easy. However, to prove that these numbers are reliable and truly random, they must be subjected to various tests. Some pseudorandom number generators developed in recent years are briefly discussed below.

Hadj Brahim et al. [9] developed a new PRNG using the DES algorithm and hyperchaotic system. The study demonstrated that the DES algorithm, which is no longer widely used today, can be used in various applications, and the resulting random numbers were observed to pass NIST tests. Umar et al. [10] proposed a new chaotic map based on the skew tent map because they thought that the basic chaotic maps might be insufficient to generate random numbers. It was noted that their proposed map exhibited effective chaotic properties. It was also demonstrated that this map can generate effective random numbers. Hameedi et al. [11] developed a hybrid generator using LFSR and LCG algorithm. This method passed the tests and was reported to be resistant to various attacks. Alloun et al. [12] designed a hybrid approach using chaos and artificial neural network. It was shown that this design could be suitable for generating random numbers in the future. De la Fraga and Ovilla-Martínez [13] proposed a method for generating random bit sequences using Brownian motion. When we look at the analysis results of this method, it has been observed that it passed the NIST and TestU01 tests.

II. PROPOSED APPROACH

The proposed method is designed to demonstrate that random numbers can be generated from the outputs of hash algorithms. A user input word is passed through the hash algorithm and converted into bits. However, generating and testing random numbers requires longer bit sequences. To achieve this, the bits obtained from the hash output and a chaotic map are XORed back into the hash algorithm as input. This way, the desired bit sequences can be easily obtained. The chaotic map and XOR operations used here increase the complexity of the proposed method and enable more reliable random number generation. In this study, a logistic map is used as the chaotic map. The mathematical model of the logistic map is given in Equation 1.

$$x_{n+1} = ax_n(1 - x_n), \quad x_n \in [0,1], \quad a \in [3.5,4] \quad (1)$$

When the parameters in Equation 1 are adjusted appropriately, numbers of desired lengths can be generated and then converted into bit sequences. The logistic map was chosen in this study because it is widely used in the literature. Future studies can use other, more complex maps to observe their effects. Furthermore, the MD5 algorithm was used for hashing. The structure of the MD5 algorithm is shown in Figure 1.

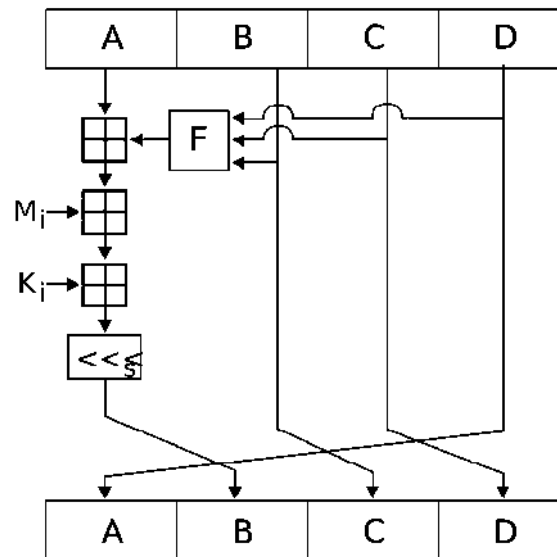


Fig. 1 MD5 algorithm

MD5 is one of the hash algorithms developed by Ronald L. Rivest in 1991. This algorithm processes data of any length and produces a 128-bit hash value at the output [14]. However, the MD5 algorithm is no longer used, particularly in cryptographic structures, because it is no longer secure. One of the main points of this study is to demonstrate that such obsolete algorithms can be used for different applications. The MD5 algorithm was chosen arbitrarily in this study because its simple structure makes it easily applicable. The effects of other hash algorithms can also be examined in future studies. The system model of the approach proposed in this study is presented in Figure 2.

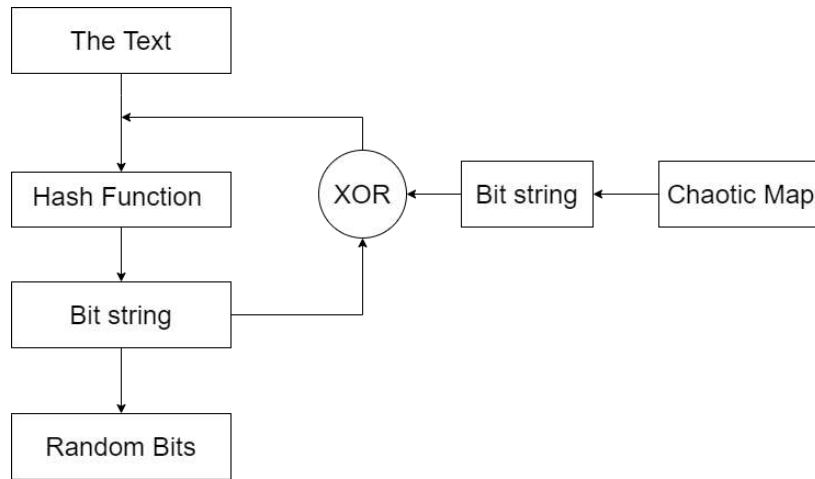


Figure 2. System model of the proposed method

III. ANALYSIS RESULTS

The proposed method generated two bit sequences, each 1 million long. The NIST SP 800-22 [15] test suite, one of the most widely used tests in the literature, was used to test the randomness of the generated bit sequences. This suite contains 15 tests. A p-value is calculated for each test. If this value falls between 0 and 1, the test is considered successful. Furthermore, the closer the p-value is to 1, the greater the randomness. Both bit sequences generated with the proposed method passed all tests. The test results are shown in Figure 3.

Table 1. NIST test results of bit sequences obtained with the proposed method

No	Test	Sequence-1	Sequence -2
		p-value	p-value
1	Frequency Test (Monobit)	0.6891	0.6891
2	Frequency Test within a Block	0.9072	0.9072
3	Run Test	0.1168	0.1168
4	Longest Run of Ones in a Block	0.1276	0.1276
5	Binary Matrix Rank Test	0.9409	0.9409
6	Discrete Fourier Transform (Spectral) Test	0.2021	0.2021
7	Non-Overlapping Template Matching Test	0.3380	0.3380
8	Overlapping Template Matching Test	0.6005	0.6005
9	Maurer's Universal Statistical test	0.3598	0.3598
10	Linear Complexity Test	0.0600	0.0600
11	Serial test	0.2458	0.2458
12	Approximate Entropy Test	0.3849	0.3849
13	Cumulative Sums (Forward) Test	0.8718	0.8718
14	Cumulative Sums (Reverse) Test	0.9823	0.9823
15	Random Excursions Test (state: +4)	0.7919	0.0984

IV. CONCLUSIONS

Random number generators are frequently used in cryptographic applications. These generators must be carefully tested, especially when used for key generation. Today's increasing data and developing technologies are increasing this need daily. Pseudo-random number generators are frequently used because they are practical to obtain and use. This study demonstrates that random numbers can be generated from the outputs of hash algorithms. The input data to the hash algorithm is supplemented with a chaotic map after the first round, increasing randomness. This way, numbers or bit sequences of desired lengths can be easily generated. Both of the resulting bit sequences passed NIST tests.

The output of the MD5 algorithm was used in this study. However, other hash algorithms can also be easily implemented. One of the important contributions of this study is the demonstration that hash algorithms, which are no longer commonly used, can be used in different applications. Furthermore, the abundance of chaotic maps motivates new research. Future studies can develop different generators using different and more complex hash algorithms and chaotic structures.

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Assessment of Drought Variability in Kastamonu Using the Standardized Precipitation Index (SPI)

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Abstract – Reliable drought assessment is crucial for sustainable basin management, as drought significantly affects water resources, agriculture, and ecosystems. This study examines drought variability in Kastamonu, Türkiye, using the Standardized Precipitation Index (SPI) at multiple timescales—annual, 3, 6, 9, and 12 months—based on precipitation records from 1960 to 2023. The aim is to evaluate short-term agricultural droughts and long-term hydrological anomalies, offering insights into precipitation variability in the region.

Monthly precipitation data from the Turkish State Meteorological Service (MGM) were aggregated into 3-, 6-, 9-, and 12-month periods and standardized against long-term mean and standard deviation values. SPI thresholds classified drought and wetness severity, and temporal changes were analyzed with time-series plots.

Results reveal clear variability across timescales. Annual SPI values indicate severe droughts in 1994, 2006, and 2007, while extremely wet years occurred in 2009, 2010, and 2014. SPI-3 highlighted short-term anomalies, including droughts in autumn–winter 2020 and autumn 2023, and wet summers in 2010, 2014, and 2023. SPI-6 captured intermediate droughts, with the most severe in late 2020 and the wettest half-year in 2014. SPI-9 emphasized extended anomalies, such as drought in March 2021 and prolonged wetness in late 2014. SPI-12 showed long-term extremes, including droughts in 1964 and 1994, and very wet conditions in 2010 and 2015.

Overall, the multi-scale SPI analysis shows that drought and wet phases in Kastamonu are part of cyclical variability. Integrating short-, intermediate-, and long-term monitoring into basin management can strengthen early warning systems, support agricultural adaptation, and enhance water planning under changing climate conditions.

Keywords – Standardized Precipitation Index (SPI), Drought Analysis, Precipitation, Water Resources Management, Kastamonu.

I. INTRODUCTION

Drought represents one of the most complex and impactful natural hazards globally, affecting water availability, agriculture, and ecosystem health [1]. Given increasing climatic variability, robust and scalable drought monitoring tools are essential for effective water resource management. Among these, the Standardized Precipitation Index (SPI) has become widely accepted due to its simplicity, statistical robustness, and applicability across various temporal scales [2], [3]. The SPI requires only precipitation data and enables the identification of drought or wet conditions at 1-, 3-, 6-, 12-month (and longer) timescales, making it versatile for meteorological, agricultural, and hydrological assessments [3].

In Turkey, SPI has been extensively employed in regional drought analyses. For example, a study in the Kızılırmak Basin utilized SPI across multiple timescales (1 to 24 months) to assess drought severity using data from 17 meteorological stations [4]. Another Western Black Sea region investigation, covering

precipitation data, involved using 1-, 3-, 6-, and 12-month SPI indices to characterize seasonal drought patterns [5]. These studies underline the SPI's capacity to reveal short-term and long-term variations in regional precipitation patterns.

Kastamonu, located within the Western Black Sea region, faces significant fluctuations in precipitation that critically influence local water management, agricultural productivity, and ecosystem stability. Therefore, this study aims to bridge that gap by applying SPI at annual, 3-month (SPI-3), 6-month (SPI-6), 9-month (SPI-9), and 12-month (SPI-12) scales to long-term precipitation data for Kastamonu. The goal is to identify the timing and severity of short-term agricultural droughts and longer-term hydrological anomalies, offering actionable insights for basin-level adaptation strategies.

II. MATERIALS AND METHODS

A. Study area

This study was conducted in Kastamonu Province, in the Western Black Sea Region of Türkiye. Kastamonu exhibits significant precipitation variability due to its topographic structure and climatic characteristics. Agriculture, forestry, and water resources management are among the province's primary land use types, making it highly sensitive to precipitation anomalies.

B. Data

Monthly precipitation data from 1960 to 2023 were obtained from the Turkish State Meteorological Service (MGM) station in Kastamonu. The dataset included continuous long-term rainfall observations, which were quality-checked for missing or inconsistent values. Annual precipitation totals were calculated by summing the monthly values for each year.

C. Method

Drought analysis was performed using the Standardized Precipitation Index (SPI). This statistical measure standardizes precipitation data by comparing the deviation from the long-term mean relative to its standard deviation [2]. SPI values were computed at five different timescales in order to capture short-term, intermediate, and long-term drought variability;

Annual SPI (SPI-12 months aggregated by year): to identify interannual variability and long-term drought/wet periods.

SPI-3 (3-month cumulative): to represent short-term and seasonal drought conditions, particularly relevant for agricultural impacts.

SPI-6 (6-month cumulative): to reflect intermediate-scale droughts, which influence both agricultural productivity and hydrological processes such as streamflow and soil moisture recharge.

SPI-9 (9-month cumulative): to capture extended seasonal-to-annual anomalies, providing insights into prolonged droughts or wet phases that affect groundwater recharge and reservoir storage.

SPI-12 (12-month cumulative): to assess long-term hydrological droughts, reflecting anomalies in river discharge, reservoir inflows, and groundwater recharge.

The SPI was calculated using the following standardized formula:

$$SPI = \frac{(P_i - P^-)}{\sigma}$$

Where P_i is the observed precipitation, P^- is the long-term mean, and σ is the standard deviation of precipitation over the reference period.

Monthly precipitation values were aggregated into 3-month, 6-month, 9-month, and 12-month rolling sums before standardization.

“SPI values were classified according to the threshold values given in Table 1 [1].

Table 1. Classification of SPI values

SPI Value Range	Category
$SPI \geq 2.0$	Extremely wet
$1.5 \leq SPI < 2.0$	Very wet
$1.0 \leq SPI < 1.5$	Moderately wet
$-1.0 < SPI < 1.0$	Normal
$-1.5 < SPI \leq -1.0$	Moderate drought
$-2.0 < SPI \leq -1.5$	Severe drought
$SPI \leq -2.0$	Extreme drought

Time series of SPI at annual, 3-month, 6-month, 9-month and 12-month scales were plotted to visualize temporal variability. Drought and wet phases were highlighted using thresholds ($SPI < -1$ and $SPI > +1$).

III. RESULTS

The Standardized Precipitation Index (SPI) was calculated for Kastamonu using long-term precipitation records (1960–2023). Analyses were performed at different temporal scales (annual, 3-month, 6-month, 9-month, and 12-month) to capture short-term agricultural droughts, intermediate anomalies, and long-term hydrological variations.

Annual SPI

The annual SPI analysis reveals significant interannual variability in Kastamonu precipitation patterns (Figure 1). Severe drought conditions were observed in 1994, 2006, and 2007, with SPI values around -1.5, whereas extremely wet years were detected in 2009, 2010, and 2014, with SPI values exceeding +2. These results indicate that the region has experienced alternating dry and wet phases, particularly with increased variability after the 2000s.

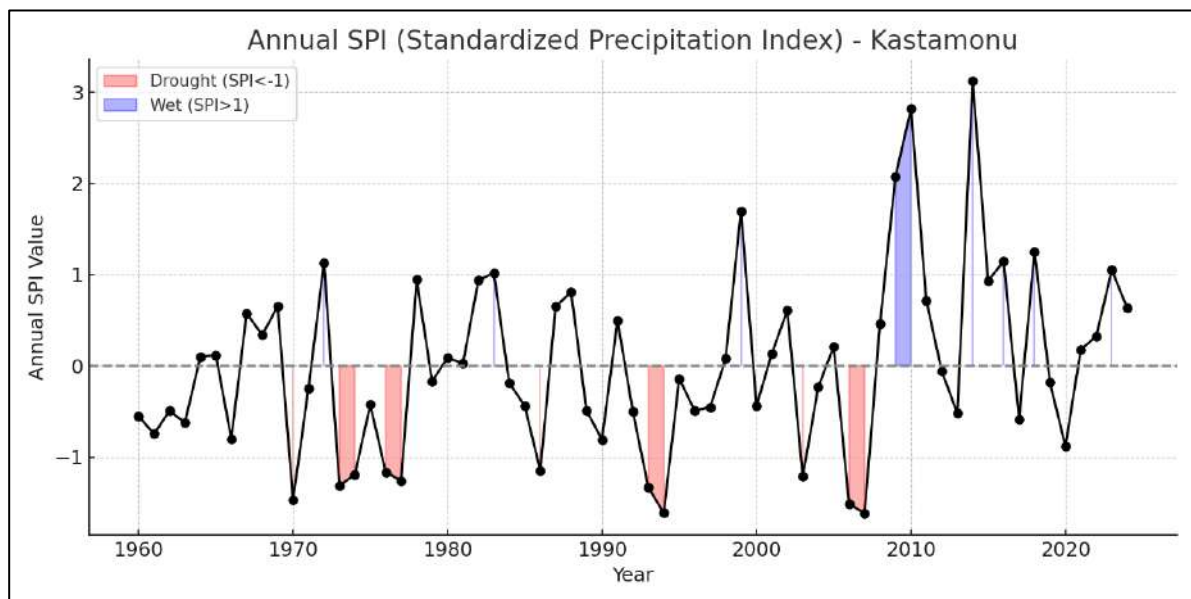


Fig. 1 Annual Standardized Precipitation Index (SPI) for Kastamonu (1960–2023)

3-Month SPI (SPI-3)

The SPI-3 results emphasize short-term fluctuations associated with agricultural drought and seasonal water availability (Figure 2). Severe drought conditions were recorded in autumn–winter 2020

(September–December) and autumn 2023, with SPI values reaching -1.6. Conversely, the most extreme wet phases were observed during summer 2010, summer 2014, and summer 2023, where SPI-3 exceeded +3, indicating exceptionally wet conditions. These findings suggest that droughts in Kastamonu tend to occur during the late growing season, while excessive wetness is concentrated in summer periods.

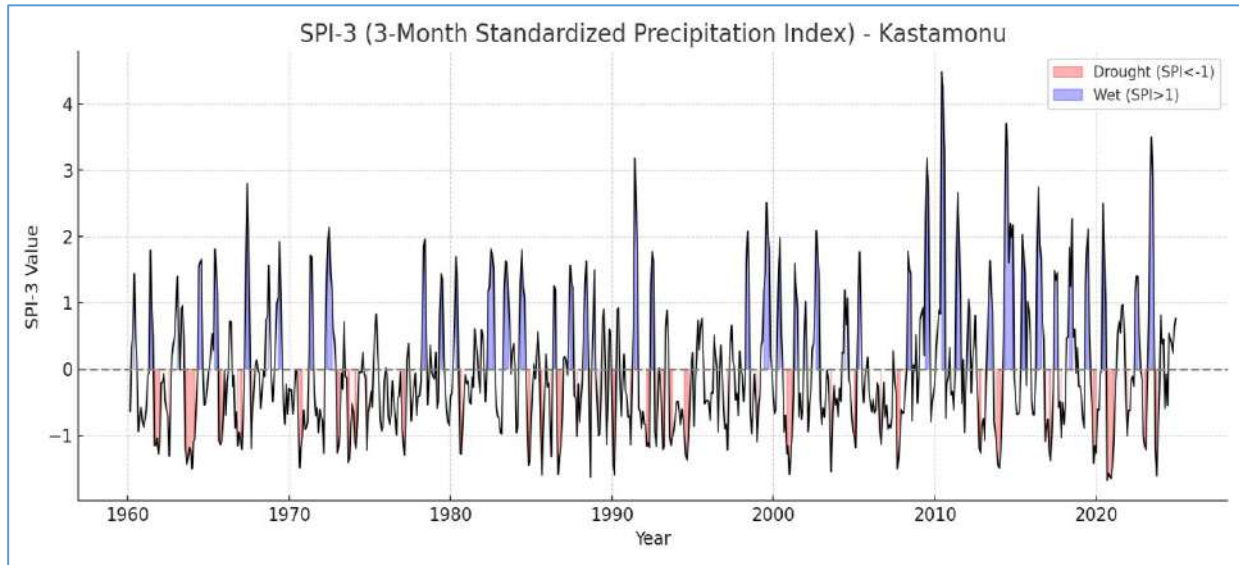


Fig. 2 Three-month Standardized Precipitation Index (SPI-3) for Kastamonu (1960–2023)

6-Month SPI (SPI-6)

The SPI-6 analysis highlights intermediate drought and wet conditions reflecting agricultural and hydrological processes (Figure 3). The most severe 6-month drought occurred in late 2020, with SPI-6 reaching -2.4, while the wettest phase was identified in September 2014 with SPI-6 exceeding +4.2. These results demonstrate that half-yearly precipitation anomalies can capture extended agricultural stress periods and potential impacts on surface water resources.

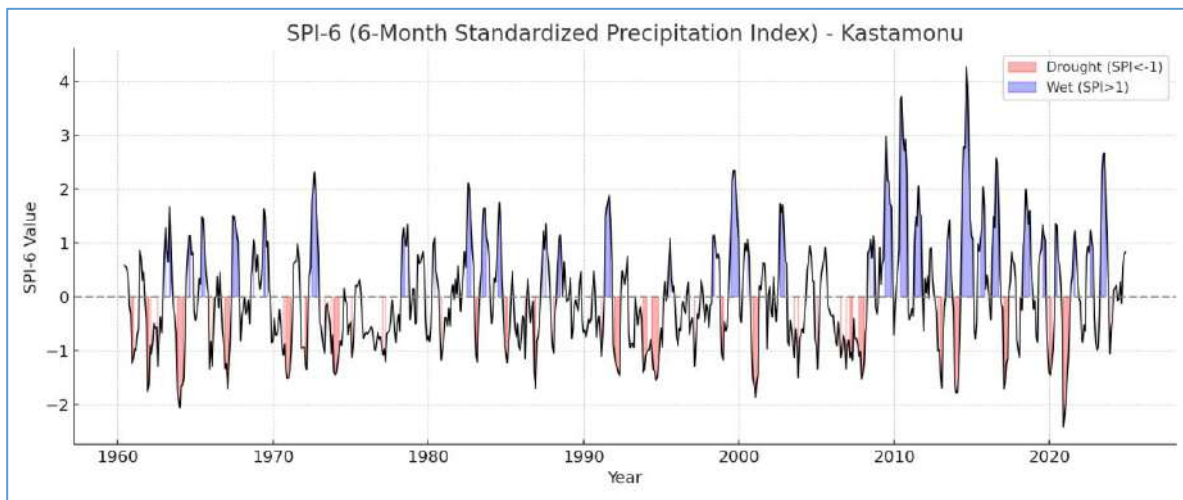


Fig. 3 Six-month Standardized Precipitation Index (SPI-6) for Kastamonu (1960–2023)

9-Month SPI (SPI-9)

The SPI-9 results provide insights into longer seasonal-to-annual hydrological anomalies (Figure 4). The driest 9-month period was observed in March 2021 (SPI-9 $\approx$ -2.4), reflecting persistent drought conditions over three consecutive seasons. Conversely, the wettest period occurred in November 2014, with SPI-9 exceeding +3.8, indicating prolonged wet conditions that could have enhanced groundwater recharge and reservoir inflows.

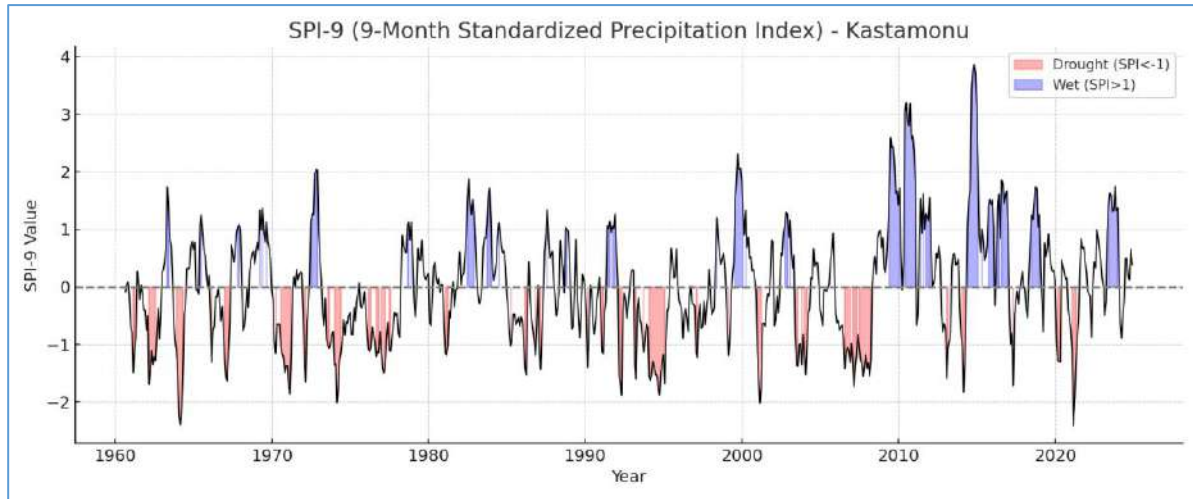


Fig. 4 Nine-month Standardized Precipitation Index (SPI-9) for Kastamonu (1960–2023)

12-Month SPI (SPI-12)

The SPI-12 analysis demonstrates the long-term hydrological variability of the region (Figure 5). Extreme drought phases occurred in 1964 and 1994, with SPI values below -2, representing prolonged and severe water deficits. In contrast, extremely wet conditions were observed in 2010 and 2015, when 12-month precipitation totals exceeded 830 mm and SPI values surpassed +3. These anomalies indicate years of unusually high-water availability that may have intensified flood and erosion risks within the city.

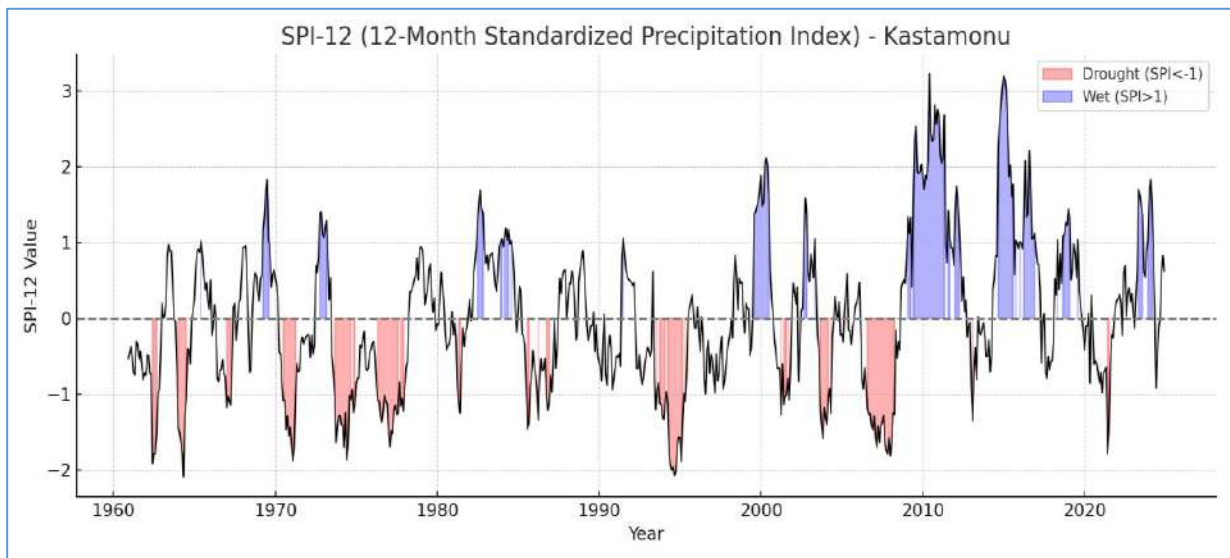


Fig. 5 Twelve-month Standardized Precipitation Index (SPI-12) for Kastamonu (1960–2023)

The multi-scale SPI analyses highlight the pronounced variability of precipitation in Kastamonu. Annual SPI values show that droughts and wet periods alternate frequently, reflecting increased climatic instability in recent decades. SPI-3 emphasizes the importance of seasonal anomalies, where agricultural activities and soil moisture are directly affected by short-term droughts or excessive rainfall events. SPI-6 and SPI-9 provide a broader perspective by capturing intermediate-to-prolonged precipitation anomalies affecting agriculture and hydrological systems. SPI-12 underlines the occurrence of multi-year hydrological anomalies, which directly affect river discharge, reservoir storage, and long-term water resource planning.

Overall, the results demonstrate that drought and wet phases in Kastamonu are not isolated events but part of a cyclical variability pattern. Effective basin management and climate adaptation strategies should

therefore incorporate short-term (SPI-3), intermediate (SPI-6 and SPI-9), and long-term (SPI-12) drought monitoring to ensure sustainable water use and disaster preparedness.

IV. DISCUSSION

This study applied the Standardized Precipitation Index (SPI) at multiple timescales (annual, 3-month, 6-month, 9-month, and 12-month) to assess drought variability in the Kastamonu. The results highlight the importance of distinguishing between short-, intermediate-, and long-term drought conditions for effective basin management.

The annual SPI analysis clearly demonstrated the alternation between drought and wet phases, with severe droughts in the mid-1990s and early 2000s, and extremely wet years in the late 2000s and early 2010s. Similar fluctuations have been reported in previous SPI-based studies in the Black Sea region, underlining the increasing variability in precipitation regimes [6].

The SPI-3 results emphasized short-term anomalies that are particularly relevant for agricultural drought. Severe drought events identified in autumn–winter 2020 and autumn 2023 align with findings from Robleh et al. [4], who reported the sensitivity of short-term SPI indices (1–3 months) in capturing rapid onset drought events in the Kızılırmak Basin. Conversely, extremely wet phases observed in the summers of 2010, 2014, and 2023 illustrate the potential risks of excessive rainfall, including waterlogging and localized flooding.

The SPI-6 analysis provided additional insights into intermediate-scale droughts that influence both agriculture and hydrology. The most severe 6-month drought occurred in late 2020 ($\text{SPI-6} \approx -2.4$), consistent with widespread drought conditions across Türkiye during that period. Conversely, the wettest half-year was recorded in 2014, when SPI-6 exceeded $+4.2$, indicating exceptionally wet conditions that likely enhanced streamflow and soil moisture recharge. The added value of SPI-6 lies in bridging agricultural and hydrological responses, making it particularly suitable for semi-annual water management planning.

The SPI-9 results highlighted extended seasonal-to-annual drought patterns. The driest 9-month period was detected in March 2021 ($\text{SPI-9} \approx -2.4$), reflecting persistent deficits over three consecutive seasons. The wettest phase, in contrast, occurred in late 2014 ($\text{SPI-9} \approx +3.8$), capturing a prolonged wet anomaly that may have significantly increased groundwater recharge and reservoir inflows. These findings demonstrate the usefulness of SPI-9 for monitoring prolonged hydrological extremes beyond seasonal timescales.

The SPI-12 results further emphasized long-term hydrological variability. Extreme droughts were identified in 1964 and 1994 ($\text{SPI-12} < -2$), while extremely wet phases in 2010 and 2015 ($\text{SPI-12} > +3$) underscored the occurrence of multi-year water surpluses. The utility of SPI-12 as a hydrological drought indicator has also been stressed in the literature, particularly for its capacity to capture anomalies in river discharge and groundwater recharge [7]. Such long-term anomalies may significantly affect water supply, reservoir storage, and ecosystem services in the basin.

These findings are consistent with broader national-scale studies that analyzed spatiotemporal drought trends in Türkiye using SPI, SPEI, and related indices [8], [9]. Collectively, the evidence suggests that drought variability in Kastamonu is part of a wider pattern of climatic fluctuations observed across the Black Sea and Central Anatolian regions.

In summary, the results demonstrate that drought and wet phases in the Kastamonu are not isolated events but reflect cyclical variability at multiple temporal scales. The integration of short-term (SPI-3), intermediate (SPI-6 and SPI-9), and long-term (SPI-12) analyses into basin management will enhance early warning capabilities, support agricultural adaptation, and improve long-term water resource planning under changing climate conditions.

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Life-Cycle Cost Optimization of Highway Pavements Using Artificial Intelligence Techniques

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Abstract – Highway pavements are among the most substantial public investments, and their design, construction, and maintenance must balance long-term performance with economic sustainability. Traditional life-cycle cost analysis (LCCA) often relies on deterministic or simplified probabilistic models that cannot fully capture uncertainties in traffic growth, material aging, maintenance timing, and climate effects—risks that can lead to underestimated costs and suboptimal interventions. Recent advances in artificial intelligence (AI) offer a powerful alternative by embedding predictive modeling, optimization, and data-driven learning into pavement management.

AI methods—spanning regression, random forests, gradient boosting, and deep neural networks—have shown strong accuracy for predicting rutting, fatigue cracking, and International Roughness Index (IRI). These forecasts can feed an AI-enhanced LCCA that evaluates construction, maintenance, and rehabilitation strategies over the service life. Unlike static approaches, AI frameworks are dynamic and update as new traffic, material, and environmental data arrive.

Preliminary evidence indicates that AI-driven LCCA can lower total costs by optimizing intervention schedules, reducing user delays, and extending service life while maintaining target performance levels. Beyond economics, fewer major rehabilitations translate into reduced material use, lower emissions, and improved sustainability. Effective deployment, however, depends on region-specific calibration to reflect local traffic and climatic conditions. Overall, AI enables more reliable, adaptive, and cost-efficient pavement management and represents a promising pathway toward sustainable highway infrastructure.

Keywords – Artificial Intelligence (AI); Life-Cycle Cost Analysis (LCCA); Pavement Management Systems; Highway Infrastructure; Machine Learning; Deep Learning; Rutting; Cracking; International Roughness Index (IRI); Sustainable Transportation.

I. INTRODUCTION

Highway pavements constitute one of the most critical infrastructure assets in modern societies, supporting economic growth, mobility, and trade. The design, construction, and maintenance of pavements require substantial financial investments, making cost-effective management essential for highway agencies. Life-Cycle Cost Analysis (LCCA) has emerged as a standard tool to evaluate long-term economic efficiency by comparing alternative design and maintenance strategies over a pavement's service life. However, conventional LCCA frameworks often suffer from limitations such as deterministic assumptions, oversimplification of deterioration processes, and the inability to adequately incorporate uncertainty in traffic growth, climate variations, and material behavior [1].

In recent years, artificial intelligence (AI) has shown remarkable potential in civil and transportation engineering, particularly in predictive modeling and decision support. AI techniques such as machine learning (ML), deep learning (DL), and hybrid approaches can capture complex nonlinear relationships between pavement performance indicators and influencing factors, which traditional models fail to

address. This advancement provides an opportunity to enhance LCCA by improving the accuracy of performance prediction and optimizing maintenance strategies under uncertainty.

The objective of this paper is to present a comprehensive review of AI applications in the context of pavement life-cycle cost optimization. The review highlights state-of-the-art approaches, compares their effectiveness against conventional methods, and discusses challenges, limitations, and future research directions. The focus is placed on how AI-driven models can support sustainable pavement management by minimizing costs, extending service life, and enhancing environmental performance [2].

Life-Cycle Cost Analysis is a systematic approach used to evaluate the total economic impact of a pavement structure from initial construction through maintenance, rehabilitation, and eventual replacement. The primary goal is to identify the alternative that provides the lowest total cost while maintaining acceptable levels of performance and safety. The essential components of LCCA include agency costs (construction, maintenance, rehabilitation), user costs (vehicle operation, travel delay, accident costs), and residual value at the end of the analysis period [3].

Traditionally, LCCA methods can be categorized into deterministic and probabilistic approaches. Deterministic methods rely on fixed input values for traffic loading, material properties, and performance models, often leading to oversimplification. Probabilistic LCCA, on the other hand, incorporates variability and uncertainty through stochastic processes such as Monte Carlo simulation, providing more realistic outcomes but requiring extensive computational resources [4].

In pavement engineering, performance models are central to LCCA. Commonly used models include empirical or mechanistic-empirical formulations that predict indicators such as rutting depth, fatigue cracking, International Roughness Index (IRI), and Pavement Condition Index (PCI). However, these models are often calibrated to specific regions and may not generalize well under varying traffic and environmental conditions. Moreover, their limited adaptability to real-time data makes them insufficient for modern pavement management systems [5].

The integration of artificial intelligence into LCCA offers a transformative pathway to overcome these limitations. By learning directly from historical performance and cost data, AI methods can generate accurate deterioration forecasts, optimize intervention schedules, and quantify trade-offs between cost and performance in a dynamic environment.

II. MATERIALS AND METHOD

A. Artificial Intelligence in Pavement Engineering

Artificial Intelligence (AI) has emerged as a transformative tool in pavement engineering, enabling advanced prediction, optimization, and decision-making processes that surpass the capabilities of conventional methods. By leveraging large datasets on traffic loading, climatic conditions, and material properties, AI models can identify complex nonlinear relationships between inputs and performance outcomes, thus supporting more reliable pavement design and management strategies [2].

B. Machine Learning Approaches

Machine learning (ML) has been widely adopted for predicting pavement performance indicators such as rutting, cracking, and the International Roughness Index (IRI). Regression-based models, including support vector regression (SVR) and polynomial regression, are effective for capturing relationships between traffic loads and deterioration trends. Ensemble techniques such as Random Forest (RF) and Gradient Boosting (GBM, XGBoost, CatBoost) provide robust predictions by combining multiple decision trees, thereby improving accuracy and reducing overfitting. These models are particularly valuable in life-cycle cost analysis (LCCA), as they can forecast deterioration curves that feed into maintenance scheduling and cost estimation frameworks [3].

C. Deep Learning Approaches

Deep learning (DL) methods, particularly Artificial Neural Networks (ANNs) and Convolutional Neural Networks (CNNs), have been applied to pavement engineering problems where large and complex datasets are available. ANNs can model deterioration trends based on traffic, climate, and material inputs,

while CNNs are effective in processing image-based pavement condition surveys for crack detection and PCI evaluation. Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks are increasingly used for time-series prediction of pavement deterioration, offering enhanced capabilities for long-term forecasting under dynamic conditions [6].

D. Hybrid and Physics-Informed Models

One of the most promising research directions involves hybrid models that combine mechanistic–empirical design principles with AI. These models leverage the theoretical understanding of pavement mechanics while using AI to calibrate and update performance predictions. For example, hybrid frameworks can integrate mechanistic strain-based criteria with machine learning forecasts to optimize layer thicknesses and rehabilitation schedules. Additionally, physics-informed machine learning is gaining attention as it allows the incorporation of engineering knowledge into neural networks, improving both prediction accuracy and interpretability [7].

E. Benefits and Challenges

AI methods significantly enhance pavement engineering by improving prediction accuracy, supporting proactive maintenance planning, and reducing life-cycle costs. However, several challenges remain. AI models require large, high-quality datasets, which may not be readily available in all regions. Moreover, black-box characteristics of many AI algorithms reduce their interpretability, posing difficulties for decision-makers. Computational requirements and the need for skilled personnel also limit the widespread adoption of AI in practice [8].

III. APPLICATIONS OF AI IN LIFE-CYCLE COST OPTIMIZATION

Artificial intelligence has introduced new possibilities for optimizing pavement life-cycle costs by combining predictive accuracy with decision-making frameworks. Unlike traditional deterministic models, AI-driven approaches can dynamically adapt to changing traffic, environmental, and material conditions, making them more suitable for real-world pavement management systems [4].

A. Prediction of Pavement Deterioration Curves

Accurate prediction of deterioration trajectories is a fundamental step in life-cycle cost analysis (LCCA). Machine learning regression models, ensemble methods, and deep learning networks are increasingly applied to forecast key performance indicators such as rutting, cracking, and IRI. By capturing nonlinear and interactive effects of traffic loading, temperature fluctuations, and material aging, AI-based models provide more realistic deterioration curves. These outputs allow agencies to anticipate the timing of interventions and avoid premature or delayed maintenance actions [5].

B. Optimization of Maintenance and Rehabilitation Schedules

Maintenance scheduling is critical for minimizing both agency and user costs throughout a pavement's service life. AI techniques, including reinforcement learning and genetic algorithms, have been applied to determine optimal intervention strategies. For instance, reinforcement learning agents can “learn” policies that minimize life-cycle costs by balancing short-term expenses with long-term benefits. Similarly, evolutionary optimization methods can generate cost-effective combinations of preventive maintenance, rehabilitation, and overlay strategies under budgetary and performance constraints [6].

C. Cost Minimization under Uncertainty

Traffic demand growth, climate variability, and material degradation introduce uncertainties that complicate decision-making. Probabilistic LCCA has traditionally attempted to capture this, but AI can incorporate uncertainty more effectively. Stochastic machine learning models and Monte Carlo simulations combined with AI predictions allow agencies to identify strategies that are not only cost-efficient but also resilient under uncertain future scenarios. This contributes to risk-informed decision-making, where life-cycle cost outcomes are evaluated under multiple possible futures [8].

D. Case Studies and Practical Applications

Several case studies have demonstrated the potential of AI-driven LCCA. For example, neural network models trained on pavement performance databases in the United States and Europe have shown improved accuracy compared to mechanistic–empirical predictions. In Asia, hybrid AI models have been applied to optimize highway maintenance schedules, achieving significant reductions in total agency costs and user delays. Although applications in Turkey remain limited, the increasing availability of performance monitoring data offers a strong foundation for integrating AI into national pavement management systems [9].

IV. COMPARATIVE ANALYSIS

The integration of artificial intelligence into life-cycle cost analysis (LCCA) offers clear advantages compared to traditional deterministic and probabilistic methods. However, both approaches present unique strengths and limitations that must be carefully evaluated.

A. AI-Based vs. Traditional Approaches

Traditional LCCA methods rely on mechanistic–empirical (M–E) models and historical data to estimate pavement deterioration and associated costs. While relatively simple and transparent, these methods are often unable to capture the complexity of real-world conditions, such as nonlinear deterioration behavior under heavy traffic or the combined influence of climate and material variability. AI-based models, by contrast, are capable of identifying hidden patterns in large datasets and modeling nonlinear, multidimensional relationships, resulting in more accurate predictions of performance indicators such as rutting, cracking, and roughness [8].

B. Benefits of AI Integration

- Improved prediction accuracy: Machine learning and deep learning models significantly outperform deterministic equations in forecasting pavement deterioration.
- Dynamic adaptability: AI models can update predictions as new data (traffic counts, weather records, performance monitoring) becomes available, supporting proactive decision-making.
- Cost savings: Optimized maintenance scheduling reduces unnecessary interventions, minimizes user delays, and lowers agency expenditures over the pavement’s service life.
- Sustainability contributions: Reduced rehabilitation frequency leads to lower energy consumption, greenhouse gas emissions, and material usage [9].

C. Challenges and Limitations

Despite its benefits, AI adoption in pavement management is not without challenges:

- Data dependency: AI models require large, high-quality, and region-specific datasets, which are often lacking in developing regions.
- Interpretability issues: Many AI techniques (e.g., deep neural networks) operate as “black boxes,” making it difficult for engineers to justify predictions to stakeholders.
- Generalization risks: Models trained on one region may not transfer well to different climates, traffic conditions, or construction practices.
- Implementation barriers: High computational costs and the need for skilled personnel may limit integration into routine pavement management systems [10].

D. Summary of Comparative Insights

Overall, AI-based methods complement rather than replace traditional approaches. While M–E models provide theoretical rigor and physical interpretability, AI enhances predictive performance and cost optimization. A hybrid framework that combines both methods is likely to represent the most effective strategy for future pavement life-cycle cost optimization.

V. FUTURE RESEARCH DIRECTIONS

While artificial intelligence (AI) has demonstrated significant potential in life-cycle cost optimization (LCCA) of highway pavements, several critical areas remain underexplored. Advancing research in these directions will ensure that AI-driven tools become practical, trustworthy, and widely adopted in pavement management systems.

A. *Explainable and Transparent AI*

One of the major barriers to adoption is the “black box” nature of many AI models. Future studies should focus on incorporating explainable AI (XAI) techniques, such as SHAP and LIME, to provide insights into how models make predictions. This will improve stakeholder trust, regulatory compliance, and decision-making accountability [6].

B. *Region-Specific Calibration and Data Enrichment*

Most AI-based studies rely on datasets from developed countries, limiting their applicability in regions with different climatic, traffic, and construction conditions. Future research should prioritize developing regional pavement databases and calibrating AI models to local contexts, particularly in countries like Turkey where climate diversity and heavy-traffic corridors require tailored solutions [7].

C. *Multi-Objective Optimization for Sustainability*

Beyond cost minimization, future LCCA frameworks should incorporate environmental and social sustainability metrics, such as greenhouse gas emissions, energy consumption, and user safety. Multi-objective optimization algorithms that balance cost, performance, and sustainability will align with global infrastructure goals and climate policies [8].

D. *Hybrid and Physics-Informed Approaches*

A promising avenue lies in combining mechanistic–empirical (M–E) design principles with AI-driven models. Physics-informed neural networks (PINNs) can integrate engineering knowledge with data-driven learning, enhancing accuracy and interpretability. Hybrid models will likely represent the next generation of pavement LCCA tools [9].

E. *Policy and Practical Implementation*

Finally, research should address how AI-driven LCCA frameworks can be translated into practical guidelines, standards, and policy recommendations for highway agencies. Pilot projects, open-access data platforms, and interdisciplinary collaboration will be essential to bridge the gap between research and real-world adoption [10].

VI. DISCUSSION

The integration of artificial intelligence into life-cycle cost analysis (LCCA) provides valuable insights that extend beyond traditional pavement management practices. The results of this study indicate that AI-driven models not only improve prediction accuracy for performance indicators such as rutting, cracking, and IRI, but also enable more efficient optimization of maintenance and rehabilitation schedules. This outcome aligns with previous findings in the literature, where machine learning and deep learning approaches have consistently outperformed empirical or mechanistic–empirical models in predicting pavement deterioration trends.

A key implication of this research is the ability of AI frameworks to address uncertainty. Traditional deterministic LCCA methods typically overlook the variability in traffic growth, material properties, and climate change impacts, leading to potentially misleading cost projections. In contrast, AI-based models incorporate diverse datasets and can adapt dynamically, thus providing more reliable and resilient decision support. This adaptability is particularly important for regions like Turkey, where environmental and loading conditions vary significantly across geographical zones.

Another important aspect is the sustainability dimension. By reducing the frequency of major rehabilitation interventions, AI-enhanced LCCA frameworks contribute to lowering greenhouse gas

emissions, conserving materials, and minimizing energy consumption. This highlights AI not only as a tool for economic efficiency but also as an enabler of sustainable transportation infrastructure.

Nevertheless, challenges remain regarding data availability, interpretability of black-box models, and practical integration into agency-level decision-making processes. Overcoming these barriers requires the development of region-specific databases, hybrid approaches that combine mechanistic principles with AI, and explainable AI methods to ensure transparency and stakeholder confidence.

VII. CONCLUSION

Life-cycle cost analysis (LCCA) is a critical tool for ensuring the long-term sustainability and cost-effectiveness of highway pavements. Traditional deterministic and probabilistic approaches, while valuable, often fail to capture the complex and uncertain interactions between traffic growth, climatic variability, and material aging. Artificial intelligence (AI) offers a powerful alternative by providing predictive accuracy, adaptability, and optimization capabilities that support more effective pavement management decisions.

This review highlighted the major AI techniques applied in pavement engineering, including machine learning, deep learning, and hybrid physics-informed models. Applications of AI in predicting deterioration curves, optimizing maintenance schedules, and minimizing costs under uncertainty demonstrate its transformative potential compared to conventional methods. Case studies worldwide confirm that AI-enhanced LCCA can significantly reduce both agency and user costs, while also contributing to sustainability by lowering emissions, material use, and rehabilitation frequency.

However, challenges remain in data availability, model interpretability, and regional calibration. Future research should therefore focus on explainable AI, integration with digital twins and IoT systems, and multi-objective optimization frameworks that incorporate environmental and social indicators. Developing region-specific pavement databases, particularly for countries like Turkey with diverse climates and traffic patterns, will be essential for practical implementation.

In conclusion, AI-driven LCCA represents a paradigm shift in pavement engineering, offering a pathway toward smarter, more sustainable, and economically efficient highway infrastructure. With continued advances in data availability, computational techniques, and interdisciplinary collaboration, AI has the potential to become an integral component of next-generation pavement management systems.

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Determination of Vitamin C in Fruit and Juice Samples of Albanian Market

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Abstract – This paper presents data on the levels of vitamin C in some fruits, fruit juices and soft drinks from the Albanian market. Vitamin C is one of the most important components of the proper functioning of the human body. Vitamin C cannot be produced by the human body, therefore it is obtained mainly through foods (fruits, vegetables) or through various supplements that contain this vitamin (and others) to their content. The most numerous recommendations are that it be obtained naturally from fruits (fresh fruit juices) and vegetables. The quantitative determination of Vitamin C was based on the ISO 6557-2:1984 standard, which is based on titration of ascorbic acid through a redox reaction with potassium iodide. In this study, 6 types of fruits (30 samples in total), 5 types of fresh fruit juice samples (20 samples in total) and 3 types of soft drink samples (12 samples in total) were taken in May – June 2025 from different markets of Tirana. From the results of the parallel samples, it was observed that vitamin C was at the reported levels in previous studies for fresh fruits but not for fruit juices and soft drinks, Vitamin C was missing in about 30% of the samples (mainly for soft drinks), while for the positive samples its values were much lower than its content on the product label. This should encourage institutions to perform continues controls on these products and the consumers to use natural products and not commercial products to obtain Vitamin C.

Keywords – Vitamin C, Fruit Samples, Juice Samples, Food Analysis, Food Quality, Redox Titration

I. INTRODUCTION

This Vitamins are organic compounds that are essential for normal human metabolism. They must be present in the diet in small amounts. Vitamins are classified into water-soluble (C and B complexes) and fat-soluble (A, D, E, K) depending on their solubility. Vitamin C is a major water-soluble antioxidant. Vitamin C is found mostly in fruits and vegetables but the body doesn't store it, requiring daily dietary intake. Many commercial fruit juices contain this vitamin. People get vitamin C today from supplements available in pharmacies. It can also be used as an additive in food products as a preservative. Vitamin C is an essential nutrient involved in the repair of tissue, the formation of collagen, and the enzymatic production of certain neurotransmitters. It is required for the functioning of several enzymes and is important for immune system function. It also functions as an antioxidant. Various health claims exist on the supposition that moderate vitamin C deficiency increases disease risk, such as for the common cold, cancer or COVID-19. There are also claims of benefits from vitamin C supplementation in excess of the recommended dietary intake for people who are not considered vitamin C deficient. Vitamin C is generally well tolerated. Large doses may cause gastrointestinal discomfort, headache, trouble in sleeping, and flushing of the skin.

Vitamin C was discovered in 1912, isolated in 1928, and in 1933, was the first vitamin to be chemically produced. The best sources of vitamin C are fruits and vegetables, especially citrus fruits, red and green peppers, kiwifruit, broccoli, strawberries, and Brussels sprouts. Orange juice, grapefruit juice, and tomato juice also contain large amounts of vitamin C, and vitamin C is added to some breakfast cereals. Vitamin C is water soluble and susceptible to heat, so cooking can reduce the vitamin C content of food.

Fruits and vegetables are the best sources of vitamin C [11]. Citrus fruits, tomatoes and tomato juice, and potatoes are major contributors of vitamin C to the American diet [8]. Other good food sources include red and green peppers, kiwifruit, broccoli, strawberries, Brussels sprouts, and cantaloupe [8,10]. Although vitamin C is not naturally present in grains, it is added to some fortified breakfast cereals. The vitamin C content of food may be reduced by prolonged storage and by cooking because ascorbic acid is water soluble and is destroyed by heat [6, 8]. Steaming or microwaving may lessen cooking losses. Fortunately, many of the best food sources of vitamin C, such as fruits and vegetables, are usually consumed raw. Consuming five varied servings of fruits and vegetables a day can provide more than 200 mg of vitamin C.

II. MATERIALS AND METHOD

2.1. Sampling of fruit and juice samples

In this study, 6 types of fruits (30 samples in total), 5 types of fresh fruit juice samples (20 samples in total) and 3 types of soft drink samples (12 samples in total) were taken from different markets of Tirana. They were selected to be as representative as possible both in their variety and in their use. The fruit samples were: apples, oranges, grapefruits, lemons, kiwis, bananas; the fruit juice samples were: oranges, red oranges, lemons, apples, multivitamins ACE and soft drinks were: orange, lemon, peach drinks (2; 3). All samples were selected in May – June 2025. The samples were transported and stored at +4°C until their analysis in the laboratory. The fruit samples were squeezed in a fruit juicer prior to their analysis.

2.3. Redox titration using iodine solution.

This method determines the vitamin C concentration in a solution by a redox titration using iodine. Iodine is added in the course of titration, the ascorbic acid is oxidized to dehydroascorbic acid, while the iodine is reduced to iodide ions.

Ascorbic acid + Iodine (I₂) → 2 I⁻ + Dehydroascorbic acid

Due to this, the iodine formed is instantly reduced to iodide as long as there is any ascorbic acid present in the solution. When all the ascorbic acid has been oxidized, the excess iodine is free to react with the starch indicator, forming a blue-black starch-iodine complex. This is the endpoint of the redox titration.

2.4. Preparation of chemicals.

2.4.1. Preparation of iodine solution (0.05mol/L)

20 g of potassium iodide was taken in a 200mL beaker, and 12.7 g of iodine crystal was added. Then 100mL of distilled water was added and swirled till the iodine was fully dissolved. The iodine solution was then transferred to a 1 L volumetric flask; after that, distilled water was added and made the solution up to 1 L.

2.4.2. Preparation of Starch indicator solution (5%).

5 g of soluble starch was added to 100mL of boiling distilled water in a conical flask by stirring. The solution was cooled down for use.

2.5. Estimation of vitamin C content by redox titration using iodine solution for juice fruit and soft drink

25mL of the sample solution was pipetted into a 200mL conical flask, 10mL of sulfuric acid and 80 ml distilled water was added to it, followed by a 3mL starch indicator solution. Then the sample solution was titrated with 0.05mol L⁻¹ iodine solution. The titration's endpoint was identified as the first permanent trace of a dark blue-black color due to the starch-iodide complex. The titration was repeated with further aliquots of sample solution until we obtained concordant results.

2.5.1. Calculation.

Ascorbic acid + I₂ → 2 I⁻ + Dehydroascorbic Acid

As iodine solution is taken as the standard solution, it is taken as 0.05mol L⁻¹.

Molar ratio of iodine = 2/1= 2

First, calculate the moles of iodine using rule,

$N = CV$

Where, C = 0.05mol L⁻¹

V = Mean value of the concordant readings

Then, calculate the moles of ascorbic acid (AA) in the given sample,

$NAA = 2N$

Finally, convert the moles of AA found to mass

$M = NAA \times MAA$

Where, MAA is the molecular mass of Ascorbic acid

III. RESULTS

The quantitative determination of Vitamin C was based on the ISO 6557-2:1984 standard, which is based on titration of ascorbic acid through a redox reaction with potassium iodide. In this study, 6 types of fruits (30 samples in total), 5 types of fresh fruit juice samples (20 samples in total) and 3 types of soft drink samples (12 samples in total) were taken from different markets of Tirana. They were selected to be as representative as possible both in their variety and in their use. The fruit samples were: apples, oranges, grapefruits, lemons, kiwis, bananas; the fruit juice samples were: oranges, red oranges, lemons, apples, multivitamins ACE and soft drinks were: orange, lemon, peach drinks (2; 3). All samples were selected in May – June 2025. The samples were transported and stored at +4oC until their analysis in the laboratory. The fruit samples were squeezed in a fruit juicer prior to their analysis.

Table 1. Vitamin C data (mg/100 g sample) for fruit samples

Fruit samples	Mean	Min	Max	STDEV
Apple (7 samples)	5.1	2.2	7.5	0.98
Orange (6 samples)	38.6	27.5	47.6	5.69
Grapefruit (3 samples)	75.3	59.3	94.2	11.3
Lemon (4 samples)	52.9	41.2	86.3	10.2
Kiwi (4 samples)	64.2	47.3	79.5	8.81
Bananas (6 samples)	6.7	3.6	11.2	1.32

Table 2. Vitamin C data (mg/100 ml sample) for fruit juice samples

Juice fruit samples	Mean	Min	Max	STDEV
Orange (5 samples)	4.1	2.8	5.5	0.35
Red orange (3 samples)	3.6	0.88	4.5	0.61
Lemon (3 samples)	8.3	5.3	14.2	2.34
Apple (5 samples)	1.3	0	3.4	1.29
Multivitamin ACE (4 samples)	4.7	3.6	11.2	2.24

Table 3. Vitamin C values (mg/100 ml sample) for soft drink samples

Soft drink samples	Mean	Min	Max	STDEV
Orange (5 samples)	0	-	-	-
Lemon (4 samples)	2.3	0	4.4	2.05
Peach (3 samples)	0	-	-	-

IV. DISCUSSION

The levels of vitamin C for the fruit samples ranged from 5.1 mg/100 g apple sample to 75.3 mg for grapefruit samples which have the maximum (Table 1). Their presence was generally similar to the levels reported in previous studies for this compound for the same fruits. It should be noted that most of the fruit samples were imported from other countries as during this period in Albania it is not the right season for any of the fruits analyzed. Some of them were also stored in refrigerators for several months. This must be the main reason for the lower values of vitamin C for some of the analyzed samples. For fruit juices their values ranged from 1.3 mg Vitamin C for 100 ml apple juice to 8.3 mg/100ml of lemon juice (Table 2). Note that, all fruit juice were prepared from industrial way not from fresh fruits so Vitamin C it is a supplement for this samples. Generally the levels of Vitamin C were lower than reported studies and/or their label thus affecting the quality of the products and deceiving consumers who claim to meet their Vitamin C needs through these drinks. This was even more serious for soft drinks (Table 3) because in most of them the presence of Vitamin C was not identified even though according to their labels it should be present. Note that, to identify the presence of Vitamin C at very low levels for these samples a 10-fold diluted titration solution was used but again the results were negative.

V. CONCLUSION

Vitamin C is one of the most important components of the proper functioning of the human body. Vitamin C cannot be produced by the human body, therefore it is obtained mainly through foods (fruits, vegetables) or through various supplements that contain this vitamin (and others) to their content. The most numerous recommendations are that it be obtained naturally from fruits (fresh fruit juices) and vegetables. Fortunately, it is found in many fruits and vegetables, therefore they should never be missing from the diet for all age groups. Although it is used as a food supplement in many foods and drinks (due to its aroma and antioxidant properties), Vitamin C is often not found at all or is found in levels much lower than the amount it should be. Thus, there are two main problems: firstly, the food product does not meet one of the most important elements of its quality and secondly, the recommended norm for vitamin C is not provided for consumers who take it as a supplement. This was the main reason for making this study for the determination of Vitamin C in some fruits, fruit juices and soft drinks from the Albanian market. The quantitative determination of Vitamin C was based on the ISO 6557-2:1984 standard, which is based on titration of ascorbic acid through a redox reaction with potassium iodide. In this study, 6 types of fruits (30 samples in total), 5 types of fresh fruit juice samples (20 samples in total) and 3 types of soft drink samples (12 samples in total) were taken in May – June 2025 from different markets of Tirana. From the results of the parallel samples, it was observed that vitamin C was at the levels reported in previous studies for fresh fruits, while for fruit juices and soft drinks, Vitamin C was missing in about 30% of the samples, while for the positive samples its values were much lower than its content on the product label. This should encourage institutions on the one hand to carry out the appropriate controls on these products and on the other hand consumers to be more inclined towards natural products and not commercial products to obtain Vitamin C.

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A Computational Approach for the Development of Novel Cyclophilin D Protein Inhibitors

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Abstract – Multiple sclerosis (MS) is a chronic neuroinflammatory disease with limited therapeutic options. Cyclophilin D (CyPD), a mitochondrial matrix protein regulating the mitochondrial permeability transition pore, has emerged as a potential therapeutic target. In this study, a computational drug design strategy was employed to identify and evaluate potential CyPD inhibitors. BindingDB was screened to retrieve 50 known CyPD inhibitors, which were subsequently used for pharmacophore modeling with PharmMapper. Pharmacophore hypotheses were applied to virtual screening of the ZINCPharmer database, yielding 22 candidate molecules. These were assessed using SwissADME for ADME-toxicity profiling, and three drug-like molecules (ZINC13127502, ZINC23128374, ZINC19862290) were selected for molecular docking against CyPD (PDB ID: 5CBT). Docking results indicated binding affinities ranging from -5.7 to -6.9 kcal/mol, with ZINC19862290 demonstrating the highest affinity. Although none of the screened compounds exceeded the binding affinity of the reference inhibitor (-8.4 kcal/mol), the binding modes of selected molecules were consistent with reported CyPD-ligand interactions. These findings highlight promising scaffolds for further optimization and suggest that molecular dynamics simulations should be conducted in future studies to validate stability and interaction profiles.

Keywords – Multiple Sclerosis, Cyclophilin D, Pharmacophore Modeling, Molecular Docking, Computational Drug Design.

I. INTRODUCTION

Multiple sclerosis (MS) is a chronic, immune-mediated neurodegenerative disease predominantly affecting young adults, with more than 3 million cases reported worldwide [1]. MS is characterized by focal demyelination in the central nervous system (CNS), leading to disrupted neuronal conduction, axonal injury, and neuroinflammation [2]. Clinically, patients present with fatigue, motor and sensory deficits, nystagmus, ataxia, speech and vision disturbances, and cognitive impairment [3].

While demyelination is the hallmark pathology, mitochondrial dysfunction has emerged as a central driver of disease progression. Oxidative stress, driven by reactive oxygen and nitrogen species (ROS/RNS), causes mitochondrial injury, energetic collapse, and axonal degeneration [4]. Experimental autoimmune encephalomyelitis (EAE) models, widely used to study MS pathogenesis, have demonstrated that Ca^{2+} overload triggers mitochondrial permeability transition pore (mPTP) opening, linking ionic imbalance to neurodegeneration [5].

Cyclophilin D (CypD), a mitochondrial matrix peptidyl-prolyl cis-trans isomerase, is a key regulator of mPTP. Under pathological Ca^{2+} accumulation, CypD sensitizes mPTP opening, resulting in impaired respiration, release of pro-apoptotic factors, and cell death [6]. Genetic deletion or pharmacological inhibition of CypD prevents pore opening, preserves mitochondrial integrity, and improves axonal survival in EAE models [7,8]. However, clinical translation of CypD inhibitors has been limited.

Cyclosporine A (CsA), the prototypical inhibitor, exhibits poor brain penetration and dose-limiting immunosuppressive effects [9]. Alternative inhibitors, such as antamanide and sanglifehrin A, suffer from low solubility or toxicity [10,11], underscoring the need for new, brain-penetrant, non-immunosuppressive molecules.

Given the limitations of currently available CypD inhibitors, the development of novel, brain-penetrant, and non-immunosuppressive compounds represents a crucial step toward effective therapeutic strategies in MS. CypD remains an attractive molecular target due to its pivotal role in regulating mitochondrial permeability transition and neuronal survival under oxidative stress conditions. By selectively inhibiting CypD, it may be possible to preserve mitochondrial function, reduce neurodegeneration, and ultimately improve clinical outcomes in MS patients.

In this study, we applied a comprehensive in silico drug discovery pipeline to identify novel CypD inhibitors. The workflow included pharmacophore modeling based on known ligands, virtual screening of large compound libraries, ADME and toxicity prediction to assess drug-likeness, and molecular docking analyses to evaluate binding affinity and interaction patterns. Through this computational strategy, we aimed to propose candidate scaffolds with favorable pharmacological profiles that could serve as starting points for further preclinical development of CypD-targeting therapies in MS.

II. MATERIALS AND METHOD

A. Identification of Cyclophilin D Inhibitors

To identify small molecules with inhibitory activity against Cyclophilin D (CyPD), the BindingDB database was queried using the keyword “peptidyl-prolyl cis-trans isomerase D.” From this search, 50 compounds with the lowest reported IC₅₀ values were retrieved for further analysis.

B. Retrieval and Validation of the CyPD 3D Structure

Three-dimensional structures of human CyPD were obtained from the RCSB Protein Data Bank (PDB) [12]. Sequence alignment was performed between the UniProt sequence of human CyPD (UniProt ID: Q08752) [13] and the retrieved PDB entries (e.g., 4O8H [14], 4O8I [14], 5CBT [15], 5CBU [15], 5CBV [15], 5CBW [15], 5CCN [15], 5CCQ [15], 5CCR [15], 5CCS [15], 6Y3E [16], 7R2I [17], 7R2J [17], 7R2L [17], 7ZDN [18], 8EJX [19], 2Z6W [20]). Percent sequence similarity values were calculated to confirm structural reliability.

C. Pharmacophore Modeling

The inhibitor ligands retrieved in mol or sdf format were prepared using Discovery Studio Visualizer (Dassault Systèmes, 2019) and converted to mol format. All ligands were compiled into a single file and uploaded to the PharmMapper web server. Pharmacophore hypotheses were generated based on common structural features of the ligands, resulting in 10 models with varying hydrogen bond donors/acceptors, hydrophobic groups, and aromatic ring features.

D. Virtual Screening and Selection of Candidate Molecules

Pharmacophore models generated by PharmMapper were employed in virtual screening using the ZINCPharmer web tool [21]. Candidate molecules with high fit scores against the pharmacophore hypotheses were identified.

E. ADME and Toxicity Evaluation

All candidate molecules were converted into sdf format using Discovery Studio Visualizer and analyzed via the SwissADME web platform [22]. Parameters evaluated included Lipinski’s rule of five compliance, topological polar surface area (TPSA), consensus log P, predicted gastrointestinal (GI) absorption, bioavailability score, and molecular weight.

F. Molecular Docking

The CyPD receptor structure was prepared using Discovery Studio Visualizer by removing water molecules, ligands, and heteroatoms; in the case of dimeric forms, a single chain was retained. Known inhibitors and the selected compounds were geometry-optimized and saved in pdb format. Docking input files (pdbqt) were generated using AutoDock Tools [23] by adding polar hydrogens and Gasteiger charges to both receptor and ligands. The binding pocket of CyPD was defined using the Grid tool in AutoDock Tools, and docking simulations were performed using AutoDock Vina [24]. The docking protocol was validated by redocking the co-crystallized ligand into the binding site.

G. Energetic and Structural Interaction Analysis

Docking results were analyzed by examining binding affinities and root-mean-square deviation (RMSD) values for each binding mode. The most energetically favorable conformation (RMSD ~2 Å) for each ligand was extracted and saved in pdb format. Interaction profiles were analyzed in Discovery Studio Visualizer, including hydrogen bonds, van der Waals contacts, and π interactions.

III. RESULTS

A. Identification of Potential CyPD Inhibitors

Database screening yielded 50 compounds with reported inhibitory activity against CyPD, including several aryl indanylketones and multiple ChEMBL entries (Table 1). These compounds represented structurally diverse scaffolds with low IC₅₀ values, making them suitable reference ligands for pharmacophore modeling.

Table 1. Inhibitors, retrieved from BindingDB

Aryl indanylketone1	1-	CHEMBL3798445	CHEMBL4436790	CHEMBL4470490	CHEMBL4585544
Aryl indanylketone2	1-	CHEMBL3798755	CHEMBL4444722	CHEMBL4471175	CHEMBL4593662
CHEMBL1557710		CHEMBL3799069	CHEMBL4445439	CHEMBL4520315	CHEMBL5275318
CHEMBL2006156		CHEMBL3799315	CHEMBL4450619	CHEMBL4526530	US8901295
CHEMBL2017129		CHEMBL3799575	CHEMBL4451136	CHEMBL4530010	US8901295_2
CHEMBL3797675		CHEMBL3799597	CHEMBL4453162	CHEMBL4540033	US8901295_3
CHEMBL3797711		CHEMBL3799661	CHEMBL4456924	CHEMBL4547673	US9975902
CHEMBL3797905		CHEMBL3799875	CHEMBL4464178	CHEMBL4563478	US9975902_2
CHEMBL3798030		CHEMBL3800488	CHEMBL4464825	CHEMBL4570230	US9975902_3
CHEMBL3798305		CHEMBL3805631	CHEMBL4466871	CHEMBL4579041	US9975902_5

B. Structural Validation of CyPD

Seventeen crystallographic structures of human CyPD were obtained from the Protein Data Bank and compared against the canonical UniProt sequence (Q08752). Sequence identity ranged between 61–62% across entries (Table 2), confirming their reliability for docking-based studies. The aligned sequences demonstrated conservation of critical residues within the active site (Figure 1).



Figure 1. Sequence match for FASTA sequence of CyPD (Uniprot ID: Q08752) and 3D structures (PDB ID: 4o8h, 4o8i, 5cbl, 5cbu, 5cbv, 5cbw, 5ccn, 5ccq, 5ccr, 5ccs, 6y3e, 7r2i, 7r2j, 7r2l, 7zdn, 8ejx, 2z6w)

Table 2. Comparisons of sequence identity ratio between FASTA sequences of 3D structures

PDB ID:	Sequence Identity (%)
7R2I	61.82
7ZDN	61.21
2Z6W	61.82
5CBT	61.82
5CBU	61.82
5CBV	61.82
5CBW	61.82
5CCN	62.20
5CCQ	62.20
5CCR	61.82
5CCS	61.21
6Y3E	61.82
8EJX	61.82
4O8H	61.82
4O8I	61.82
7R2J	61.82
7R2L	61.82
6R8O	62.20

C. Pharmacophore Hypothesis Generation and Candidate Screening

Analysis of the reference inhibitors resulted in ten pharmacophore hypotheses characterized by variable numbers of hydrogen bond acceptors/donors, hydrophobic groups, and aromatic features (Table 3). Virtual screening against these models identified 22 candidate molecules from the ZINC database with high pharmacophore fit values (Table 4).

Table 3. Hypothesis models retrieved from PharmMapper and Features

Hypothesis	Hydrogen Bond Acceptors	Hydrogen Bond Donor	Hydrophobic	Ring Aromatic
1	4	4	2	-
2	4	4	1	2
3	4	2	2	2
4	4	2	2	2
5	4	2	3	-
6	4	2	2	2
7	4	2	3	-
8	4	2	3	-
9	6	2	1	2
10	6	2	1	2

Table 4. Molecules and features retrieved from ZINCPharmer databases

Hypothesis	ZINC ID	RMSD	Molecular Weight	Rotatable Bonds
1	08214770	1.548	587	15
2	94313213	1.022	717	15
2	85867961	1.444	789	15
2	33861486	1.334	616	15
2	04556705	1.307	443	15
2	16969255	1.336	464	12
2	85867249	1.366	750	15
3	85867378	1.372	587	15
3	09970473	1.549	469	15
3	94303268	1.329	750	15
3	94303285	1.433	752	15
3	12153442	1.350	464	12
3	14952519	1.350	448	11
3	85902197	1.106	735	15
3	94303262	1.455	764	15
3	35092275	1.314	464	12
3	13127502	1.180	354	6
3	23128374	1.764	429	10
3	04098556	1.234	464	12
3	19862290	1.435	377	8
3	33861406	1.170	600	15
3	70454922	1.176	614	15

D. ADME and Toxicological Profiles

ADME evaluation demonstrated that most candidates failed to meet drug-likeness criteria, particularly due to high molecular weight or unfavorable polarity. However, three molecules (ZINC13127502, ZINC23128374, and ZINC19862290) satisfied Lipinski's rule of five, displayed high predicted gastrointestinal absorption, and achieved favorable bioavailability scores (Table 5). These compounds were therefore prioritized for docking experiments.

Table 5. ADME-Toxicology features of molecules

ZINC No	LIPINSKI (rule of five)	TPSA (Å ²)	Consensus Log Po/w	Bioavailability	Molecular Weight g/mol	GI Absorption
08214770	No	342.65 Å ²	-7.84	0.17	586.61	Low
04556705	No	212.88 Å ²	-2.57	0.17	442.56	Low
09970473	No	189.53 Å ²	-0.98	0.17	468.54	Low
12153442	No	210.51 Å ²	-0.16	0.17	464.38	Low
13127502	Yes	118.06 Å²	2.46	0.55	354.38	High
14952519	No	190.28 Å ²	0.26	0.17	448.38	Low
16969255	No	210.51 Å ²	-0.09	0.17	464.38	Low
23128374	Yes	115.17 Å²	3.61	0.55	428.50	High
33861486	No	277.27 Å ²	-0.04	0.17	616.48	Low
35092275	No	210.51 Å ²	-0.20	0.17	464.38	Low
85867249	No	210.63 Å ²	0.79	0.17	749.95	Low
85867378	No	342.65 Å ²	-7.72	0.17	586.61	Low
85867961	No	167.04 Å ²	1.53	0.17	716.92	Low
85902197	No	195.11 Å ²	0.77	0.17	734.93	Low
94303262	No	198.35 Å ²	0.75	0.17	763.98	Low
94303268	No	207.14 Å ²	0.59	0.17	749.95	Low
94303285	No	229.17 Å ²	-0.52	0.17	751.94	Low
94313213	No	167.04 Å ²	1.53	0.17	716.92	Low
04098556	No	167.04 Å ²	1.53	0.17	616.48	Low
19862290	Yes	139.59 Å²	1.36	0.56	376.38	High
33861406	No	257.04 Å ²	0.73	0.17	600.48	Low
70454922	No	210.54 Å ²	-0.07	0.17	464.38	Low

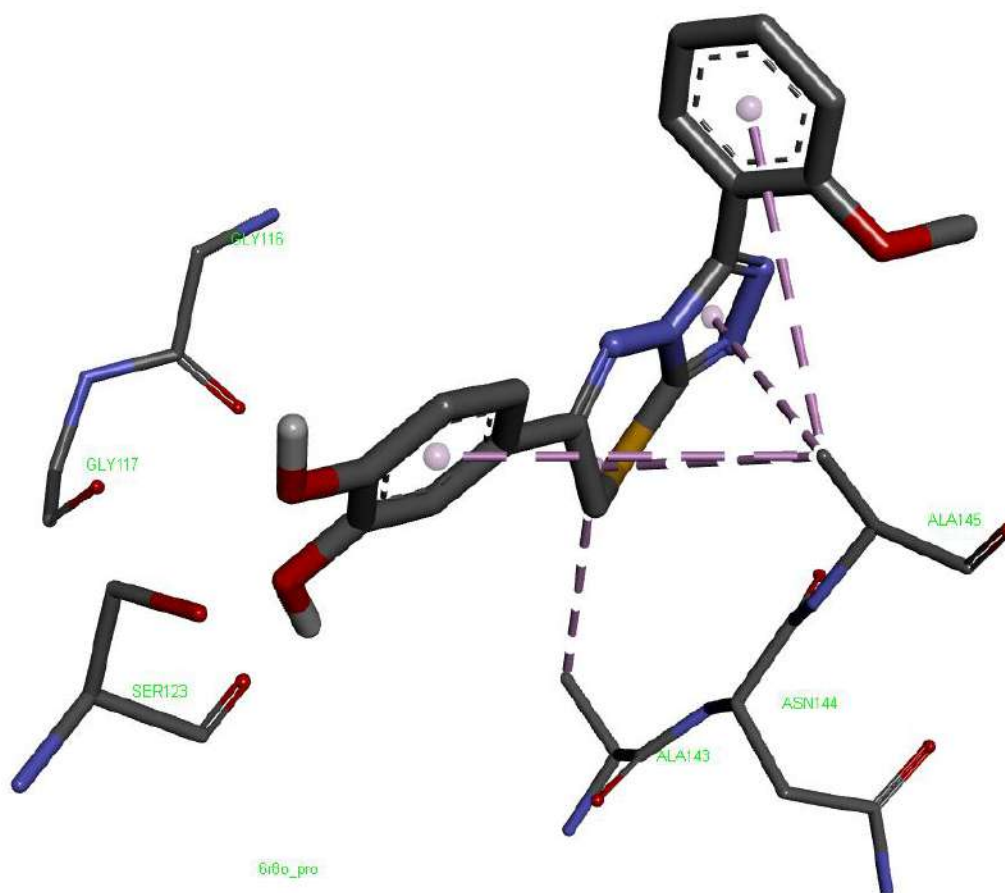
E. Binding Affinities and Interaction Profiles by Molecular Docking

Docking results revealed that the co-crystallized inhibitor achieved the strongest binding affinity (−8.4 kcal/mol). Among the screened candidates, ZINC19862290 showed the most favorable binding (−6.9 kcal/mol), followed by ZINC13127502 (−6.6 kcal/mol) and ZINC23128374 (−5.7 kcal/mol) (Table 6). All three compounds exhibited stable binding conformations, with RMSD values below 2.0 Å for their best poses.

Table 6. Binding affinity between CyPD and 3 molecules from SWISSADME results

	Binding Mode	Binding Affinity	Distance from best mode (Å)	
			RMSD l.b.	RMSD U.b.
ZINC13127502	1	-6.6	0.000	0.000
	8	-6.1	1.997	6.055
	16	-5.6	2.924	3.919
ZINC19862290	1	-6.9	0.000	0.000
	2	-6.8	0.622	2.545
	3	-6.5	1.440	3.239
ZINC23128374	1	-5.7	0.000	0.000
	4	-5.0	4.269	7.516
	13	-4.3	2.909	5.520
Inhibitor	1	-8.4	0.000	0.000
	5	-6.5	2.969	3.646
	11	-6.3	3.432	4.128

Interaction analysis demonstrated that ZINC13127502 engaged in π - π stacking with aromatic residues and multiple hydrogen bonds, indicating a stable and specific binding mode (Figures 2–3). ZINC19862290 exhibited strong hydrogen bonding and van der Waals contacts within the CyPD pocket, while ZINC23128374 showed weaker interactions, consistent with its lower docking score. Comparison with the co-crystallized inhibitor confirmed that the candidate ligands occupied similar regions of the binding site and recapitulated several key residue contacts.

Figure 2. Interaction between CyPD and ZINC13127502 molecules (Purple lines demonstrates π interactions)

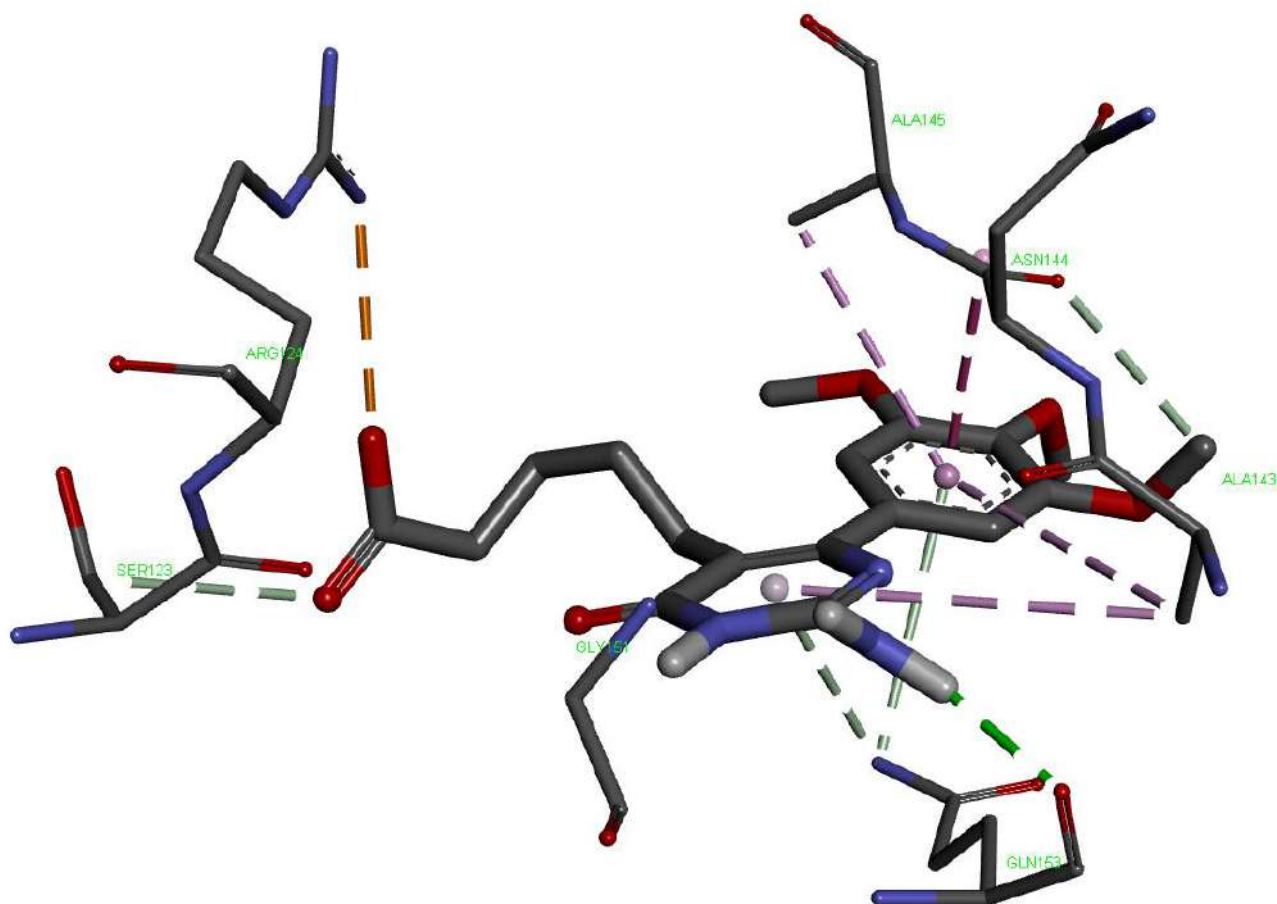


Figure 3. Interaction between CypD and ZINC19862290 molecules (Purple and orange dashed lines represent different types of π interactions between the molecule and amino acid residues. Green dashed lines indicate hydrogen bonds, where light green corresponds to carbon–hydrogen bonds and dark green corresponds to conventional hydrogen bonds.)

IV. DISCUSSION

In this study, a computational drug discovery pipeline was applied to identify novel Cyclophilin D (CypD) inhibitors with potential therapeutic value in multiple sclerosis. BindingDB screening initially provided 50 candidate molecules, which were refined by pharmacophore modeling and ZINCPharmer searches, yielding 22 compounds. ADME/Tox predictions indicated that ZINC13127502, ZINC19862290, and ZINC23128374 showed the most favorable drug-likeness and oral bioavailability profiles, with ZINC13127502 and ZINC19862290 meeting Lipinski's criteria and displaying high gastrointestinal absorption. Molecular docking further supported their inhibitory potential, with binding affinities comparable to known CypD inhibitors (-6.6 to -6.9 kcal/mol). Interaction analysis revealed that ZINC13127502 formed multiple hydrogen bonds and π – π interactions with active-site residues, while ZINC19862290 engaged both hydrophobic contacts and hydrogen bonds essential for stabilizing the binding pose.

These binding characteristics are consistent with previously reported inhibitor scaffolds, highlighting the role of aromatic stacking and polar interactions in CypD inhibition. Compared to classical inhibitors such as cyclosporine A and sanglifehrin A, which suffer from immunosuppression, toxicity, and poor CNS penetration, the identified candidates demonstrated more favorable pharmacokinetic properties and could serve as starting points for safer, non-immunosuppressive modulators. Nevertheless, further optimization and validation are needed to confirm their mitochondrial protective capacity and *in vivo* efficacy in experimental autoimmune encephalomyelitis and related neurodegenerative models.

V. CONCLUSION

Although none of the identified ligands surpassed the affinity of the known inhibitor, ZINC19862290 and ZINC13127502 showed promising docking scores and favorable ADME profiles. These scaffolds may serve as starting points for structural optimization aimed at improving binding affinity and brain permeability. Previous studies have highlighted the challenge of developing selective, non-immunosuppressive CypD inhibitors due to poor solubility and blood–brain barrier penetration of existing compounds [25–29]. In this context, the molecules identified here represent valuable candidates for future molecular dynamics simulations and experimental validation.

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Dünya ve Türkiye’de Keten (*Linum usitatissimum* L.) Üretimi

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Özet – Keten, Linaceae (Ketengiller) familyasından, 5000 yıldır lifleri ve tohumları için yetiştirildiği bilinen bir endüstri bitkisidir. Anavatanı Akdeniz Havzası ve Güneybatı Asya’dır. Bitkinin yabani formları tek ya da çok yıllık olabilirken, kültür çeşitleri tek yıllıktır. Dünya’da tohum için keten yetiştiren ülkelerin başında Kanada, Çin, ABD ve Hindistan gelmektedir. Dünya keten yağı üretiminin %50’den fazlası Çin ve ABD’ye aittir. Liflik keten üretiminde ise Çin, Fransa, Rusya ve Beyaz Rusya başı çekmektedir. Anadolu’da keten kültürü geleneksel olarak binlerce yıldır yapılmaktadır. Ancak her geçen yıl keten ekim alanı ve üretimi azalmaktadır. Lif için keten üretimi en fazla Marmara ve Karadeniz, tohum için keten üretimi en fazla Orta ve Güneydoğu Anadolu Bölgeleri’nde yapılmaktadır. Türkiye’de 2004 yılında toplam 2.200 dekar alanda toplam 80 ton keten üretimi yapıyorken, bu rakam 2024 yılında 1.320 dekar alana gerilemekle birlikte, artan verim ile üretim 188 ton olarak kaydedilmiştir. Bu çalışma, dünya ve Türkiye’de keten üretimi ile ticaretini ele alınmıştır.

Anahtar Kelimeler – Keten, *Linum Usitatissimum* L., Yağlık Keten, Liflik Keten, Üretim.

I. GİRİŞ

Lif bitkileri insanların birçok önemli ihtiyaçlarını karşılama açısından önemli bitki gruplarından. Dünya nüfusunun 7 milyarı aşması kişi başına düşen lif miktarı tüketimini de artırmıştır. Ülkemizde en fazla ekim alanına sahip olan lif bitkisi pamuk olup, bu bitki sıcak Akdeniz kuşağının sahip olduğu iklimde yazlık olarak yetiştirilmektedir. Pamuk bitkisinin toplam sıcaklık isteği fazla olup uzun bir vejetasyona sahiptir. Bu nedenle Türkiye’de Akdeniz, Ege ve Güneydoğu Anadolu bölgelerinin dışındaki bölgelerde yetiştirilememektedir. Türkiye’de mevcut lif üretimi, tüketimi karşılayamamaktadır. Dolayısıyla, tekstil sektörümüzün ihtiyaç duyduğu hammaddenin önemli bir bölümü ithalatla karşılanmaktadır. Üretimimizin tüketimi karşılayabilmesi için ekim alanlarının, verim ve kalitenin artırılması, fiyat politikaları gibi var olan sorunlar çözülmelidir [1]. Bununla birlikte Türkiye’de temel lif bitkisi olarak yetiştirilen pamuk bitkisi yanında diğer bazı lif bitkilerinin de üretiminin artırılması gereklidir. Bunların başında ise keten ilk sırada gelmektedir.

Keten (*Linum usitatissimum* L.), 13 cins ve 300 kadar türü içeren *Linaceae* familyasına bağlı bir türdür. *Linum* cinsinin dünyada tek ve çok yıllık olmak üzere 100, ülkemizde ise 38 kadar türü mevcuttur. İki değişik forma sahip olan keten, lif ve yağ üretiminde kullanılan tek yıllık bir endüstri bitkisidir. Uzun boylu, yüksekten dallanan ve kuvvetli liflere sahip olan formları lif üretimi amacı ile kısa boylu kısmen alçaktan dallanan formları ise yağ elde etmek amacı ile yetiştirilmektedir. Yağ tipi ketenlerin boyları 60-80 cm ve sap kalınlığı 5-6 mm, lif tipi ketenlerin boyları 100-120 cm ve sap kalınlığı ise 2-3 mm dolayındadır.

Ülkemizde yıldan yıla düşüş gösteren keten tarımı ile gerek tekstil sanayisinde lifi gerekse yağ sanayisinde tohumunun kullanımı giderek azalmıştır. Fakat tohumunun bileşiminde bulunan Omega-3 ve Omega-6 yağ asitlerince zengin olması keten bitkisinin yeniden gündeme gelmesine sebep olmuştur.

Keten bitkisinin başta endüstri olmak üzere çok geniş kullanımı bulunmaktadır. Saplarından elde edilen liflerinden özellikle tekstil sanayinde yararlanılmaktadır. Keten liflerinden dokunan kumaşlar serin tutma, yıkanabilirlik, parlaklık, renk sağlamlığı, çekmeye dayanıklılık gibi özellikleri nedeni ile tercih

edilmektedir [2]. Diğer taraftan keten lifleri dayanıklılık yönünden diğer bitkisel lifler arasında başta yer almaktadır. Fakat keten kumaşlarının kolay buruşması, ketende önemli bir dezavantajdır.

Lifinin bütün bu üstün özelliklerine rağmen, yapay lif endüstrisindeki gelişmeler, keten üretimini, daha ziyade tohumculuk yönüne kaydırmış; ancak, son zamanlarda, çoğu ülkelerde zorunlu tutulan yeni çevre koruma yasalarının etkisiyle, lif bitkilerine ilgi artmaya başlamıştır. Bunun doğal bir sonucu olarak, biyolojik ayrışabilen, yeniden değerlendirilebilen organik dokuma hammaddesi pazarı giderek genişlemektedir. Dolayısıyla, birçok ülke, bu talebi karşılayabilmek için, lif bitkileri endüstrilerini yeniden kurmakta veya genişletmektedir [3].

Yağlık keten tohumlarında %30-45 arasında yağ bulunur. Keten yağı (bezir yağı), çoklu doymamış bir yağ asidi olan linolenik asit (ω -3) bakımından zengin birkaç yağdan birisidir. Keten yağı; %6 palmitik asit, %4 stearik asit, %14 oleik asit, %12 linoleik asit ve %64 linolenik asit içerir. Yüksek doymamışlık özelliği nedeniyle keten yağı çok hızlı kurur. Bu nedenle, özellikle keten yağı endüstriyel amaçlı olarak vernik, cila, bezir, boya ve sabun imalatında kullanılır. Son yıllarda yapılan yoğun ıslah çalışmaları sonucunda linolenik asit içeriği düşük fakat linoleik asit içeriği yüksek keten çeşitleri geliştirilmiş, böylece keten yağı sadece endüstriyel amaçlı değil yemeklik yağ olarak da kullanılmaya başlamıştır. Ketenin iklim değişikliğine uyum sağlayan, çevreci bir tarla bitkisi olması, ekildiği yerlerde işlendiğinde farklı endüstri alanlarının ihtiyaçlarını karşılayabilen yüksek ekonomik getiri potansiyeli, etkili bir gıda takviyesi sağlaması gibi sayısız önemli özellikleri nedeniyle tarımının artacağı öngörülmektedir. Bu çalışma ile günümüzde dünya ve Türkiye’de keten üretimi ile ticareti ele alınmıştır.

II. DÜNYA KETEN ÜRETİMİ VE TİCARETİ

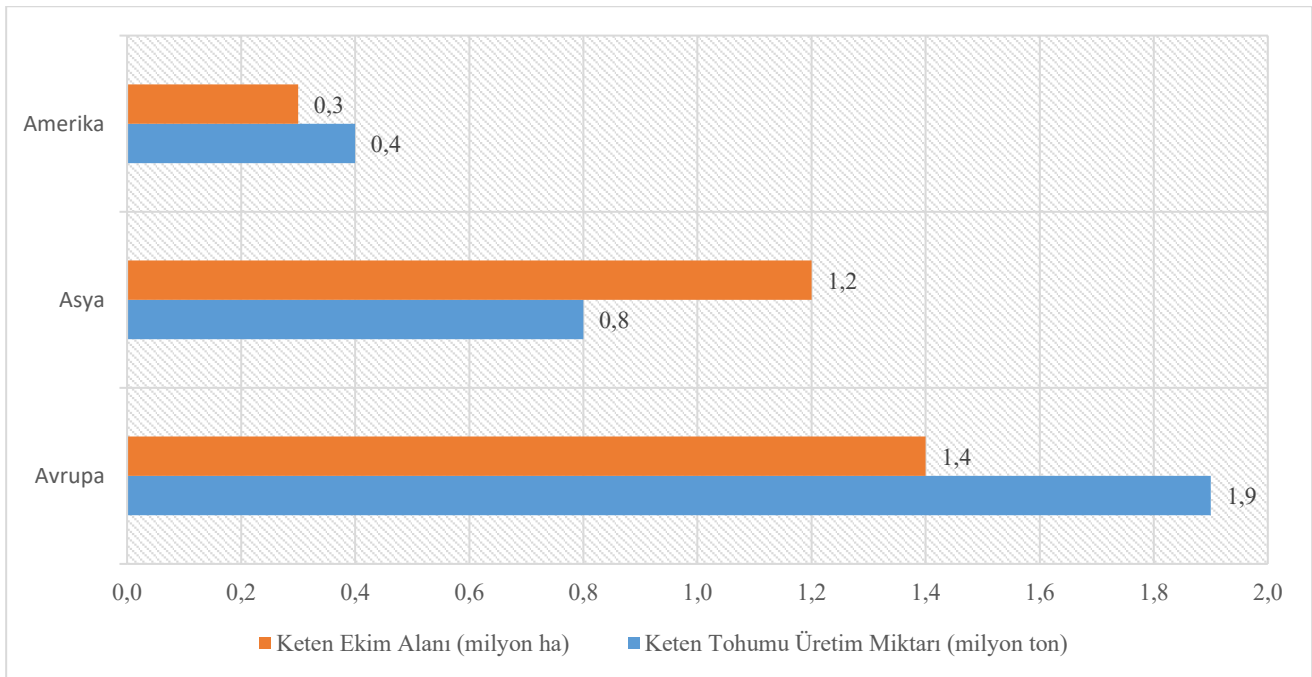
Küresel keten talebi ve üretimi, tarihsel olarak rekabet, savaş ve politika çatışmaları gibi çeşitli faktörlere dayalı sıkça dalgalanma yaşamıştır. Ancak, 20. Yüzyılın sonlarına doğru, özellikle 1980’lerden sonra, dünya ekonomisinde keten talebi ve üretimi yeniden yükselmeye başlamıştır. Bunun nedenlerinden biri ketenin, yapay ve kompozit malzemelerde girdi olarak kullanılmaya başlanmasıdır. Fransa, Çin ve İtalya gibi lider keten üreticilerinin, özellikle 1980’lerden 21. yüzyılın başlarına kadarki dönemde, toplam yıllık keten üretim miktarlarının önemli ölçüde arttığı görülmüştür.

Tablo 1. Dünya Keten Ekim Alanı, Üretim ve Verim Değerleri

Yıllar	Üretim Miktarı (Milyon ton)	Ekim Alanı (Milyon ha)	Verim (kg/da)	Keten Yağı Üretimi (Milyon ton)
1961	3.0	7.5	40	0.9
1970	4.2	7.4	57	1.0
1980	2.3	5.4	42	0.7
1990	2.9	4.4	66	0.7
2000	2.0	2.6	77	0.7
2010	1.8	2.0	89	0.5
2019	3.1	3.2	96	0.8
2020	3.4	3.5	96	0.7
2021	3.3	4.1	81	0.7
2022	4.0	4.5	88	0.7
2023	2.6	3.1	84	-

Tablo 1’de görülebileceği gibi, 1961 yılında dünya keten üretim miktarı 3 milyon ton iken 1970 yılında 4.2 milyon ton ile en yüksek seviyeye ulaşmıştır. Son 5 yıllık döneme baktığımızda dünyada keten üretim miktarı dalgalı bir seyir izlemiştir. 2019 yılında 3.1 milyon ton olan üretim miktarı 2022 yılında 4 milyon tona yükselmişse de 2023 yılında 2.6 milyon tona gerilemiştir. Dünyada keten ekim alanı üretim miktarı ile paralellik göstermektedir. 1961 yılında keten ekim alanı 7.5 milyon ha iken, 2010 yılında 2 milyon ha’a kadar düşmüştür. Son 5 yılda ise en fazla ekim alanı 2022 yılında (4.5 milyon ha) gerçekleşmiştir. Keten dünya ortalama verimine baktığımızda ise; 1961 yılında 40 kg/da ile en düşük verim ortalamasına sahipken en yüksek verim ortalamasına 96 kg/da ile 2019 ve 2020 yıllarında ulaşmıştır. Dünya’da keten yağı üretimi çok fazla değişiklik göstermemiştir. 1961 yılında sadece 0.9 milyon ton’luk bir üretim gerçekleştirilmiştir. En fazla keten yağı üretimi 1 milyon ton ile üretim miktarının en fazla olduğu 1970 yılında gerçekleşmiştir. Takip eden yıllarda keten yağı üretimi artış göstermemiştir ve 2010 yılında 0.5 milyon ton’a kadar düşmüştür [4].

2023 yılı keten üretim miktarını kıtalar temelinde incelersek (Şekil 1); 1.9 milyon ton üretim miktarı ile Avrupa kıtası ilk sırada yer almıştır. Avrupa kıtasını sırasıyla; Asya (0.8 milyon ton) ve Amerika (0.3 milyon ton) takip etmiştir. Şekil 1’de yer almayan Afrika ve Okyanusya kıtasında sırasıyla 93 bin ton ve 9 bin ton’luk bir üretim gerçekleşmiştir. 2023 yılında keten üretiminin %50’sinden fazlası Avrupa kıtasında gerçekleşmiştir. Avrupa kıtası 1.4 milyon ha ile 2023 yılında en fazla keten ekim alanına sahip kıta olmuş ve Avrupa kıtasını sırasıyla; 1.2 milyon ha ile Asya, 0.3 milyon ha ile Amerika ve 90 bin ha ile Afrika kıtası takip etmiştir. 2023 yılında Okyanusya’nın ekim alanı sadece 9 bin ha’dır. 2023 yılı kıtalar temelinde keten verim ortalamasına baktığımızda, üretim miktarı sıralamasıyla farklılık gösterdiği görülmüştür. Ekim alanı bakımından ilk sırada yer alan Avrupa kıtasının verim ortalaması 90 kg/da’dır. Amerika kıtası 113 kg/da ile verim ortalaması bakımından kıtalar bazında ilk sırada yer almıştır. Üretim miktarı bakımından ikinci sırada yer alan Asya kıtası verim ortalaması (68 kg/da) bakımından son sıradadır. Afrika ve Okyanusya’nın 2023 yılı keten verim ortalaması ise sırasıyla; 103 kg/da ve 107 kg/da’dır [4].



Şekil 1. Kıtalar Temelinde 2023 Yılı Keten Ekim Alanı ve Üretimi

Dünya keten üretimine ülkeler bazında baktığımızda (Tablo 2); Rusya, Kazakistan, Kanada ve Çin söz sahibi ülkeler olarak görülmüştür. 2023 yılında bu dört ülkenin toplam üretim miktarının 2 milyon ton’a yakın olduğu görülmüştür. Bu üretim miktarı 2023 yılı dünya keten üretiminin %76’sından fazlasını oluşturmaktadır. Tablo 2’de görülebileceği gibi, Rusya’nın keten üretimi (2023) 1.100 bin ton olarak gerçekleşmiştir. Rusya’yı sırasıyla Kazakistan (362 bin ton), Kanada (273 bin ton), Çin (260 bin ton) ve Hindistan (167 bin ton) takip etmiştir [4].

Tablo 2. Ülkeler Bazında Keten Ekim Alanı, Üretim ve Verim Değerleri

Yıllar	2013			2018			2023		
Ülkeler	Üretim miktarı (bin ton)	Ekim alanı (bin ha)	Verim (kg/da)	Üretim miktarı (bin ton)	Ekim alanı (bin ha)	Verim (kg/da)	Üretim miktarı (bin ton)	Ekim alanı (bin ha)	Verim (kg/da)
Rusya	300	438	68	558	730	76	1.100	1.290	85
Kazakistan	295	384	77	933	1.077	87	362	726	50
Kanada	730	412	177	492	342	144	273	238	114
Çin	399	313	127	366	279	131	260	200	130
Hindistan	147	296	50	174	326	53	167	239	70
Etiyopya	88	96	92	97	84	116	81	82	99
ABD	85	70	122	113	80	142	75	65	116
Ukrayna	32	42	76	24	32	75	54	47	113
Fransa	16	8	190	46	25	185	51	27	192

Kaynak: [4]

Son 10 yıllık keten üretim miktarlarına baktığımızda Tablo 2’de yer alan ülkelerin çoğunda dalgalı bir üretim görülmektedir. Tablo 2’de yer alan ülkeler arasında 10 yıllık dilimde keten üretiminin önemli ölçüde arttığı ülke ise Rusya olmuştur. 2013 yılında sadece 300 bin ton olan üretim miktarı 2023 yılında 1.1 milyon ton’a yükselmiştir. Dünya’da 2023 yılı keten ekim alanlarına baktığımızda ise, 1.290 bin ha ile Rusya ilk sırada yer alırken, bu ülkeyi sırasıyla; Kazakistan (726 bin ha), Hindistan (239 bin ha), Kanada (238 bin ha) ve Çin (200 bin ha) takip etmiştir. Tablo 2’de yer alan ülkelerin verim değerlerine (2023 yılı) baktığımızda ise Fransa 192 kg/da ile ilk sırada yer almıştır. Ekim alanı bakımından 2. sırada yer alan Kazakistan ise 50 kg/da verim ortalaması ile son sırada yer almıştır [4].

2023 yılı dünya keten tohumu ithalat miktarı 2.6 milyon ton iken aynı yıl keten ham yağı ithalat miktarı ise; 257 bin ton olarak gerçekleşmiştir. 2023 yılı keten tohum ithalatı 1.5 milyar dolar, ham yağ ithalatı 0.3 milyar dolar olarak kaydedilmiştir. İhracat miktarları ise; dünya keten tohumu için 2.5 milyon ton ve ham yağ için 204 bin ton olarak gerçekleşmiştir. 2023 yılı dünya keten tohumu ihracat değeri 1.3 milyar dolar seviyelerindeyken, ham yağ ihracatı yaklaşık 0.3 milyar dolar seviyelerinde gerçekleşmiştir [4].

Dünya keten tohum ithalatında Çin, Belçika, ABD ve Polonya en dikkat çeken ülkelerdir. 2023 yılında Çin 1.2 milyon ton keten ithal etmiş ve toplamda 587 milyon dolar harcamıştır. Aynı yılda Belçika 500 bin ton, ABD 126 bin ton ve Polonya ise 120 bin ton keten ithalatı yapmışlardır. 2023 yılında Rusya, Kazakistan, Kanada keten tohumu ihracatı yapan önemli ülkelerdir. Rusya 2023 yılında toplam 1.3 milyon ton keten ihracatı yapmıştır. Rusya’yı 416 ton ile Kazakistan ve 218 bin ton ile Kanada takip etmiştir. Rusya, Kazakistan ve Kanada bu ihracattan sırasıyla 573, 228 ve 163 milyon dolar gelir elde etmişlerdir [4].

III. TÜRKİYE KETEN ÜRETİMİ VE TİCARETİ

Türkiye’nin bir dönem geleneksel tarım ürünleri arasında yer alan keten bitkisinin üretimi, günümüz Türkiye’sinde ithal ikâme politikaları ve keten iplik yerine daha ucuz alternatiflerin popüler olması gibi sebepler ve ekonomik olarak rekabet edememesi nedeniyle oldukça azalmıştır. 1961 yılında Türkiye’nin toplam yıllık keten üretiminin 6.750 ton civarında olduğunu gösterirken, 2000’lere doğru bu miktar 7 tona gerilemiştir. Bu eğilim 21. yüzyılda da devam etmiş; örneğin 2020’de Türkiye’deki keten üretimi sadece 3 ton olarak kayıtlara geçmiştir. FAO verilerine bakıldığında 1961 yılında Türkiye en çok keten lifi üreten 8.

ülke iken,1980'lerden sonra üretimde düşüş görülmeye başlanmış ve dünya arenasından çekilmiştir. Günümüzde ise keten lifi ve tohumuna ihtiyaç artmasına rağmen ne yazık ki ülkemizde üretimi halen oldukça düşük düzeydedir.

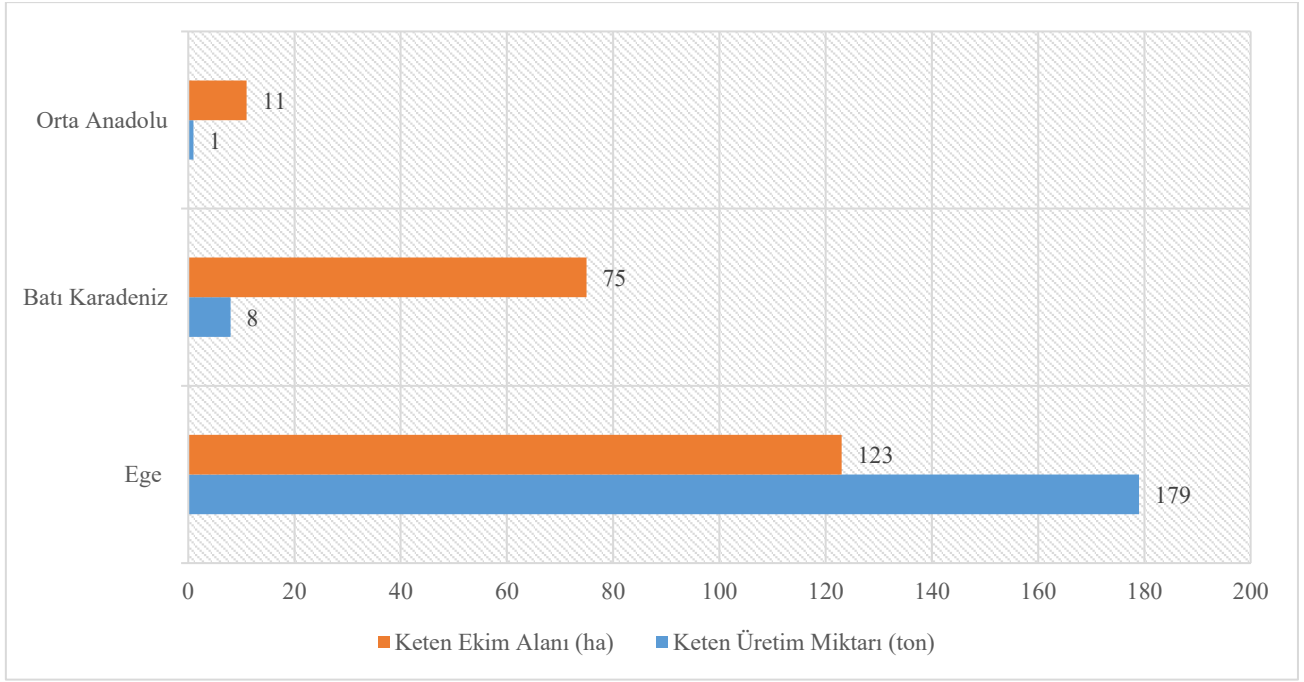
Türkiye’de keten üretimine dair kayıtlar incelendiğinde, 2004 yılından 2024 yılına kadar 11 üretim sezonunda yetiştiriciliği yapılmıştır. 2004 yılından itibaren üretim miktarı yıllar içerisinde dalgalı bir seyir göstermiştir. Tablo 3’ün incelenmesi ile de görülebileceği gibi; 2004 yılında 80 ton olan üretim miktarı 2009 yılında 1 tona kadar düşmüştür. 2009 yılı ile 2021 yılları arasında sadece 2012 yılında üretimi bulunmaktadır. 2021 yılında keten üretimi 1 ton iken 2024 yılında 188 ton ile en fazla üretim miktarına ulaşmıştır. Türkiye’de keten ekim alanı en yüksek seviyeye 2004 yılında (2.200 da) ulaşmıştır. 2024 yılında ise 1.320 da alanda ekimi gerçekleştirilmiştir. Türkiye’nin ortalama keten verimi dünya ortalamasının üzerindedir. 2023 yılında dünya keten verim ortalaması 84 kg/da iken, aynı yıl Türkiye’nin verim ortalaması 131 kg/da olarak gerçekleşmiştir. 2024 yılında ise Türkiye keten verim ortalaması 142 kg/da ile en yüksek seviyeye ulaşmıştır [2].

Tablo 3. Türkiye Keten Ekim Alanı, Üretim ve Verim Değerleri

Yıllar	Üretim Miktarı (ton)	Ekim Alanı (da)	Verim (kg/da)
2004	80	2.200	36
2005	86	1.760	49
2006	84	1.460	58
2007	48	806	60
2008	40	670	60
2009	1	20	50
2012	13	180	72
2021	1	10	100
2022	8	95	84
2023	32	245	131
2024	188	1320	142

Kaynak: [5]

2024 yılında Türkiye’de keten üretimine bölgeler temelinde dağılımına baktığımızda (Şekil 2) sadece Ege Bölgesi, Batı Karadeniz Bölgesi ve Orta Anadolu Bölgesinde üretim yapıldığı görülmektedir. 2024 yılında 179 ton ile Ege Bölgesi ilk sırada yer almaktadır. Ege Bölgesi’ni sırasıyla; 8 ton ile Batı Karadeniz Bölgesi ve 1 ton ile Orta Anadolu Bölgesi takip etmiştir. 2024 yılında Ege Bölgesi keten tohumu üretimi bakımından Türkiye’nin %95’inden fazlasına sahip olmuştur. 2024 yılında Ege Bölgesi ekim alanı bakımından da (123 ha) ilk sırada yer almıştır. Bunu sırasıyla Batı Karadeniz Bölgesi (75 ha) ve Orta Anadolu Bölgesi (11 ha) bölgeleri takip etmiştir. Üretimin yapıldığı bu üç bölge içerisinde ortalama keten veriminin en yüksek olduğu bölge 145 kg/da ile Ege Bölgesi en düşük olduğu bölge ise 91 kg/da ile Orta Anadolu Bölgesi olmuştur [5].



Şekil 2. 2024 Yılı Türkiye Bölgeler Ölçeğinde Keten Ekim Alanı ve Üretimi

Türkiye’de keten üretiminin en fazla yapıldığı iller ile en fazla üretim miktarına sahip bölgeler arasında paralellik görülmektedir. Tablo 4’te Türkiye’de keten üretiminin ilk kayıt altına alındığı 2004 yılı, 2012 yılı ve 2024 yılı incelenmiştir. Tablo 4’te de görüldüğü üzere üretim yılları içerisinde üretim yapılan illerde sürekli değişimler olmuştur. Son yıllarda en fazla keten tohumu üretim miktarına sahip iller sırasıyla Uşak, Tokat ve Van’dır. 2004 yılında Türkiye’de 80 ton’luk üretimin tamamı Diyarbakır ve Kocaeli illerine aittir. Aynı yıl Sinop’ta 250 da alan ekimi yapılmış olmasına rağmen hasadı yapılamamıştır. 2012 yılında ise; Türkiye’de yapılan 13 ton’luk üretimin tamamı Karabük ve Muş illerinde gerçekleşmiştir. 2024 yılı Türkiye’nin keten üretim miktarının (188 ton) en fazla olduğu yıldır ve bu üretim miktarı Uşak (179 ton), Tokat (8 ton) ve Van (1 ton) illerine aittir [5].

Tablo 4. İl Temelinde Keten Ekim Alanı, Üretim ve Verim Değerleri

-	2004			2012			2024		
İller	Üretim miktarı (ton)	Ekim alanı (da)	Verim (kg/da)	Üretim miktarı (ton)	Ekim alanı (da)	Verim (kg/da)	Üretim miktarı (ton)	Ekim alanı (da)	Verim (kg/da)
Diyarbakır	50	990	51	-	-	-	-	-	-
Karabük	-	-	-	6	100	70	-	-	-
Kocaeli	30	960	31	-	-	-	-	-	-
Muş	-	-	-	7	80	75	-	-	-
Sinop	0	250	0	-	-	-	-	-	-
Tokat	-	-	-	-	-	-	8	75	107
Uşak	-	-	-	-	-	-	179	1.231	145
Van	-	-	-	-	-	-	1	11	91

Kaynak: [5]

Tablo 4'ün incelenmesinden anlaşılabacağı gibi, keten üreten illerin ekim alanı ile üretim miktarı arasında paralellik görülmüştür. Nitekim 2024 yılında keten ekim alanı en fazla 1.231 da ile Uşak ilinde olup bunu sırasıyla 75 da ile Tokat, 11 da ile Van illeri takip etmiştir. Keten üretiminin yoğun olduğu illerin verimlerine baktığımızda ise, 2024 yılında en yüksek verim 145 kg/da ile üretimin en fazla olduğu Uşak iline aittir [5].

Türkiye'nin keten tohumu ihracat miktarı 2023 yılında 7 bin ton, ihracat değeri 6 milyon dolar olarak gerçekleşmiştir. 2023 yılı keten tohumuna ait ithalat miktarı ise 46 bin ton, ithalat değeri 22 milyon dolar seviyesinde olmuştur. Keten yağı ithalat ve ihracatı ise 2023 yılında yok denecek kadar az seviyede gerçekleşmiştir [4].

IV. SONUÇLAR

Keten bitkisi, kökünden tohumuna her bir bölümü birbirinden farklı endüstrilerin hammaddesine dönüşebildiği için, katma değeri yüksek bir bitkidir. Bitkinin adaptasyonunun yüksek olması, toprak isteklerinin az olması, aynı toprakta ikinci bir ürünün yetişmesi için toprağı hazırlaması ve dinlendirmesi gibi pek çok avantajları bulunmaktadır. Ayrıca, kışlık ekimde yeterince yağmur aldığında, ekstra su ihtiyacı olmaması nedeniyle susuz tarıma son derece uygundur.

Türkiye'de ketenin tarihsel gelişimi, bilinen en eski kültür bitkilerimizden biri olması, ülke ekolojisinin hem yağlık hem liflik keten yetiştiriciliği için uygunluğu göz önüne alındığında gerek dünya ve insanlığın geleceği gerekse iklim değişikliği açısından önem taşıyan bu bitki ve türevlerinin yaygınlaşabilmesi açısından ülkemizde keten tarımının desteklenmesi konusu önem taşımaktadır.

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HT/HP Gaz Kondensat Karışımının Viskozitesini Hesaplayacak Model Denklemlerin Geliştirilmesi

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Özet – HT/HP Gaz kondensat karışımı ifadesi, petrol ve doğal gaz mühendisliğinde yüksek sıcaklık / yüksek basınç koşullarında bulunan gaz kondensat akışkanlarını tanımlar. Gaz kondensatlar, yüzey koşullarına çıkarıldığında hem gaz hem de sıvı faz üretebilen, kritik sıcaklığı yüksek, genellikle orta-ağır hidrokarbon fraksiyonları (C₅+) içeren doğal gaz akışkanlarıdır. HT/HP koşullarda bulunan kondensatlar, standart gaz kondensatlara göre daha farklı faz davranışları sergiler. HT/HP gaz kondensat üretimi normal gaz kondensatlara göre çok daha karmaşık ve pahalıdır. Çünkü yüksek basınç yüksek sıcaklık koşulları, hem akışkan davranışında hem de yüzey-tesisat tarafında ciddi zorluklar yaratır. Gaz kondensatlar, yüksek değerli sıvı fraksiyonlar (C₅–C₁₂, nafta, benzinlik kondensat) içerdiği için çok değerlidir. Gaz kondensat sıvısının viskozitesi hafif–orta sıvı hidrokarbonlar içerdiği için 1–3 cP civarındadır ve hafif petrolden daha düşüktür, gaz fazı ise çok düşüktür genellikle 0.01–0.03 cP aralığındadır.

Bu çalışmada, 140 °C de yüksek basınç/yüksek sıcaklıkta gaz kondensat karışımının laboratuvar ortamında deneysel olarak elde edilen viskozite değerlerini ampirik olarak verebilecek model denklemi elde edilmeye çalışıldı. Karışımın viskozitesini basınca bağlayan model denklemleri geliştirildi. Modellemede kullanılan veri literatürde yer alan deneysel bir çalışmadan alındı. Modellemede CurveExpert Professional 2.7.3 programı kullanılarak programın kütüphanesindeki lineer ve non- lineer modellerin deneysel veriye uygunluğu araştırıldı. Modelleme sonucunda yüksek korelasyon katsayısına sahip ve deneysel veriyi yüksek oranda kapsayabilecek olanlar seçildi. Modellerin uygunluğu korelasyon katsayıları yanı sıra MBE, RMSE ve chi-kare gibi istatistiksel testler kullanılarak araştırıldı.

Anahtar Kelimeler – Gaz Kondensat, Viskozite, HTHP, Modelleme, İstatistiksel Analiz.

I. GİRİŞ

Gaz kondensat, rezervuar koşullarında tek fazlı gaz gibi davranan, ancak yüzeye çıkarıldığında basınç ve sıcaklığın düşmesiyle birlikte sıvı ve gaz fazına ayrılan hidrokarbon karışımıdır. İçerdiği hidrokarbonlar genellikle: CH₄, C₂H₆ gibi hafif gazlar ve C₅–C₁₂ olarak orta-ağır fraksiyonlar vardır. Rezervuar basıncı çığırma noktasını altına inince sıvı kondensat çökmesi, Retrograd yoğuşma gerçekleşir. Kritik noktaya yakın olduklarından dolayı kritik noktaya yakınsı akışkan davranışı gösterebilirler [1].

Yüzeye çıkarılan gaz kondensat karışımı, ayırma ve işleme tesislerinde gaz ve sıvı ürünlere ayrılır:

Ayırma: Üç fazlı ayırıcılar ile yapılır, gaz, petrol ve su olarak ayrılır. Gaz, boru hattına veya geri enjeksiyona gönderilirken, kondensat (C₅–C₁₂) sıvı ürün olarak toplanır. Varsa su ise arıtma tesisine gönderilir.

İşleme: gaz kısmı, kurutulur, CO₂/H₂S gibi asidik bileşenler uzaklaştırılır. Doğalgaz şebekesine verilir veya LNG' ye dönüştürülür. Kondensat kısmı, stabilizasyon ünitesinde gazdan arındırılır. Rafinerilere gönderilerek benzin, nafta, jet yakıtı gibi ürünlere işlenir. Gaz kondensatın sıvı kısmı ise petrokimya

hammaddesi, rafineri beslemesi, benzin harmanında gaz kısmı ise elektrik üretimi, LNG, şehir gazı, sanayi yakıtı olarak kullanılır.

HT/HP Gaz Kondensatın Basıncı, 10.000 psi'den sıcaklığı, 150–180 °C üstü büyüktür. Rezervuar koşullarında tek fazlı gaz gibi görünür. Basınç düşürüldüğünde yoğuşma gerçekleşir ağır fraksiyonlar sıvı faza geçer. Yoğuşma Mekanizması, Yüksek P-T koşullarından dolayı kritik noktaya yakın davranış gösterebilir. HT/HP gaz kondensat rezervuarları, mühendislik açısından özel öneme sahiptir çünkü klasik gaz veya petrol rezervuarlarından çok daha farklı faz davranışları, üretim sorunları ve tasarım zorlukları içerir [2].

Üretimde Karşılaşılan Sorunlar

Retrograd yoğuşma nedeniyle rezervuar içinde sıvı faz birikir. Bu sıvı, gözeneklerde hapsolür ve gazın geçirgenliğini azaltır. Çiğlenme noktasının üzerinde üretim yapmak gerekir, aksi halde kondensat kayıpları olur. Ancak HT/HP sahalarında rezervuar basıncı çok yüksek olduğu için basıncı yönetmek ve sabit tutmak zordur. Yoğuşan sıvı faz, kuyu çevresinde gaz akışını tıkar. Gaz üretimi düşer, kondensat verimi azalır. HT/HP gaz kondensat akışkanları genellikle CO₂, H₂S içerir. Yüksek sıcaklık ve basınçta bu gazlar, çelik ekipmanlarda şiddetli korozyon yapar. Hidrat, wax, asfaltın çökmesi gibi yoğun sıvı fraksiyonlar oluşma riskini artırır. Özellikle üretim yüzeye taşındığında ani basınç-sıcaklık değişimleri ciddi akış problemleri yaratır.

Çalışma Zorlukları [2]

150–200 °C sıcaklık, 10.000–15.000 psi basınç nedeniyle özel alaşımlar, yüksek dayanımlı çelikler gerekir. Kuyu başı ve tamamlama ekipmanlarının maliyeti çok yüksektir. Kritik noktaya yakın davranış gösteren bu akışkanlarda faz davranışını doğru tahmin etmek için gelişmiş durum denklemleri modelleri gerekir. Yanlış tahmin üretim planlamasında büyük kayıplara neden olur. Rezervuar basıncını çiğlenme noktasının üzerinde tutmak için gaz geri enjeksiyonu yapılır. Ancak HT/HP sahalarında enjeksiyon ve yüzey tesisatı çok pahalıdır. Yüksek basınç nedeniyle patlama, sızıntı ve kuyu kontrolü riskleri yüksektir. Sondajda blowout önleyici (BOP) tasarımları çok kritik hale gelir.

Mühendislik Açısından Önemi [2,3]

Faz davranışları daha karmaşıktır, PVT analizlerinde durum denklemleri kullanılarak hassas modelleme gerekir. Üretim sırasında basıncın çiğlenme noktasının üzerinde tutulması önemlidir. Rezervuar gözeneklerinde sıvı kondensatın çökmesi ile kuyu çevresinde sıvı birikimini önlemek için gaz geri enjeksiyonu önerilir. Gaz geri enjeksiyonu, üretilen gazın veya dışarıdan temin edilen başka bir gazın tekrar rezervuara enjekte edilerek basıncın kontrol altında tutulması ve hidrokarbon üretiminin artırılması işlemidir. Gaz kondensat rezervuarlarında Geliştirilmiş Petrol/Gaz Geri Kazanımı yöntemlerinden özellikle CO₂ enjeksiyonu ve zengin gaz enjeksiyonu, retrograd yoğuşma problemini azaltmak ve üretimi artırmak için kritik öneme sahiptir. Zengin gaz = C₂+ ve C₃+ bileşenlerce zengin gaz anlamına gelir. Korozyon ve malzeme seçimi önemlidir. Yüksek T ve P koşulları, ayrıca kondensatın asidik bileşenler içermesi, kuyu tamamlama ve boru hattı tasarımında özel alaşımları gerektirir.

II. MATERYAL VE YÖNTEM

Bu çalışmada, bileşimi Tablo 1' de verilen 140 °C de HT/HP Gaz Kondensatın viskozitesini basınca bağlı olarak hesaplanabilmesine olanak tanıyacak model denklemleri geliştirildi. Modellemede kullanılan veri literatürde yer alan deneysel bir çalışmadan alınmış ve bileşimi Tablo 1'de viskozite verisi Tablo 2'de verilmiştir [4].

Tablo 1. 140 °C de HT/HP Gaz kondensat Karışımı Bileşimi [4]

Bileşen	mol %	Bileşen	mol %
N2	0,34	nC5	0,85
CO2	3,59	C6	1,38
C1	67,42	C7	1,5
C2	9,02	C8	1,69
C3	4,31	C9	1,14
iC4	0,93	C10	0,8
nC4	1,71	C11+	4,58
iC5	0,74		

Tablo 2. 140 °C de HT/HP Gaz Kondensat Karışımı için viskozite değerleri [4]

P (bar)	Viskozite (cP)	P (bar)	Viskozite (cP)
1035,20	0,1052	621,50	0,0729
966,30	0,0999	552,60	0,0674
894,00	0,0943	483,60	0,0619
828,40	0,0891	414,70	0,0563
759,40	0,0837	396,40	0,0547
690,50	0,0783		

B. Modelleme Çalışması

Tablo 2’ de verilen basınç ve viskozite verisi CurveExpert Professional 2.7.3 kullanılarak modellenmiştir. Modelleme çalışmasında CurveExpert Professional 2.7.3 Kütüphanesinde bulunan lineer ve non lineer formdaki tüm model denklemler veriye uygulanarak viskoziteyi basıncın fonksiyonu olarak hesaplayabilmeye olanak tanıyacak modeller elde edilmiştir. Modelleme sonucunda yüksek korelasyon katsayılarına sahip modeller seçildikten sonra aşağıda verilen istatistiksel analiz metotları kullanılarak modellerden hesaplanan değerlerin Tablo 2’ deki değerleri hesaplayabilmedeki güvenilirleri araştırılmıştır.

C. Hata Analizi

Modellerden elde edilen değerlerin uyumunu ortaya koymak amacı ile MBE, RMSE ve ki-kare gibi istatistiksel testler uygulanmıştır. MBE, RMSE ve Ki-kare gibi istatistiksel metrikler, analizlerde doğruluğu, hata payını ve uygunluğu değerlendirmek için kullanılır. Bu hata değerlerinin hesaplanmasında kullanılan matematiksel ifadeler sırası ile aşağıda verilmektedir.

MBE: MBE, model tahminlerinin sistematik olarak hedef değerden ne kadar saptığını gösteren bir metriktir. Ortalama hata oranını belirler ve modelin tahminlerinin sistematik olarak hedefin üzerinde mi, altında mı olduğunu anlamaya yardımcı olur.

$$MBE = \frac{1}{N} \sum_{i=1}^N (P_{model} - P_{tablo}) \quad (1)$$

MBE değeri pozitifse model tahminleri, gerçek değerlerin üzerinde bir eğilim gösterir. Negatifse model, gerçek değerlerin altında kalma eğilimindedir. Sıfıra yakın bir MBE değeri, modelin sistematik hata yapmadığını gösterir.

RMSE: RMSE, model tahminlerinin gerçek değerlere ne kadar yakın olduğunu ölçen bir hata metriktir. Özellikle regresyon modellerinde, tahmin doğruluğunu anlamak için kullanılır ve tahmin hatalarının büyüklüğünü vurgular.

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (P_{D,model} - P_{D,tablo})^2 \right]^{1/2} \quad (2)$$

RMSE değeri ne kadar küçükse modelin tahmin doğruluğu o kadar yüksektir. RMSE'nin büyüklüğü modelin, gerçek değerlere kıyasla ortalama olarak ne kadar hata yaptığını gösterir. Metrik, hataların karekökünü aldığından, büyük hatalar daha fazla önem kazanır.

Ki kare: Ki-kare testi, gözlenen frekansların beklenen frekanslarla ne kadar uyumlu olduğunu ölçen bir istatistiksel testtir.

$$\chi^2 = \frac{\sum_{i=1}^N (P_{D,tablo} - P_{D,model})^2}{N-n} \quad (3)$$

Ki-kare değeri, gözlenen ve beklenen frekanslar arasındaki farkın büyüklüğünü gösterir. Ki-kare değeri arttıkça gözlenen değerlerin beklenen değerlerden farklı olduğu söylenebilir. Belirli bir güven aralığında, elde edilen Ki-kare değeri, kritik değeri aşarsa hipotez reddedilir ve iki değişkenin bağımsız olmadığı sonucuna varılır.

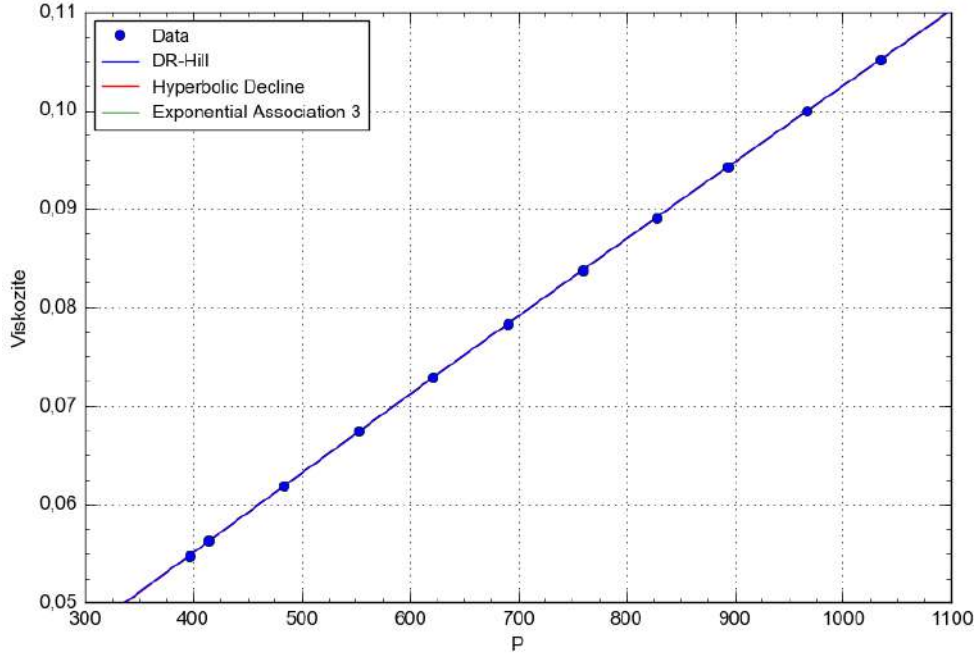
III. BULGULAR

Modelleme çalışmasında CurveExpert Professional 2.7.3 Kütüphanesinde bulunan lineer ve non lineer formdaki tüm model denklemler veriye uygulanarak viskoziteyi basıncın fonksiyonu olarak hesaplayabilmeye olanak tanıyacak modeller elde edilmiştir. Modelleme sonucunda en yüksek korelasyon katsayısına sahip olan model denklemleri ve katsayıları Tablo 3' de verilmiştir.

Tablo 3. HT/HP Gaz Kondensat Karışımı için basıncın fonksiyonu olarak viskozitenin hesaplandığı modeller ve katsayıları

Model adı	Model ve Sabitleri			
DR- Hill	$\alpha = 2,38 \times 10^{-2}$	$\theta = 0,947$	$y = a + \frac{\theta x^\eta}{\kappa^\eta + x^\eta}$ $\eta = 1,060$	$\kappa = 9,56 \times 10^3$
Hyperbolic Decline	$q_0 = 2,15 \times 10^{-2}$	$a = -2,45 \times 10^2$	$y = q_0(1 + bx/a)^{(-1/b)}$ $b = -1,08$	
Exponential Association 3	$a = 1,02$	$b = 1,02$	$y = a(b - e^{-cx})$ $c = 8,2 \times 10^{-5}$	
Heat Capacity	$a = 2,52 \times 10^{-2}$	$b = 7,74 \times 10^{-5}$	$y = a + bx + c/x^2$ $c = -1,89 \times 10^2$	
Rational Model			$y = \frac{1 + bx}{1 + cx + dx^2}$	
Hoerl	$a = 2,04 \times 10^{-2}$	$b = 9,66 \times 10^{-5}$	$c = 2,08 \times 10^{-4}$	$d = -6,70 \times 10^{-8}$
	$a = 2,34 \times 10^{-3}$	$b = 1,00$	$y = ab^x c^x$ $c = 0,510$	
			$y = a(x - b)^c$	
Shifted Power	$a = 1,44 \times 10^{-4}$	$b = -2,26 \times 10^2$	$c = 0,924$	
Polynomial Regression (n=2)	$a = 2,22 \times 10^{-2}$	$b = 8,35 \times 10^{-5}$	$c = -3,23 \times 10^{-9}$	

Tablo 3’ de verilen modellerden en yüksek korelasyon katsayısına sahip olanların Tablo 2’ deki veriyi açıklayabilme düzeyleri Şekil 1’de verilmiştir. Şekilden görüldüğü üzere seçilen üç model deneysel veriyi %100 oranında açıklayabilmektedir.



Şekil 1. Modellerin deneysel veriyi ifade etme düzeyleri

Tablo 2’de verilen veriyi modellemede yüksek korelasyon katsayılarına sahip modeller belirlendikten sonra korelasyon katsayısı, MBE, RMSE ve χ^2 gibi istatistiksel testler uygulanmış ve model değerlerinin deneysel veriye uygunluğu araştırılmıştır. Sonuçlar Tablo 4’de verilmiştir.

Tablo 4’deki istatistiksel analiz sonuçlarından görüldüğü üzere, tüm modellerin çok yüksek korelasyon katsayısı verdiği ve deneysel veriyi açıklamada özellikle DR-Hill, Exponential Association 3, Rational Model, Hoerl ve Polynomial Regression (n=2) modellerinin istatistiksel analiz sonuçlarının da diğerlerine göre çok iyi olduğu görülmüştür.

Tablo 4. Tablo 3’ de verilen modellerin istatistiksel analizi

	r	MBE	RMSE	χ^2
DR- Hill	0,99999	$2,69 \times 10^{-6}$	$5,754 \times 10^{-5}$	$5,406 \times 10^{-7}$
Hyperbolic Decline	0,99997	$7,13 \times 10^{-2}$	0,00302	0,779
Exponential Association 3	1,00000	$3,45 \times 10^{-5}$	0,03015	$5,682 \times 10^{-7}$
Heat Capacity	1,00000	$6,89 \times 10^{-2}$	$3,154 \times 10^{-5}$	0,758
Rational Model	1,00000	$3,43 \times 10^{-5}$	$3,84 \times 10^{-5}$	$7,697 \times 10^{-7}$
Hoerl	0,99999	$-5,85 \times 10^{-8}$	$5,377 \times 10^{-5}$	$3,812 \times 10^{-7}$
Shifted Power	0,99997	$-3,67 \times 10^{-2}$	0,03668	0,453
Polynomial Regression (n=2)	1,00000	$-8,14 \times 10^{-17}$	$4,947 \times 10^{-5}$	$4,075 \times 10^{-7}$

IV.SONUÇLAR

HT/HP gaz kondensat sahalarında en kritik problem retrograd yoğuşma nedeniyle oluşan kondensat blokajıdır. Buna ek olarak yüksek viskoziteli sıvı fazın düşük hareketliliği, korozyon, akış güvenliği, kuyu tamamlama ve modelleme zorlukları üretim sürecini karmaşıktırır. Çözüm için genelde gaz geri enjeksiyonu, gelişmiş malzeme seçimi, hassas faz davranışı modellemesi ve güçlü akış güvenliği stratejileri gerekir.

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Doğal Gazın Viskozitesini Sıcaklık Ve Basınca Bağlı Olarak Hesaplayabilecek Model Denklemlerin Geliştirilmesi

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Özet – Doğal gaz; hafif hidrokarbonların çeşitli karışımlarından, düşük yoğunluk ve viskoziteye sahip ağır hidrokarbonlardan ve ayrıca hidrojen sülfür, karbondioksit ile azot gibi az miktarda bulunan inorganik ya da hidrokarbon dışı bileşenlerden meydana gelir. Petrol sıvılarıyla ilişkili bir enerji kaynağı olmasına rağmen, özellikleri sıvı hidrokarbonlardan farklıdır. Doğal gazın fiziksel nitelikleri; basınç, sıcaklık ve içerdiği bileşenlere bağlı olarak önemli ölçüde değişkenlik gösterir. Gazın mühendislikte en sık dikkate alınan özelliklerinden biri viskozitedir. Viskozite, akışkanın hareketine karşı gösterdiği direnç olarak tanımlanır. Bu özellik; özellikle gözenekli ortamlarda akış davranışlarının incelenmesi, kimya ve petrol mühendisliği uygulamalarında yapılan simülasyon çalışmaları için kritik öneme sahiptir.

Bu nedenle, bu çalışmada, deneysel olarak elde edilen viskozite verisini ampirik olarak verebilecek model denklemi elde edilmeye çalışıldı. Bu amaçla 323,15-473,15 K sıcaklık 34-138 MPa basınç aralığında doğalgazın viskozitesini sıcaklık ve basınca bağlayan model denklemleri geliştirildi. Ayrıca Pedersen, Lohrenz–Bray–Clark (LBC) ve modifiye edilmiş LBC (HW2) modellerinin deneysel veriyi açıklayabilme düzeyleri de incelendi. Modellemede kullanılan veri ile isimleri verilen viskozite modellerinin sonuçları literatürde yer alan deneysel bir çalışmadan alındı. Modellemede CurveExpert Professional 2.7.3 programı kullanılarak programın kütüphanesindeki lineer ve non- lineer modellerin deneysel veriye uygunluğu araştırıldı. Modelleme sonucunda tüm parametrelerin tek bir modelle hesaplanabilmesine olanak tanıyacak modeller seçildi. Modellerin uygunluğu korelasyon katsayıları yanı sıra MBE, RMSE ve chi-kare gibi istatistiksel testler kullanılarak araştırıldı.

Anahtar Kelimeler – Viskozite, Doğalgaz, Modelleme, İstatistiksel Analiz, Basınç, Sıcaklık.

I. GİRİŞ

Doğal gaz, yer kabuğundaki organik maddelerin (bitki, hayvan kalıntıları) milyonlarca yıl boyunca yüksek sıcaklık ve basınç altında ayrışmasıyla oluşur. Doğal gaz, genellikle üç şekilde bulunur [1]:

1. Bağımsız gaz: Petrol içermeyen, saf gaz rezervuarları.
2. Petrolle ilişkili gaz: Petrol rezervuarlarında çözünmüş halde bulunan veya serbest fazda petrolün üzerinde duran gaz.
3. Kaya gazı ve sıkı formasyon gazı: Düşük geçirgenlikli kayalarda bulunan, özel üretim teknikleri gerektiren gaz.

Doğal gaz, genellikle dikey veya yatay kuyularla üretilir. Konvansiyonel rezervuarlarda doğal akışla veya yapay kaldırma yöntemleriyle, sıkı formasyonlarda ve kaya gazında hidrolik çatlatma (fracking) ve

yatay sondaj teknikleri ile üretilir. Üretim sırasında oluşabilecek sorunlar arasında basınç düşümü, kondensat birikmesi, su üretimi yer alır.

Ham gaz genellikle safsızlıklar içerir ve doğrudan kullanılmaz. İşleme adımları [1]:

1. Ayırıştırma: Su buharı, katı parçacıklar ve sıvı hidrokarbonlar (gaz kondensat) ayrılır.
2. Asit gaz giderme: CO₂ ve H₂S gibi istenmeyen bileşenler amin prosesi ile uzaklaştırılır.
3. Su giderme: Trietilen glikol veya moleküler elekler kullanılarak su buharı uzaklaştırılır.
4. Doğal gaz sıvılarının ayrılması: Etilen, propan, bütan gibi değerli sıvı hidrokarbonlar ayrılır.
5. Şebeke gazı hazırlanması: %90'dan fazlası metan olacak şekilde saflaştırılır.

Bazı durumlarda sıvılaştırılarak veya sıkıştırılarak taşınır.

Doğal gazın viskozitesi, gaz moleküllerinin birbirine sürtünmesine karşı gösterdiği dirençtir. Petrolden farklı olarak çok düşüktür, çünkü gaz fazında moleküller arasındaki etkileşim zayıftır. Basınç arttıkça viskozite çok hafif yükselir; sıcaklık arttıkça ise azalır. Akış hesaplarında, Boru hattı tasarımında basınç kaybı hesapları, Rezervuar simülasyonlarında akışkan davranışını modellemek için viskozitesinin bilinmesi önemlidir [2].

II. MATERYAL VE YÖNTEM

Bu çalışmada 323,15-473,15 K sıcaklık 34-138 MPa basınç aralığında ve bileşimi Tablo 1'de verilen Doğal gazın viskozitesini sıcaklık ve basınca bağlayan model denklemleri geliştirildi. Literatürde yaygın kullanılan viskozite modelleri Pedersen [3-4], Lohrenz–Bray–Clark (LBC) [5] ve modifiye edilmiş LBC (HW2) [6]' nin deneysel veriyi açıklayabilme düzeyleri de araştırıldı. Modelleme de kullanılan veri ile literatürde çok yaygın kullanılan modellerin sonuçları yayınlanmış bir deneysel çalışmadan alındı [7] . Geliştirilen modeller ve literatürde yaygın kullanılan modellerin iİstatistiksel analizleri yapıldı.

Tablo 1. Doğal Gazın Bileşimi [7]

Bileşen	Molekül Ağırlığı	Bileşim
		(Mol %)
C ₁	16,043	88,83
C ₂	30,069	5,18
C ₃	44,096	1,64
i _C	58,123	0,16
nC ₄	58,123	0,27
iC ₅	72,150	0,04
nC ₅	72,150	0,04
CO ₂	44,010	2,24
N ₂	28,010	1,60

B. Modelleme Çalışması

Tablo 2' de verilen ilk 3 sütun yani sıcaklık, basınç ve viskozite verisi CurveExper Professional 2.7.3 kullanılarak modellenmiştir. Modelleme çalışmasında CurveExper Professional 2.7.3 Kütüphanesinde bulunan lineer ve non lineer formdaki tüm model denklemler veriye uygulanarak viskoziteyi hem sıcaklığın hem de basıncın fonksiyonu olarak hesaplayabilmeye olanak tanıyacak iki parametrelili modeller elde

edilmiştir. Tablo 2’de verilen literatürdeki mevcut modellerden hesaplananlar ile aynı veya daha yüksek korelasyon katsayılarına sahip modeller belirlendikten sonra aşağıda verilen istatistiksel analiz metotları kullanılarak modellerden hesaplanan değerlerin Tablo 2’deki değerleri hesaplayabilmedeki güvenilirleri araştırılmıştır.

C. Hata Analizi

Tablo 2’de verilen değerler ile CurveExper Professional 2.7.3’den elde edilen modellerden elde edilen değerlerin uyumunu ortaya koymak amacı ile MBE, RMSE ve ki-kare gibi istatistiksel testler uygulanmıştır. MBE, RMSE ve Ki-kare gibi istatistiksel metrikler, analizlerde doğruluğu, hata payını ve uygunluğu değerlendirmek için kullanılır. Bu metotlar, özellikle modelleme çalışmalarında ve hipotez testlerinde karşılaştırma ve model performansını ölçmek amacıyla yaygındır. Bu hata değerlerinin hesaplanmasında kullanılan matematiksel ifadeler sırası ile aşağıda verilmektedir.

MBE: MBE, model tahminlerinin sistematik olarak hedef değerden ne kadar saptığını gösteren bir metriktir. Ortalama hata oranını belirler ve modelin tahminlerinin sistematik olarak hedefin üzerinde mi, altında mı olduğunu anlamaya yardımcı olur.

$$MBE = \frac{1}{N} \sum_{i=1}^N (P_{model} - P_{tablo}) \quad (1)$$

MBE değeri pozitifse model tahminleri, gerçek değerlerin üzerinde bir eğilim gösterir. Negatifse model, gerçek değerlerin altında kalma eğilimindedir. Sıfıra yakın bir MBE değeri, modelin sistematik hata yapmadığını gösterir.

RMSE: RMSE, model tahminlerinin gerçek değerlere ne kadar yakın olduğunu ölçen bir hata metriktir. Özellikle regresyon modellerinde, tahmin doğruluğunu anlamak için kullanılır ve tahmin hatalarının büyüklüğünü vurgular.

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (P_{D,model} - P_{D,tablo})^2 \right]^{1/2} \quad (2)$$

RMSE değeri ne kadar küçükse modelin tahmin doğruluğu o kadar yüksektir. RMSE’nin büyüklüğü modelin, gerçek değerlere kıyasla ortalama olarak ne kadar hata yaptığını gösterir. Metrik, hataların karekökünü aldığından, büyük hatalar daha fazla önem kazanır.

Ki kare: Ki-kare testi, gözlenen frekansların beklenen frekanslarla ne kadar uyumlu olduğunu ölçen bir istatistiksel testtir.

$$\chi^2 = \frac{\sum_{i=1}^N (P_{D,tablo} - P_{D,model})^2}{N-n} \quad (3)$$

Ki-kare değeri, gözlenen ve beklenen frekanslar arasındaki farkın büyüklüğünü gösterir. Ki-kare değeri arttıkça gözlenen değerlerin beklenen değerlerden farklı olduğu söylenebilir. Belirli bir güven aralığında, elde edilen Ki-kare değeri, kritik değeri aşarsa hipotez reddedilir ve iki değişkenin bağımsız olmadığı sonucuna varılır.

III. BULGULAR

Tablo 2’de verilen ilk 3 sütün deneysel çalışma sonuçlarını sonrasındaki 3 sütün ise literatürde yaygın kullanılan viskozite modellerinden hesaplanan viskozite değerlerini göstermektedir [9]. Son 4 sütün ise doğalgazın viskozitesinin sıcaklık, basıncın fonksiyonu olarak hesaplanabilmesinde kullanılabilecek en yüksek uyumu gösteren modellerden hesaplanan viskozite değerlerini göstermektedir. Modelleme

çalışmasında CurveExper Professional 2.7.3 Kütüphanesinde bulunan lineer ve non lineer formdaki tüm model denklemler veriye uygulanarak viskoziteyi hem sıcaklığın hem de basıncın fonksiyonu olarak hesaplayabilmeye olanak tanıyacak iki parametrelili modeller elde edilmiştir.

Tablo 2. Bileşimi Tablo 1’de verilen Doğalgaz için Literatürde verilen [7] ve bizim geliştirdiğimiz modellerden hesaplanan viskoziteler

T	P	η	Pedersen	LBC	HW2	Full Cubic	Full Quadratic	Rational	Power Model E	Reciprocal Linear Logarithmic
323,15	34,61	0,028	0,028	0,029	0,028	0,028	0,029	0,029	0,029	0,295
323,15	51,88	0,036	0,034	0,037	0,036	0,036	0,036	0,036	0,036	0,352
323,15	69,08	0,043	0,04	0,044	0,043	0,043	0,042	0,042	0,043	0,409
323,15	86,25	0,049	0,044	0,051	0,05	0,049	0,048	0,048	0,049	0,467
323,15	103,52	0,055	0,048	0,057	0,056	0,055	0,054	0,054	0,054	0,529
323,15	120,7	0,06	0,052	0,063	0,062	0,060	0,060	0,059	0,059	0,596
323,15	137,79	0,064	0,055	0,07	0,067	0,064	0,065	0,064	0,064	0,668
373,15	34,6	0,026	0,025	0,024	0,023	0,026	0,026	0,027	0,026	0,277
373,15	51,9	0,032	0,031	0,03	0,029	0,032	0,032	0,032	0,033	0,327
373,15	69	0,038	0,036	0,035	0,034	0,038	0,038	0,038	0,039	0,375
373,15	86,23	0,042	0,04	0,04	0,039	0,043	0,043	0,043	0,044	0,424
373,15	103,56	0,048	0,043	0,045	0,044	0,048	0,048	0,048	0,049	0,474
373,15	120,78	0,053	0,047	0,049	0,048	0,053	0,053	0,053	0,053	0,527
373,15	137,79	0,057	0,05	0,053	0,053	0,057	0,057	0,058	0,057	0,582
423,15	34,6	0,025	0,024	0,026	0,025	0,025	0,024	0,025	0,024	0,263
423,15	51,79	0,029	0,029	0,033	0,031	0,030	0,029	0,030	0,030	0,307
423,15	69,06	0,035	0,033	0,039	0,037	0,035	0,035	0,035	0,035	0,350
423,15	86,27	0,039	0,037	0,044	0,043	0,039	0,039	0,040	0,040	0,392
423,15	103,51	0,044	0,04	0,049	0,049	0,044	0,044	0,044	0,044	0,434
423,15	120,72	0,048	0,043	0,054	0,054	0,048	0,048	0,049	0,048	0,478
423,15	137,78	0,052	0,046	0,06	0,059	0,052	0,052	0,053	0,052	0,524
473,15	34,63	0,024	0,024	0,023	0,023	0,024	0,024	0,023	0,022	0,252
473,15	51,83	0,028	0,028	0,029	0,027	0,028	0,029	0,028	0,028	0,292
473,15	69,05	0,033	0,032	0,033	0,032	0,033	0,033	0,032	0,032	0,330
473,15	86,27	0,037	0,035	0,038	0,036	0,037	0,037	0,037	0,037	0,367
473,15	103,5	0,041	0,038	0,042	0,04	0,041	0,041	0,041	0,041	0,404
473,15	120,75	0,045	0,041	0,045	0,044	0,045	0,045	0,045	0,045	0,442
473,15	137,75	0,049	0,043	0,049	0,048	0,049	0,048	0,049	0,048	0,481

Tablo 2’de verilen literatürdeki mevcut modellerden hesaplananlar ile aynı veya daha yüksek korelasyon katsayılarına sahip modeller belirlendikten sonra korelasyon katsayısı, MBE, RMSE ve χ^2 gibi istatistiksel testler uygulanmış ve model değerlerinin deneysel veriye (3.Sütun) uygunluğu araştırılmıştır. Sonuçlar Tablo 3’de görülmektedir.

Tablo 3. Tablo 2’ de verilen modellerin istatistiksel analizi

	Pedersen	LBC	HW2	Full Cubic	Full Quadratic	Rational	Power Model E	Reciprocal Linear Logarithmic
r	0,99750	0,96658	0,96835	0,99952	0,99874	0,99791	0,99739	0,99426
MBE	-3,36x10 ⁻³	0,00111	-3,72x10 ⁻¹⁹	9,19x10 ⁻¹²	6,51x10 ⁻¹³	-7,81x10 ⁻⁹	-1,88x10 ⁻⁵	0,37400
RMSE	0,00424	0,00330	0,00302	0,00034	0,00050	0,00064	0,00072	0,38547
χ^2	0,01089	0,00625	0,00565	0,00009	0,00024	0,00036	0,00056	9,41397

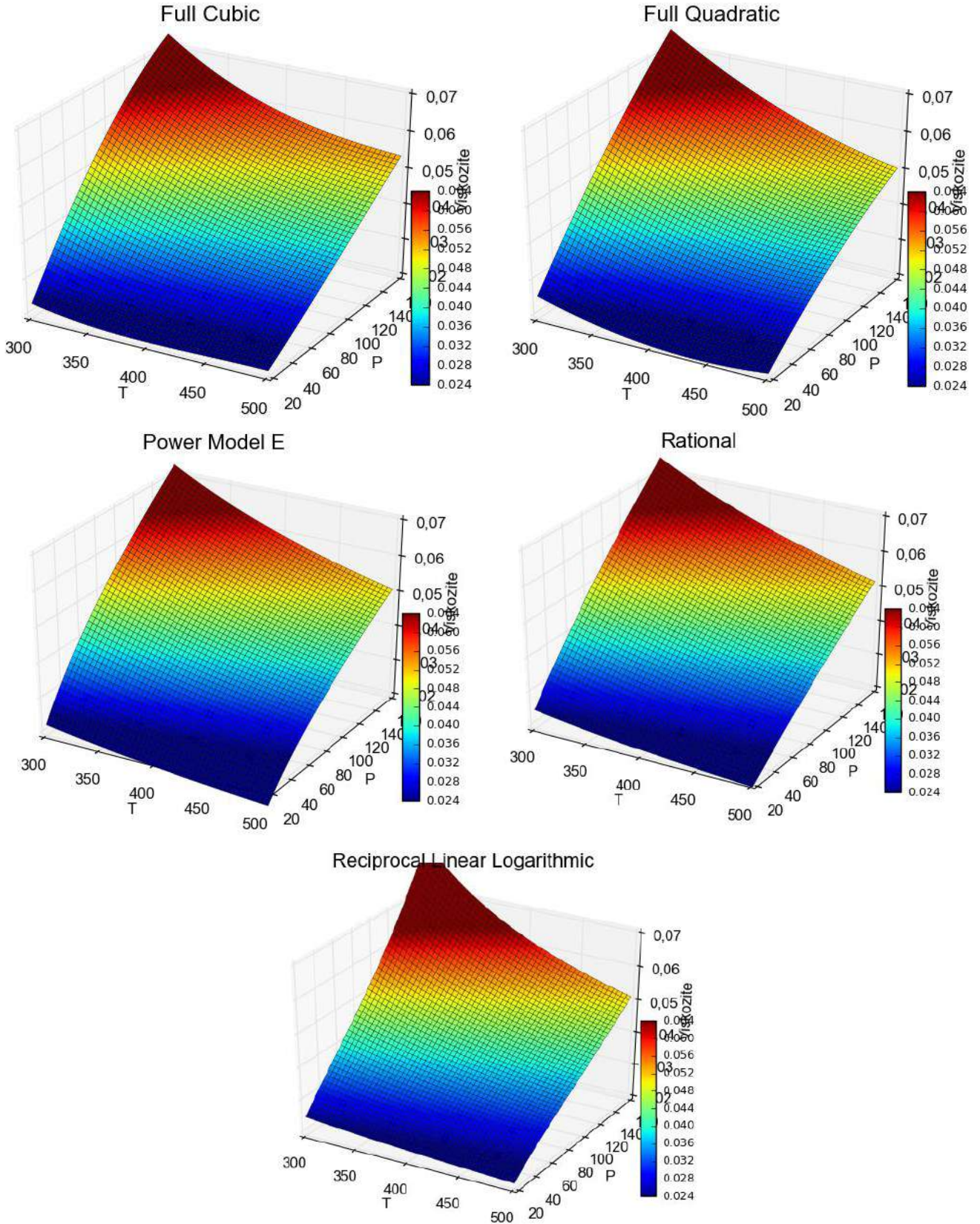
Tablo 3’den görüldüğü üzere Curve Expert Professional 2.7.3’den elde edilen model denklemlerin istatistiksel analiz sonuçları Literatürdeki viskozite modellerin istatistiksel analizinden çok daha iyi. Full Qubic ise en iyi sonuçları veren Pedersen modelinden daha yüksek korelasyon katsayısı vermiştir. Geliştirilen modellerin katsayıları Tablo 4’de verilmiştir.

Tablo 4. Doğal gaz için sıcaklık basıncın fonksiyonu olarak viskozitenin hesaplandığı modeller ve katsayıları

Model isimleri	Modeller ve Sabitleri			
	$y = a + bx_1 + cx_2 + dx_1^2 + ex_2^2 + fx_1^3 + gx_2^3 + hx_1x_2 + ix_1^2 + jx_1x_2^2$			
Full Qubic	a = 9,34x10 ⁻² b = -6,18x10 ⁻⁴ c = 1,46x10 ⁻³	d = 1,51x10 ⁻⁶ e = -2,74x10 ⁻⁶ f = -1,16x10 ⁻⁹	g = -1,13x10 ⁻⁹ h = -3,79x10 ⁻⁶ i = 2,52x10 ⁻⁹	j = -6,26x10 ⁻⁹
	$y = a + bx_1 + cx_2 + dx_1^2 + ex_2^2 + fx_1x_2$			
Full Quadratic	a = 7,14x10 ⁻² b = -2,86x10 ⁻⁴	c = 6,63x10 ⁻⁴ d = 3,43x10 ⁻⁷	e = -5,35x10 ⁻⁷ f = -7,06x10 ⁻⁷	
Power Model E	$y = a \cdot x_1^b \cdot x_2^c$			
	a = 0,248	b = -0,725	c = 0,574	
	$y = \frac{a + b \cdot x_1 + c \cdot x_2}{1 + d \cdot x_1 + e \cdot x_2}$			
Rational	a = 7,69x10 ⁴ b = 3,27x10 ²	c = 5,37x10 ³ d = 3,70x10 ⁴	e = 1,74x10 ⁴	
Reciprocal Linear Logarithmic	$y = 1/(a + b \ln(x_1) + c \ln(x_2))$			
	a = -5,7037	b = 15,2824	c = -13,7293	

IV. TARTIŞMA

En yüksek korelasyon katsayısını veren modellerin deneysel veriyi açıklayabilme düzeyleri grafiksel olarak Şekil 1’de verilmiştir.



Şekil 1. Modellerin deneysel veriyi ifade etme düzeyleri

V. SONUÇLAR

Doğal gaz viskozitesinin doğru bir şekilde belirlenmesi; üretim faaliyetlerinin verimli yürütülmesi, boru hatlarında taşınması ve depolama sistemlerinin güvenilir tasarımı açısından temel bir gerekliliktir. Ancak mevcut deneysel ve teorik korelasyonlar çoğu zaman yüksek basınç ve sıcaklık koşullarında yeterli hassasiyet sağlayamamakta, bunun yanında karmaşıklık ve güvenilirlik sorunları ortaya çıkmaktadır. Yaptığımız çalışma verilen sıcaklık ve basınç aralığı için Tablo 1’de verilen bileşimdeki doğal gazın viskozitesini hesaplamada Reciprocal Linear Logarithmic modeli dışında diğer tüm modellerin literatürde yaygın kullanılan modellerden daha iyi sonuç verdiği görülmüştür.

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İNGİLİZCE ÖĞRETMENLİĞİ BÖLÜMÜ ÖĞRETMEN ADAYLARININ İSTİHDAM KAYGILARI

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Özet – Öğretmen adaylarında istihdam kaygısı, mezuniyet sonrası mesleğe atanamama, belirsiz çalışma koşulları ve geleceğe dair güvensizlik algılarından beslenen önemli bir psikososyal olgu olarak karşımıza çıkmaktadır. Bu araştırmanın amacı, İngilizce Öğretmenliği lisans programında öğrenim gören öğretmen adaylarının istihdam kaygılarını incelemektir. Nitel araştırma yaklaşımıyla yürütülen çalışmada durum çalışması deseni kullanılmıştır. Örneklem seçiminde kasıtlı örnekleme yöntemine uygun olarak istihdam kaygısının yoğunlaştığı farklı şubelerde okuyan son sınıf öğrencilerinden seçilmiştir. Çalışma grubunu, Türkiye’de bir devlet üniversitesinde öğrenim gören 26 son sınıf İngilizce Öğretmenliği bölümünde öğrenim gören öğretmen adayı oluşturmaktadır. Veriler, yarı yapılandırılmış görüşme formu aracılığıyla toplanmış ve betimsel analiz yöntemiyle çözümlenmiştir. Araştırma bulgularına göre öğretmen adaylarının tamamının istihdam kaygısı taşıdığı görülmüştür. Katılımcılar en çok atama ve kontenjan yetersizliği, sınav ve mülakat süreçlerindeki belirsizlikler ile mesleğin toplumsal ve ekonomik statüsü gibi konularda kaygı yaşadıklarını ifade etmiştir. Bulgular, öğretmen adaylarının kaygılarının bireysel faktörlerden çok sistemsel ve yapısal sorunlara dayandığını göstermektedir. Bu sonuç, öğretmen yetiştirme politikalarının ve istihdam süreçlerinin gözden geçirilmesi gerekliliğini ortaya koymaktadır.

Anahtar Kelimeler – Öğretmen Adayları, İstihdam Kaygısı, İngilizce Öğretmenliği, Nitel Araştırma, Eğitim Politikaları.

I. GİRİŞ

Eğitim sistemlerinin kalitesi, büyük ölçüde öğretmen niteliği ve öğretmenlerin çalışma koşullarına bağlıdır. Bu bağlamda öğretmen adaylarının istihdam kaygısı, yalnızca bireysel bir duygu durumu değil; öğretmen arz-talep dengeleri, mesleğe giriş süreçleri ve sistem düzeyindeki politika düzenlemeleriyle yakından ilişkili yapısal bir olgudur. Uluslararası rapor ve incelemeler, öğretmen emeği piyasalarında arz-talep dengesizlikleri ve bölgesel/alan bazlı açıklar bulunduğunu; politikaların öngörülebilirliği ile seçim-yerleştirme süreçlerinin güvenilirliğinin, adayların motivasyon ve mesleğe bağlılıklarıyla yakından ilişkili olduğunu göstermektedir [1].

Türkiye’de kamuya öğretmen alımı merkezi sınav ve mülakat uygulamaları etrafında yürütülmekte; bu süreçlerin özellikle yabancı dil (İngilizce) alanında aday algısı üzerindeki etkileri nitel çalışmalarla belgelenmektedir. KPSS’nin kökenleri, etkileri ve sonuçlarına ilişkin nitel örnek olay bulguları, adayların süreci rekabetçi ve güçlü bir seçme aygıtı olarak deneyimlediklerini ortaya koymaktadır [2]. Seçme sürecinin adalet ve şeffaflık boyutu da tartışılmakta; adayların algılanan adalet düzeyi ile sürece yönelik duygusal değerlendirmeleri arasında ilişkiler rapor edilmektedir [3].

Öğretmenlerin iş-iyi oluşu ve mesleğin toplumdaki değeri, istihdam ve elde tutma ile birlikte ele alınmaktadır. TALIS 2018 [4] sonuç raporuna göre, öğretmenlerin mesleki iyi oluşu, iş yükü/stres, karar

alma özerkliği ve mesleğin toplumsal itibarı gibi göstergeler bir arada değerlendirilmekte ve ülkeler arası karşılaştırmalı kanıtlar sunulmaktadır (OECD, 2020). Bu göstergeler, aday düzeyindeki istihdam kaygısının yalnızca bireysel değişkenlerden değil, aynı zamanda okul ve sistem düzeyindeki koşullardan da etkilendiğini düşündürmektedir.

Alanyazında İngilizceyi yabancı dil olarak öğreten/öğretmeye hazırlanan gruplar üzerinde yapılan çalışmalar, kaygı, iş stresi ve tükenmişlik arasındaki ilişkilerin özellikle öz-yeterlik ve akademik dayanıklılık gibi psikolojik değişkenlerle anlamlı biçimde bağlantılı olduğunu göstermektedir. Yabancı bir dil olarak İngilizce öğretmenlerinde öz-yeterlik ve tükenmişlik arasındaki olumsuz ilişki farklı örneklemelerde doğrulanmış ([5], [6]); değerlendirme okuryazarlığının (teacher assessment literacy) iş stresi ve tükenmişlik ile ilişkisi ise büyük örneklemli karma yöntem bir çalışmada gösterilmiştir [7]. Öte yandan öğretmenlerde stres, tükenmişlik, anksiyete ve depresyonun yaygınlığına ilişkin kapsamlı bir derleme, bu göstergelerin küresel ölçekte önemli bir politika ve sağlık meselesi olduğunu vurgulamaktadır [8].

Bu araştırma, söz konusu arka plan üzerine inşa edilmiştir. İngilizce öğretmenliği lisans programında öğrenim gören öğretmen adaylarının istihdam kaygılarına ilişkin algıları nitel bir yaklaşımla ele alınmış; adayların kaygı gerekçeleri tematik olarak çözümlenmiştir. Bu yönüyle çalışma, merkezi sınav ve kontenjan politikaları ile adayların öznel kaygı deneyimleri arasındaki ilişkileri görünür kılarak, öğretmen yetiştirme ve istihdam politikalarına kanıta dayalı çıkarımlar sunmayı amaçlamaktadır.

II. YÖNTEM

Araştırma Modeli

Bu araştırma, nitel araştırma yaklaşımı çerçevesinde durum çalışması (case study) desenine dayanmaktadır. Araştırmanın temel amacı, İngilizce Öğretmenliği bölümü öğretmen adaylarının istihdam kaygılarını ortaya çıkarmaktır. Bu nedenle araştırma, katılımcıların kendi deneyim ve algılarını derinlemesine incelemeye olanak tanıyacak şekilde tasarlanmıştır.

Çalışma Grubu

Araştırmanın çalışma grubunu, Türkiye’de bir devlet üniversitesinin İngilizce Öğretmenliği bölümünde öğrenim görmekte olan 26 son sınıf öğretmen adayı oluşturmaktadır. Katılımcılar amaçlı örnekleme yöntemlerinden kolay ulaşılabilir durum örnekleme yoluyla seçilmiştir. Katılımcıların kodlanması sırasında her birine K1, K2, ..., K26 şeklinde numaralandırılmış takma adlar verilmiştir.

Veri Toplama Aracı

Veriler, araştırmacılar tarafından geliştirilen yarı yapılandırılmış görüşme formu aracılığıyla toplanmıştır. Formda öğretmen adaylarının istihdam kaygılarını belirlemeye yönelik açık uçlu sorular yer almaktadır. Sorular, uzman görüşleri alınarak kapsam geçerliliği sağlandıktan sonra uygulanmıştır.

Veri Toplama Süreci

Görüşmeler gönüllülük esasına dayalı olarak gerçekleştirilmiş ve katılımcıların gizliliği korunmuştur. Görüşmelerden elde edilen yanıtlar yazılı hale getirilmiş, katılımcı ifadeleri değiştirilmeden araştırmaya dâhil edilmiştir.

Veri Analizi

Elde edilen veriler, betimsel analiz tekniği ile çözümlenmiştir. İlk aşamada, katılımcı görüşleri araştırma sorularına uygun olarak temalar ve kodlar altında toplanmıştır. Daha sonra frekans dağılımları çıkarılarak tablolar halinde sunulmuştur. Analiz sürecinde doğrudan alıntılara yer verilerek bulguların güvenilirliği artırılmıştır.

III. BULGULAR

Tablo 1. Öğretmen Adaylarının İstihdam Kaygı Durumu

Tema:	Kodlar	Katılımcılar	<i>f</i>
Evet	Atama/Kontenjan yetersizliği	K2, K3, K4, K6, K10, K12, K13, K14, K16, K17, K19, K20, K21, K22, K23, K25, K26	18
	Sınav ve rekabet baskısı	K1, K3, K4, K6, K14, K16, K18, K19, K21, K24, K25	11
	Ekonomik Durum ve Mesleğin saygınlığı	K5	1
Toplam			26

Katılımcıların tamamı ($n=26$) kamu okullarında öğretmen istihdamı konusunda kaygılı olduklarını belirtmiştir. “Evet” diyenlerin gerekçeleri özellikle atama/kontenjan yetersizliği ve sınav/mülakat baskısı üzerinde yoğunlaşmıştır. En güçlü tema, atama/kontenjan yetersizliği olmuştur ($f=19$). Azalan atamalar ve öğretmenlik bölümlerinin çok fazla öğrenci mezun etmesi nedeniyle ciddi bir istihdam baskısı hissettiklerini belirtmiştir. İkinci önemli tema, sınav ve rekabet baskısıdır ($f=11$). Katılımcılar özellikle KPSS’nin zorluğu, belirsizlikler ve mülakat uygulamaları nedeniyle kaygı yaşadıklarını ifade etmiştir. Görece az sayıda dile getirilen bir tema, mesleğin geleceği ve toplumsal saygınlığıdır ($f=1$). Katılımcılardan yalnızca biri öğretmenliğe yönelik toplumsal saygının azalması ve ekonomik koşulların yetersizliği nedeniyle kaygı duyduğunu belirtmiştir. Atama yetersizliği sebebiyle istihdam kaygısı yaşadığını belirten öğretmenlerden katılımcı 2 “Tabi ki. Çünkü atamalar çok düştü. Bu durum da ister istemez istihdam kaygısını artırıyor” diyerek atama sayısındaki düşüşe dikkat çekmiştir. Yine katılımcı 4 “Evet, bölümün alımı az olduğu için istihdam kaygısı yüksek.” Demekle alımlardaki sayıya dikkat çekmiştir. “Evet, kesinlikle kaygılarım var çünkü öğretmen alımlarındaki belirsizlik, yıllık kontenjan azlığı kaygımı artırıyor.” Diyen 3. katılımcı (K3) yine aynı duruma vurgu yapmıştır. Sınav ve rekabet baskısına öğretmen adaylarının ifadelerine örnek olarak “Öğretmen alımlarındaki belirsizlik, yıllık kontenjanlar ve sınav sistemi yüzünden kaygı duyuyorum.” (K3) ve “Yetersiz yapılan alımlar ve ne olacağı belli olmayan sınav sistemi nedeniyle kaygılıyım.” (K16) ifadeleriyle sınav sistemini ve istihdam usulünü eleştirmiştir. Tüm bu sıkıntıları ifade etmekle birlikte farklı bir açıdan değerlendirme yapan K5 “Yetersiz maaş ve mesleğe olan saygının gün geçtikçe azalması özellikle istihdam olmak üzere mesleğe ve mesleğin geleceğine yönelik kaygılarımı artırıyor.” sözleriyle mesleğin ekonomik ve sosyolojik durumuna dikkatleri çekmiştir.

Tablo 2. Öğretmen Adaylarının İstihdam Kaygısını Artıran Konular

Kodlar	Katılımcılar	<i>f</i>
Eğitim Politikaları / Sistemsel Sorunlar	K2, K3, K4, K6, K8, K11, K12, K13, K14, K15, K16, K17, K18, K19, K21, K22, K25, K26	17
Sınav/Mülakat Sistemi	K1, K18, K24	3
Ekonomik Kaygılar	K5	1
Bölüm Fazlalığı / Mezun Yoğunluğu	K20	1
Toplam		26

En yoğun dile getirilen kaygı kaynağı eğitim politikaları ve sistemsal sorunlardır. Katılımcıların büyük bir kısmı atama sayılarının düşmesi, kontenjan yetersizliği, mezun fazlalığı, istihdamda belirsizlik ve öğretmen alım süreçlerindeki düzensizlikleri kaygı nedeni olarak belirtmiştir. Bu bulgu, öğretmen adaylarının bireysel özelliklerinden çok yapısal sorunlara odaklandığını göstermektedir. Bu konuda bazı katılımcılar “Atamalar çok düştü. Bu durum da ister istemez istihdam kaygısını artırıyor.” (K2) ve “Öğretmen alımlarındaki belirsizlik, yıllık kontenjan azlığı kaygımı artırıyor.” (K3) diyerek istihdam uygulamasındaki bir takım sıkıntılara değinmiştir. Bazı katılımcılar kaygılarının özellikle sınavların zorluğu, sürekli değişen sınav sistemi ve mülakatlarda adalet sorunlarından kaynaklandığını ifade etmiştir. Bu durum, seçme ve yerleştirme süreçlerinin güven vermediğini ve öğretmen adayları üzerinde stres yarattığını ortaya koymaktadır. Sadece birer katılımcı ekonomik koşullara ve eğitim fakültelerinin sayısının artması, buna bağlı olarak mezun yoğunluğuna vurgu yapmıştır. Adaylar, mezun sayısının artmasına rağmen istihdamın aynı ölçüde artmamasını kaygı verici bulmaktadır. Bu konuda kodlarda görüş beyan eden katılımcıların örnek ifadeleri aşağıda yer almaktadır:

K3: “Öğretmen alımlarındaki belirsizlik, yıllık kontenjanlar ve sınav sistemi yüzünden kaygı duyuyorum.”

K16: “Yetersiz yapılan alımlar ve ne olacağı belli olmayan sınav sistemi nedeniyle kaygılıyım.”

K5: “Yetersiz maaş ve mesleğe olan saygının gün geçtikçe azalması kaygılarımı artırıyor.”

IV. SONUÇ, TARTIŞMA VE ÖNERİLER

Öğretmen adaylarının istihdam kaygısı, büyük ölçüde **yapısal eğitim politikalarındaki belirsizlik ve dengesizliklerden** kaynaklanmaktadır. Atama sayılarındaki düşüş, sınav ve mülakat süreçlerindeki sorunlar ve mesleğin saygınlığına ilişkin algı, bu kaygıyı çok boyutlu hale getirmektedir. Bu durum, öğretmen adaylarının geleceğe yönelik belirsizlik yaşadıklarını ve mesleki güvensizlik algısının güçlendiğini göstermektedir.

İngilizce Öğretmenliği bölümü öğretmen adaylarının istihdam kaygılarının merkezinde **eğitim politikalarındaki belirsizlikler ve sistemsal sorunlar** yer almaktadır. Bunun yanı sıra **sınav/mülakat uygulamaları, ekonomik koşullar ve mezun yoğunluğu** da farklı düzeylerde kaygı yaratan unsurlar olarak öne çıkmaktadır. Sonuç olarak, öğretmen adaylarının istihdam kaygısı çok boyutlu bir olgudur; ancak belirleyici unsur, büyük ölçüde sistemsal politikalar ve eğitim yönetimindeki belirsizliklerdir.

Bu araştırma, İngilizce öğretmenliği lisans programında öğrenim gören öğretmen adaylarının istihdam kaygılarını inceleyerek önemli bulgular ortaya koymuştur. Araştırmaya katılan tüm adayların istihdam konusunda kaygı duyduklarını ifade etmeleri, sorunun bireysel bir durumdan ziyade yapısal bir nitelik taşıdığını göstermektedir. Katılımcıların büyük çoğunluğunun “atama/kontenjan yetersizliği” temasında yoğunlaşması, Türkiye’de öğretmen istihdamı ile öğretmen yetiştirme arasındaki uyumsuzluğun altını çizmektedir. Eğitim fakültelerinin fazla sayıda mezun vermesi, atama sayılarının düşmesiyle birleştiğinde adayların mesleki geleceklerini belirsiz ve güvensiz görmelerine yol açmaktadır.

Öğretmen adaylarının kaygılarının ikinci önemli kaynağı ise sınav ve mülakat süreçlerindeki belirsizliktir. KPSS’nin zorluğu, sınav sisteminde yaşanan sık değişiklikler ve mülakat uygulamalarının adaletine dair soru işaretleri, adayların güvensizlik algısını artırmaktadır. Bu durum, yalnızca bireysel stres faktörü değil, aynı zamanda sistemsal güven krizine işaret etmektedir. Alanyazında da benzer şekilde öğretmen seçim süreçlerindeki şeffaflık eksikliğinin adayların motivasyonunu zayıflattığı ve mesleki bağlılığı olumsuz etkilediği rapor edilmiştir [3].

Görece az sayıda katılımcı tarafından dile getirilse de mesleğin ekonomik ve toplumsal statüsüne yönelik kaygılar, öğretmenlik mesleğinin değer algısıyla ilişkilidir. Öğretmenlerin özlük haklarının yetersizliği ve mesleğe yönelik saygının azalması, adayların geleceğe dönük mesleki bağlılıklarını

zedeleleyen ek bir unsur olarak karşımıza çıkmaktadır. OECD'nin [4] raporları da öğretmenlerin iş iyi oluşunun mesleğin toplumdaki algısıyla doğrudan bağlantılı olduğunu vurgulamaktadır.

Sonuç olarak, öğretmen adaylarının istihdam kaygısı çok boyutlu bir olgudur. Bu kaygılar, büyük ölçüde eğitim politikalarındaki belirsizlikler, istihdam süreçlerindeki yapısal sorunlar, sınav/mülakat sistemindeki güven problemleri ve mesleğin toplumsal-ekonomik konumundaki zayıflamalar ile açıklanmaktadır. Araştırma, yalnızca bireysel değil, sistemsel düzeyde çözümler üretilmesi gerektiğini göstermektedir. İstihdam kaygısının azaltılması, hem adayların mesleki motivasyonunu hem de eğitim sisteminin sürdürülebilirliğini güçlendirecek bir adım olacaktır. Bu sonuçlara bağlı olarak aşağıda yer alan öneriler sunulmuştur:

- Öğretmen istihdamı planlamasında arz-talep dengesi dikkate alınmalı, fakültelerden mezun olan aday sayısı ile atama kontenjanları arasında uyum sağlanmalıdır.
- KPSS ve mülakat uygulamalarında adalet ve şeffaflık artırılmalı, öğretmen adaylarının güvenliğini sarsan belirsizlikler giderilmelidir.
- Öğretmen adaylarının kaygılarını azaltmak için fakültelerde rehberlik ve psikolojik danışma hizmetleri güçlendirilmeli, kariyer planlama etkinlikleri düzenlenmelidir.

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ÖĞRETMEN İSTİHDAM POLİTİKALARI VE İSTİHDAM KAYGISI ÜZERİNE BİR DEĞERLENDİRME

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Özet – Öğretmen istihdam politikaları, eğitim sisteminin ihtiyaçları ile öğretmen arzı arasındaki dengeyi sağlamaya yönelik stratejik düzenlemeler iken; bu politikaların niteliği ve uygulanış biçimi, öğretmen adaylarının mesleki geleceklerine ilişkin kaygı düzeylerini doğrudan etkileyen belirleyici bir unsur olarak öne çıkmaktadır. Bu araştırmanın amacı, İngilizce Öğretmenliği lisans programında öğrenim gören son sınıf öğretmen adaylarının mevcut öğretmen istihdam politikaları hakkında görüşlerini ortaya koymaktır. Nitel araştırma yaklaşımıyla yürütülen çalışmada durum çalışması deseni kullanılmıştır. Çalışma grubunu, Türkiye’de bir devlet üniversitesinde öğrenim gören 26 son sınıf öğretmen adayı oluşturmaktadır. Veriler, yarı yapılandırılmış görüşme formu aracılığıyla toplanmış ve betimsel analiz yöntemiyle çözümlenmiştir. Araştırma bulgularına göre istihdam sayısı ve oranındaki belirsizliğin İngilizce Öğretmenliği bölümü öğretmen adaylarının tamamına göre istihdam sayıları ve kendi içinde dağılımlarındaki belirsizlikler istihdam konusunda kaygılanmalarına sebep olmaktadır. Öğretmen adaylarının istihdam kaygısını en çok artıran unsur atama ve kontenjan belirsizliğidir. Katılımcılar, bazı yıllarda yüksek sayıda, bazı yıllarda düşük sayıda alım yapılmasının ve branşlara bağlı olarak alım miktarının değişken olmasının güven duygusunu zedelediğini vurgulamaktadır. Öğretmen adayları Milli Eğitim Akademisi uygulamasının istihdam kaygılarına sebep olduğunu belirtmiştir. Genel anlamda sistemin ve akademinin nasıl işleyeceğine dair belirsizlik en çok üzerinde durulan kaygı sebebidir.

Anahtar Kelimeler – Öğretmen Adayları, İstihdam Kaygısı, İngilizce Öğretmenliği, Nitel Araştırma, Eğitim Politikaları.

I. GİRİŞ

Küresel ölçekte öğretmen arzı-talep dengesi birçok ülkede kırılgan hâle gelmiş ve öğretmen adaylarının istihdam süreçlerindeki belirsizlikleri, eğitim politikalarının önemli bir meselesi haline getirmiştir. UNESCO’nun “Global Report on Teachers”, 2030’a kadar dünya genelinde milyonlarca ek öğretmene ihtiyaç duyulacağını ve öğretmen işgücünün güçlendirilmesinin acil bir politika önceliği olduğunu ortaya koymaktadır [1]. Bu durum, öğretmen adaylarının mesleğe geçiş süreçlerinde “atanabileceğim mi?” sorusuna ilişkin kaygı algısını besleyen makroekonomik ve kurumsal bağlamı oluşturmaktadır.

Uluslararası literatürde, öğretmen adaylarının stresi, duygusal yükü ve öz-yeterlik algısı araştırma odakları arasında yer almaktadır. Örneğin, Kanada’daki öğretmen adaylarına dönük olarak yapılan çalışma duygusal ve fiziksel taleplerin adaylar üzerinde stres ve psikolojik yük oluşturduğunu ve adayların stresi yönetme becerileri konusunda destek beklediklerini göstermektedir. Bu çalışma, öğretmen eğitimi programlarının stres yönetimi, öz bakım, duygusal düzenleme ve etkili iletişim gibi bileşenleri müfredatına dahil etmesinin faydalı olacağı önerisini sunmaktadır [2]. Benzer şekilde, Filipinler örneğinde yapılan araştırmada, öğretmen adaylarının öğretim kaygısı ile öğretim öz-yeterliği arasında anlamlı bir ilişki tespit

etmiştir. Araştırmada, sınıf yönetimi kaygısı, öğretim uygulaması sürecinde adayların öz-yeterlik inançlarına en güçlü etki eden faktör olarak belirlenmiştir [3]. Bu bulgular, adayların duygusal deneyimlerinin yalnızca bireysel becerilerle değil, öğretim süreçlerine yönelik algılarla da bağlantılı olduğunu göstermektedir.

Türkiye özelinde, öğretmen istihdamı genellikle merkezi atama sistemi ve branşlara göre kontenjan dağılımı esasına dayanır. Bu sistemsal yapı, adayların “kaç kişi alınacak?”, “branş dağılımı nasıl olacak?” gibi belirsizliklerle sıkça karşılaşmasına yol açar ve bu belirsizlikler adaylar açısından istihdam kaygısını artırabilir. Ayrıca, yeni kurumsal düzenlemeler (örneğin Milli Eğitim Akademisi gibi modeller) adayların mesleğe geçiş süreçlerine yönelik algılarını değiştirme potansiyeline sahiptir.

Bu çalışma, İngilizce öğretmenliği son sınıf öğrencilerinin istihdam kaygılarını ve bu kaygıların kurumsal, politik unsurlarla ilişkisini anlamayı amaçlamaktadır. Çalışma şu iki temel araştırma sorusuna odaklanmaktadır:

1. Devlet okullarına öğretmen alımlarında toplam sayı ve branşlara göre dağılımlardaki belirsizlikler, öğretmen adaylarının istihdam kaygısını nasıl etkilemektedir?
2. Milli Eğitim Akademisi uygulamasının öğretmen adaylarının istihdam kaygısına etkisi nasıldır?

II. YÖNTEM

Araştırma Modeli

Bu araştırma, nitel araştırma yaklaşımı çerçevesinde durum çalışması deseni ile yürütülmüştür. Bu desen, belirli bir olguya ilişkin katılımcıların görüşlerini ayrıntılı biçimde ortaya koymaya olanak tanımaktadır. Çalışmada, öğretmen adaylarının istihdam kaygıları fenomen olarak ele alınmış ve mevcut duruma ilişkin derinlemesine veriler toplanmıştır.

Çalışma Grubu

Çalışma grubunu, Türkiye’de bir devlet üniversitesinin Eğitim Fakültesi İngilizce Öğretmenliği bölümünde öğrenim gören 26 son sınıf öğretmen adayı oluşturmaktadır. Katılımcılar amaçlı örnekleme yöntemlerinden maksimum çeşitlilik örnekleme ile belirlenmiştir. Bu yöntemle, cinsiyet, başarı düzeyi, mezuniyet sonrası planlar ve sosyo-ekonomik farklılıklar açısından çeşitlilik sağlanarak görüşlerin zenginleştirilmesi hedeflenmiştir.

Veri Toplama Aracı

Veriler, araştırmacı tarafından hazırlanan yarı yapılandırılmış görüşme formu ile toplanmıştır. Formda, öğretmen adaylarının istihdam politikaları, kontenjan belirsizlikleri, Milli Eğitim Akademisi uygulaması ve genel mesleki kaygılarına yönelik açık uçlu sorular yer almıştır. Görüşme formu, alan uzmanlarının görüşleri doğrultusunda geliştirilmiş ve pilot uygulamadan sonra son haline getirilmiştir.

Veri Toplama Süreci

Veri toplama süreci, 2024 güz yarıyılında gerçekleştirilmiştir. Katılımcılarla bireysel görüşmeler yapılmış, her görüşme ortalama 25–30 dakika sürmüştür. Görüşmeler görüşme esnasında araştırmacılarca yazıya aktarılmıştır. Katılımcılara araştırmanın amacı açıklanmış, gönüllülük esasına göre sürece katılmaları sağlanmış ve gizlilik ilkesi korunmuştur.

Veri Analizi

Toplanan veriler, betimsel analiz yöntemiyle çözümlenmiştir. Öncelikle verilen yanıtlar yazıya aktarılmış, ardından araştırma sorularına uygun tematik çerçeve oluşturulmuştur. Katılımcı görüşleri kodlanmış, benzer kodlar bir araya getirilerek tablolar oluşturulmuştur. Kodlama sürecinde iki araştırmacı bağımsız olarak çalışmış, elde edilen kodlar karşılaştırılmış ve tutarlılık sağlanmıştır. Bulgular tablolar halinde sunulmuş, doğrudan katılımcı alıntıları ile desteklenmiştir.

III. BULGULAR

İstihdam Sayı ve Oranlarındaki Belirsizliklerin Öğretmen Adayı İstihdam Kaygısına Etkisi

Katılımcılara yöneltilen “Devlet okullarına öğretmen alımlarında toplam sayı ve her bölüme verilen kadro sayılarındaki (Oran) belirsizliklerin öğretmen adaylarının istihdam kaygısı üzerindeki etkisi nasıldır?” sorusuna verilen cevaplar tablo 2’de verilmiştir.

Tablo 2. İstihdam Sayısındaki ve Oranlarındaki Belirsizliğin Etkileri

Kodlar	Katılımcılar	<i>f</i>
Atama/Kontenjan belirsizliği	K2, K3, K4, K6, K7, K10, K14, K16, K18, K21, K25	11
Gelecek kaygısı	K1, K8, K9, K11, K13, K15, K17	7
Genel belirsizlik	K12, K22, K24	3
Mesleği değersizleştirme	K5, K26	2
Toplam		26

İngilizce Öğretmenliği bölümü öğretmen adaylarının tamamına göre istihdam sayıları ve kendi içinde dağılımlarındaki belirsizlikler istihdam konusunda kaygılanmalarına sebep olmaktadır. Adaylardan 3’ü (K19-K20-K23) kaygılandıklarını ifade etmekle birlikte detay vermemiştir. Öğretmen adaylarının istihdam kaygısını en çok artıran unsur atama ve kontenjan belirsizliğidir ($f=11$). Katılımcılar, bazı yıllarda yüksek sayıda, bazı yıllarda düşük sayıda alım yapılmasının güven duygusunu zedelediğini vurgulamaktadır. Bu konuda: (Katılımcı 2) K2: “Atamalar çok düştü. Bu durum da ister istemez istihdam kaygısını artırıyor.” ve K3: “Öğretmen alımlarındaki belirsizlik, yıllık kontenjan azlığı kaygımı artırıyor.” diyerek alımlardaki belirsizliğe ve düşüşe vurgu yapmıştır.

Bir diğer kaygı sebebi mesleki anlamda gelecek kaygısıdır ($f=7$). Belirsizliklerin öğretmen adaylarının sadece mesleki değil, meslek edinimine bağlı olarak genel yaşam planlarını da etkilediği görülmektedir. Bu konuda K8: “Her yıl değişen kontenjanlar geleceğe dair plan yapmamı imkânsız hale getiriyor.” ve K11: “Belirsizlik yüzünden mesleki gelecek konusunda güvensizlik hissediyorum.” ifadeleriyle belirsizliğin gelecek algılarına olan negatif etkilerine vurgu yapmışlardır.

Bazı katılımcılar ($f=3$) genel belirsizlikten söz etmiş, ayrıntı vermeden bu süreci kaygı kaynağı olarak belirtmiştir. Konuyla ilgili olarak K12: “Ne zaman, kaç kişi alınacağı belli olmadığı için sürekli bir kaygı yaşıyorum.” ve K22: “Her şey belirsiz, bu da istihdam konusunda stres yaratıyor.”

Az sayıda katılımcı ($f=2$) ise mesleğin değer kaybettiğini ifade etmiştir. Onlara göre belirsizlik, öğretmenlik mesleğinin toplumsal ve ekonomik statüsünü zedelemektedir. Örneğin K5: “Yetersiz maaş ve mesleğe olan saygının gün geçtikçe azalması kaygılarımı artırıyor.” ve K26: “alımların da keyfiyete göre yapılması mesleğe değer verilmemesi anlamına geliyor. Değer kaybı da her geçen yıl istihdam kaygımı artırıyor.” diyerek mesleki saygı boyutuna vurgu yapmıştır.

Öğretmen adaylarının istihdam kaygılarının merkezinde atama ve kontenjan belirsizliğinin yer aldığını görülmektedir. Katılımcıların büyük bölümü alım sayılarındaki düzensizlikten etkilenmiş, bu durumun yalnızca iş bulma şanslarını değil, genel gelecek planlarını da belirsizleştirdiğini belirtmiştir. Sınav ve alım süreçlerindeki öngörülemezlik, adaylarda sürekli bir güvensizlik duygusu yaratmaktadır. Az sayıda da olsa, mesleğin toplumsal değerine ilişkin kaygılar dikkat çekmektedir. Sonuç olarak, istihdam kaygısı çok boyutlu olsa da en güçlü belirleyici faktörün öngörülemeyen atama politikaları olduğu söylenebilir.

Milli Eğitim Akademisinin Kaygıya Etkisi

Öğretmen adaylarına yöneltilen “Öğretmenlik Meslek Kanunu’yla birlikte kamu istihdam politikasında yer alan Milli Eğitim Akademisi uygulamasının kaygı düzeyinize bir etkisi var mı? Nasıl etkilemektedir?” sorusuna ilişkin cevaplar Tablo 3’te kategorize edilerek verilmiştir.

Tablo 3. Milli Eğitim Akademisi Uygulamasının İstihdam Kaygısına Etkisi

Kodlar	Katılımcılar	f
Belirsizlik Oluşturma	K1, K3, K4, K15, K22, K23, K24, K25, K26	9
Süre Kaygısı	K2, K5, K6, K8, K9, K10, K14, K16, K20, K21	8
Lisansı Değersizleştirme	K7, K17, K18, K19	4
Atanmayı Zorlaştırma	K12	1
Toplam		26

Öğretmen adaylarının tamamı Milli Eğitim Akademisi uygulamasının istihdam kaygılarına sebep olduğunu belirtmiş fakat 2 aday (K11-K13) detaylı bilgi vermek istememiştir. Genel anlamda sistemin ve akademinin nasıl işleyeceğine dair belirsizlik en çok üzerinde durulan kaygı sebebidir(f=9). Bu konuda katılımcılar: K3: “Sistemin nasıl işleyeceği belli değil, bu da kaygı veriyor.” K25: “Belirsizlik kaygı seviyemi artırıyor.” K26: “Uygulamanın detayları belli olmadığı için sürekli kaygı yaşıyorum.” K1: “Evet etkiliyor, çünkü belirsizlik var.” diyerek belirsizliğin en önemli kaygı sebebi olduğunu ifade etmişlerdir.

Bir diğer husus da uygulamanın işe başlama süresini uzatması ve bu süreçte çekilebilecek zorluklardır. Bu konuda öğretmen adayları: K5: “Akademi süresi uzadıkça iş bulmak gecikecek.” K10: “Akademide fazladan zaman kaybetmek kaygı verici. Bu sürecin şartları da istenen düzeyde olmayacak gibi görüldüğünden kaygım artıyor.” K13: “Akademi, süreci gereksiz şekilde uzatıyor ve rekabeti artırıyor.” K21: “Akademide geçen sürede gelir olmayacağı için ekonomik açıdan zorlayıcı olacak.” gibi ifadelerle uygulama süresinin uzunluğuna ve sürecin farklı açılardan zorlayıcılığına vurgu yapılmıştır.

Lisansı Değersizleştirme kategorisi altında fakültelerde alınan eğitimin akademiyle yetersiz gösterileceği endişesi dile getirilmiştir. Bu konuda öğretmen adayları: K7: “Fakültede aldığımız eğitimle akademi arasında fark olacak, akademi sanki lisansı tamamlayıcı bir süreç gibi okulda aldığımız dersler kıymet kaybedecektir. Bu durum da kaygı vericidir.” K19: “Akademi, fakültelerdeki eğitimi gereksiz ve yetersiz göstermektedir.” ifadeleriyle uygulamanın lisans eğitimi değersizleştireceğine yönelik fikirler ortaya koymuştur.

Az sayıda öğretmen adayı(f=2) akademinin öğretmen olarak atanmayı zorlaştıracak olduğunu düşünmektedir. Bu konuda: K12: “Bu sistem farklı eksikliklerinden dolayı atanmayı daha da zorlaştıracak gibi görünmekte. Zaten var olan sınava yeni sınav ve uzun soluklu staj dönemi eklemek işi yokuşa sürmek gibi oluyor.”

Milli Eğitim Akademisi uygulaması, öğretmen adaylarının istihdam kaygısını artırıcı bir unsur olarak görülmektedir. En çok dile getirilen kaygılar atama süresinin uzaması ve belirsizliklerdir. Bunun

yanında lisans eğitiminin değersizleşeceği ve atanmanın zorlaşacağı önemli kaygı alanlarıdır. Bu bulgular, öğretmen adaylarının yeni sistemle ilgili güven eksikliği yaşadığını ve geleceğe yönelik kaygılarının daha da arttığını göstermektedir.

IV. SONUÇ, TARTIŞMA VE ÖNERİLER

Bu araştırmada İngilizce Öğretmenliği bölümü son sınıf öğrencilerinin öğretmen istihdam politikaları hakkındaki görüşleri incelenmiştir. Bulgular, öğretmen adaylarının en güçlü kaygı alanının atama ve kontenjan belirsizliği olduğunu göstermektedir. Katılımcılar, yıllara göre değişen öğretmen alım sayılarının güven duygusunu zedelediğini ve gelecek planlarını zorlaştırdığını vurgulamıştır. Bunun yanı sıra, bazı adaylar belirsizliklerin mesleğin toplumsal değerini azalttığını ifade etmiştir. Bu sonuçlar, UNESCO'nun [1] öğretmen arz-talep dengesine ilişkin küresel raporunda da belirtildiği üzere, birçok ülkede öğretmen istihdam politikalarının kırılgan yapısı ile örtüşmektedir. Benzer biçimde Darling-Hammond, öğretmen yetiştirme ve istihdam politikalarındaki istikrarsızlığın öğretmen adaylarının mesleğe olan güvenini azalttığını ve gençlerin bu mesleği tercih etme isteğini düşürdüğünü vurgulamaktadır [4].

Ayrıca, Milli Eğitim Akademisi uygulamasının adaylarda ek kaygıya neden olduğu tespit edilmiştir. Özellikle sistemin nasıl işleyeceğine dair belirsizlikler, sürecin uzunluğu ve fakültelerde alınan eğitimin değersizleşebileceği algısı, adayların geleceğe yönelik güvensizliklerini artırmıştır. Dolayısıyla istihdam kaygısının çok boyutlu bir olgu olduğu, ancak en güçlü belirleyicinin öngörülemez atama politikaları olduğu sonucuna ulaşılmıştır. Bu sonuç, Zito ve arkadaşlarının Kanada'da yaptıkları çalışmayla paralellik göstermektedir [2]. Söz konusu araştırmada, belirsiz geçiş süreçlerinin öğretmen adaylarında stres yarattığı ve öz-yeterlik algısını zayıflattığı tespit edilmiştir. Benzer şekilde Gorospe, Filipinler'de yaptığı araştırmada öğretim kaygısı ile öz-yeterlik arasında anlamlı bir ilişki olduğunu, belirsizliğin öğretmen adaylarının mesleki özgüvenini düşürdüğünü ortaya koymuştur [3].

İstihdam kaygısının yalnızca mesleki değil, aynı zamanda yaşam planları üzerinde de etkili olduğu tespit edilmiştir. Katılımcıların ifadeleri, belirsizliğin kariyer planlamasının ötesinde kişisel yaşam düzenlerini de etkilediğini göstermektedir. Bu bulgu, Klassen ve Chiu'nun araştırmasıyla benzerlik taşımaktadır [5]. Söz konusu çalışmada, yüksek kaygı düzeyine sahip öğretmen adaylarının mesleki doyumlarının düşük olduğu, bunun da psikolojik stres ve gelecek güvensizliği yarattığı belirtilmiştir. Kyriacou da öğretmenlerde stresin, sistemsel belirsizliklerle doğrudan bağlantılı olduğunu ve uzun vadede mesleği bırakma riskini artırdığını vurgulamaktadır [6].

Bunun yanında, bazı öğretmen adayları belirsizliklerin mesleğin toplumsal değerini zedelediğini ifade etmiştir. Bu kaygı, uluslararası araştırmalarla da desteklenmektedir. Örneğin Ingersoll, öğretmenlik mesleğinde yüksek devir oranlarının ve iş güvencesizliğinin mesleğin statüsünü düşürdüğünü ve öğretmen açığını daha da derinleştirdiğini belirtmiştir [7]. Benzer şekilde Skaalvik ve Skaalvik, öğretmenlik mesleğinin saygınlığındaki azalma ve iş güvencesizliği algısının, tükenmişlik ve motivasyon kaybıyla ilişkili olduğunu göstermektedir [8].

Sonuç olarak, bu araştırma bulguları öğretmen adaylarının istihdam kaygılarının çok boyutlu olduğunu ortaya koymaktadır. Atama ve kontenjan belirsizliği, Milli Eğitim Akademisi sürecindeki öngörülemezlik ve mesleğin değer kaybı algısı, adayların mesleğe geçiş sürecinde karşılaştıkları başlıca kaygı alanlarıdır. Bulgular, uluslararası literatürle de uyumlu olarak, öğretmen istihdam politikalarının şeffaflık, öngörülebilirlik ve mesleğin statüsünü güçlendirme ilkeleri doğrultusunda yeniden ele alınması gerektiğini göstermektedir. Bu konuda aşağıda yer alan öneriler sunulmaktadır:

- Kontenjanların şeffaf olması ve uzun vadeli bir planlama yapılabilir
- Milli Eğitim Akademi uygulamasının işleyişi, süresi ve adaylara sağlayacağı katkılar ayrıntılı bir şekilde kamuoyuyla paylaşılmalı adayların kafasındaki belirsizlikler giderilebilir.

- Üniversitelerde son sınıf öğretmen adaylarına yönelik stres yönetimi, öz-yeterlik geliştirme ve kariyer planlama programları açılmalı; adayların belirsizliklerle başa çıkma kapasiteleri artırılabilir.

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Comparative Analysis Of Sgdm And Adam Algorithms Using Covid 19 Images

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Abstract – Accurate computer-aided medical diagnosis is vital to human life. Artificial intelligence systems that will diagnose diseases from X-ray, MRI, CT scan, or biopsy data must learn. Optimizations like Adam and Stochastic Gradient Descent with Momentum (SGDM) enable these networks to learn from data. Using SGDM and Adam is important because it accelerates the learning process of neural networks, makes them stable, and provides better results. Such algorithms should be used to correctly adjust the weights in the neural network, to minimize the error (loss) function, and to ensure that the model makes more accurate predictions. In this study, a detailed comparative analysis of two different optimization algorithms, SGDM and Adam, was conducted using COVID-19 images. The Adam algorithm achieved an average accuracy of 0.8941, while the SGDM algorithm achieved an accuracy of 0.9133. The SGDM algorithm performed better than the Adam algorithm.

Keywords – Algorithm, Deep Learning, Artificial Intelligence, Medical Diagnosis.

I. INTRODUCTION

Today, artificial intelligence has become an important tool for supporting doctors in medical diagnostic processes [1]. Deep learning-based systems are used for early diagnosis of diseases by analyzing large amounts of medical data [2]. One of the most critical elements for the success of these systems is optimization algorithms. Adam and SGDM are the two most commonly used optimization methods in deep learning [3]. Optimization algorithms enable artificial neural networks to learn from data. These algorithms play a vital role in medical image analysis, cancer diagnosis, and the detection of heart disease and neurological disorders [4]. The Adam algorithm, thanks to its adaptive learning rate, enables models to be trained more quickly and effectively [5]. SGDM, on the other hand, offers a learning process that is stable and more amenable to generalization [3]. This allows AI models to produce reliable results not only on training data but also on real patient data. High accuracy in medical diagnostic processes is crucial for patient safety. The efficient learning provided by Adam and SGDM helps reduce misdiagnosis rates. These algorithms are particularly valuable in diseases where early diagnosis is critical, such as cancer [1]. Without optimization algorithms, AI systems cannot learn accurately and provide reliable diagnoses. Therefore, optimization techniques are indispensable in AI applications in modern medicine. Consequently, the Adam and SGDM optimization algorithms are crucial for both speed and accuracy in medical diagnostics.

Recent advances in deep learning and convolutional neural networks have significantly increased our success in object classification and recognition. Deep neural networks are a type of advanced neural network with multiple hidden layers that can learn more detailed and complex representations of input data. Due to their ability to run on specialized hardware, deep learning models can adapt to large datasets and continuously improve with increasing data volumes. These features allow them to outperform many classical machine learning methods. Furthermore, unlike traditional machine learning models, deep

learning models do not require manual segmentation or feature extraction. This makes deep learning models more popular and facilitates binary or multiple classification tasks by fully automating classification tasks [6].

Deep learning has become an important tool in the field of medical image classification, and optimization algorithms play a significant role in this process. Algorithms such as stochastic gradient descent (SGD) and Adam are widely used in training deep neural networks [7,8]. SGDM with momentum adds a momentum term to increase the speed of SGD, while the Adam algorithm provides faster convergence with adaptive learning rates [9]. The impact of these algorithms on medical image classification has been investigated in studies [10,11]. In particular, SGDM achieved high accuracy by reducing the classification error from 6.12% to 5.44% [10]. The Adam algorithm provided high accuracy and stability in gastrointestinal image classification [5]. Comparison of these optimization algorithms is important for improving the performance of medical image classification models [11].

The aim of this study is to compare the performances of SGDM and Adam algorithms statistically.

II. MATERIALS AND METHOD

The Adam optimization algorithm stands for Adaptive Moment Estimation and is widely recognized as a popular and effective method for deep learning tasks with its ability to adaptively adjust both the learning rate and momentum for each parameter. By computing exponential moving averages of both gradients and squared gradients, Adam maintains separate learning rates for each parameter and adjusts them as learning progresses. This adaptability allows Adam to perform well on a wide range of deep learning tasks, from simple to complex models [12, 13].

SGDM provides more reliable and faster learning, especially in critical applications such as medical diagnosis and image classification. It updates the weights according to the gradient of the loss function using only one data sample or a small mini-batch at each iteration. This enables fast training on large datasets, but sometimes progresses jerkily and unevenly. Momentum maintains the "direction of motion" by taking into account previous steps in weight updates. This reduces the fluctuations in gradient descent and allows for faster minima.

Confusion Matrix

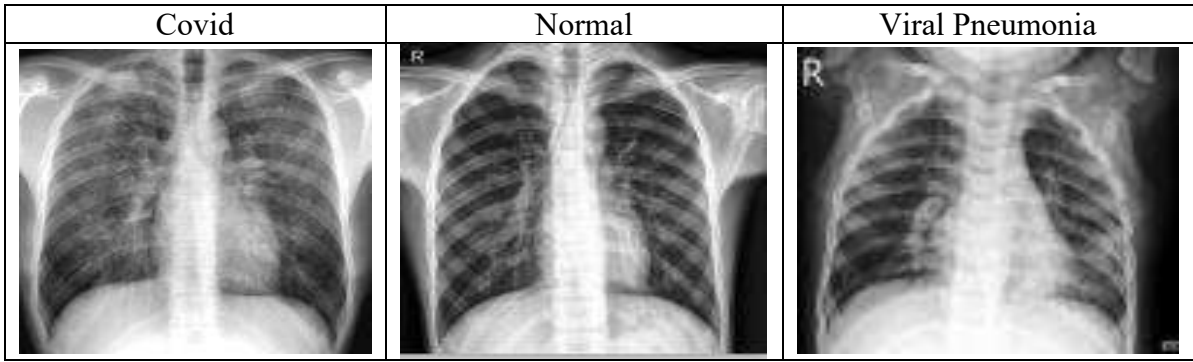
The Confusion Matrix compares the model's predictions with the actual values. For a typical classification, the table is as follows:

- TP: True positive predictions (correctly classifying a patient as sick)
- TN: True negative predictions (correctly classifying a healthy person as healthy)
- FP: False positives (classifying a healthy person as sick)
- FN: False negatives (classifying a patient as healthy)

III. RESULTS

In this study, two different algorithms were analyzed on the Covid-19 dataset. The dataset and its properties used in this study are shown in the table [14]. The dataset consists of three different classes: COVID-19, Viral Pneumonia, and Normal.

Table 1. Dataset images



CM metrics were used in experimental studies to ensure statistical accuracy. CM results obtained from the Adam algorithm are shown in the table.

Table 2. CM results obtained from the Adam algorithm

CM	Covid	Normal	Viral Pneumonia
Covid	24	0	2
Normal	1	12	5
Viral Pneumonia	0	1	17

CM results obtained from SDGM are shown in the table.

Table 3. CM results obtained from the SDGM algorithm

CM	Covid	Normal	Viral Pneumonia
Covid	24	0	2
Normal	1	13	4
Viral Pneumonia	1	0	17

Figure 1 shows the ROC curve graph obtained from viral pneumonia images using the Adam algorithm.

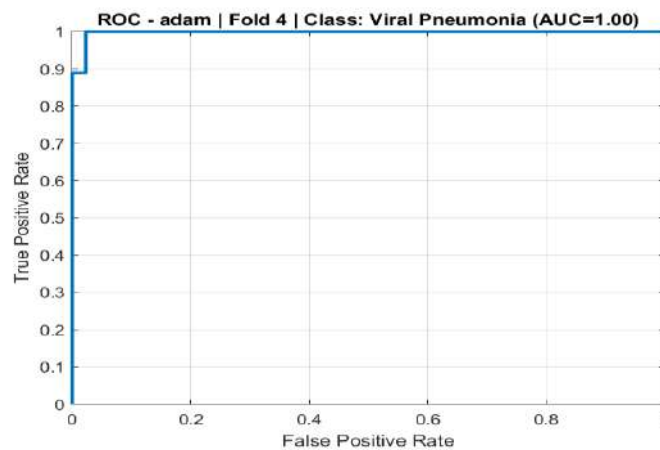


Fig. 1 Roc Curve of Viral Pneumonia Classification Using the Adam Algorithm

Figure 2 shows the Roc curve graph obtained from normal images using the Adam algorithm.

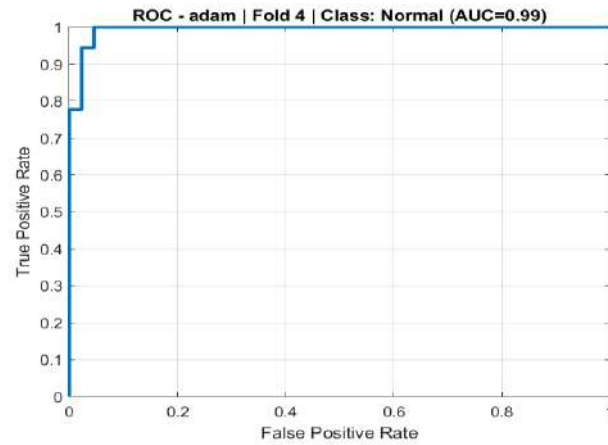


Fig. 2 Roc Curve of the Adam algorithm normal class

Figure 3 shows the Roc curve graph obtained from COVID images using the Adam algorithm.

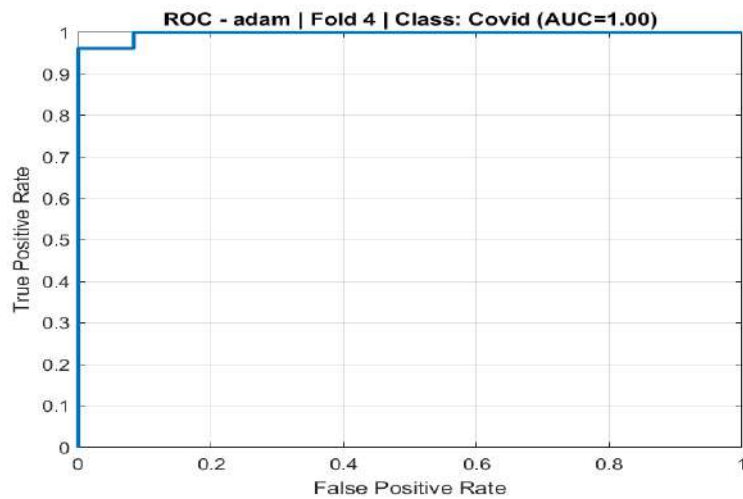


Fig. 3 Adam Algorithm COVID Classification Roc Curve

Figure 4 shows the Roc curve graph obtained from viral pneumonia images using the SGDM algorithm.

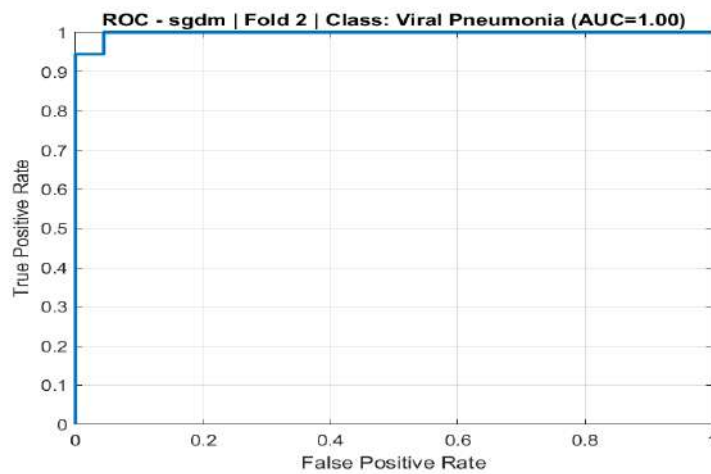


Fig. 4 SGDM algorithm Roc curve for viral pneumonia class

Figure 5 shows the Roc curve plot obtained from normal images using the SGDM algorithm.

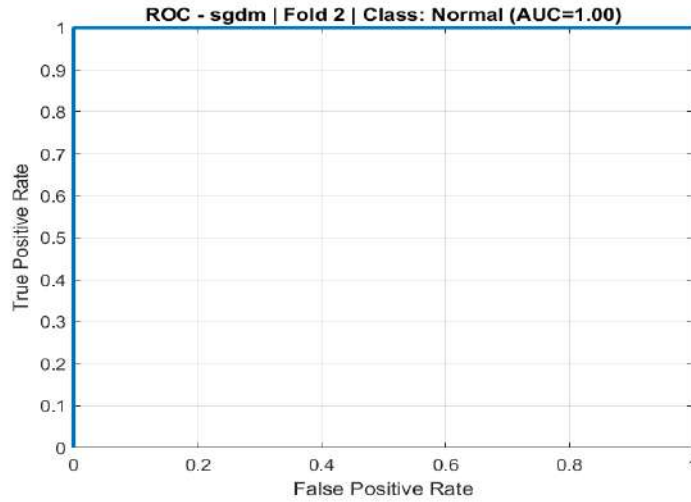


Fig. 5 Roc Curve of the SGDM algorithm's normal class

Figure 6 shows the Roc curve graph obtained from COVID images using the SGDM algorithm.

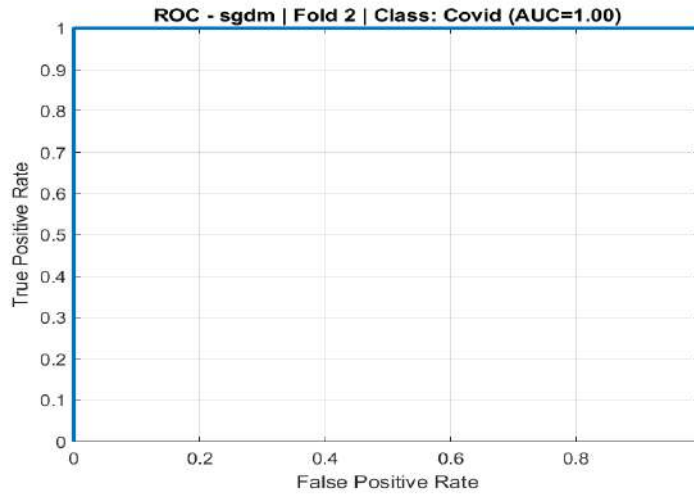


Fig. 6 Roc Curve of the Covid algorithm's normal class

According to the results, the best results were obtained from the sgdm algorithm.

IV. CONCLUSION

Adam uses an adaptive learning rate for weight updates and applies a separate rate for each parameter. SGDM uses a single learning rate and momentum. It is more stable but sometimes converges more slowly. The SGDM and Adam algorithms play a critical role in training deep learning models. Both algorithms utilize gradient information in weight updates, ensuring accurate model learning. SGDM reduces jitter and ensures stable convergence thanks to momentum, while Adam optimizes parameters more flexibly and quickly with adaptive learning rates. These algorithms reduce training time and improve model performance, especially on large and complex datasets. They support accurate and reliable results in critical applications such as medical diagnosis and image classification. In conclusion, SGDM and Adam are fundamental optimization tools for both fast and secure learning processes in deep learning systems. The Adam algorithm performed best for two classes, while the SGDM algorithm performed best for all three classes. Future studies can compare the performance of different algorithms with hybrid models.

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Experimental Determination of Spearmint Sorption Isotherms Using Salt Solutions

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Abstract – Efficient drying and reliable storage are central to maintaining the quality of agricultural and medicinal plants. In forced convection drying and solar energy storage systems, the determination of equilibrium moisture content (EMC) is a key parameter for optimizing operating conditions and ensuring product stability. Sorption isotherm curves describe the relationship between moisture content and relative humidity, providing essential insights into hygroscopic equilibria that guide the design of energy-efficient drying strategies.

This study investigates the sorption isotherms of spearmint (*Mentha spicata*), an aromatic and medicinal plant widely utilized in food and pharmaceutical industries. The saturated salt solution method was employed to determine EMC at four controlled temperatures (20, 35, 45, and 55 °C). Experimental measurements were analyzed to evaluate the influence of temperature on moisture sorption behavior.

The experimental data were further modeled using the Henderson equation, a widely applied empirical approach for predicting sorption characteristics. The results confirmed the strong suitability of this model, as it accurately described the equilibrium sorption profiles of spearmint across the studied temperature range.

The findings contribute to a deeper understanding of spearmint's drying and storage characteristics, offering practical guidelines for process optimization. Beyond this specific case, the study emphasizes the broader relevance of sorption modeling in solar drying applications, where precise prediction of EMC supports improvements in energy efficiency, product quality, and sustainable post-harvest management.

Keywords: Sorption Isotherm, Equilibrium Moisture Content, Spearmint (*Mentha Spicata*), Henderson Model, Forced Convection Drying, Solar Drying.

I. INTRODUCTION

Moisture sorption isotherms express the relationship between equilibrium moisture content and relative humidity at constant temperature. These curves are fundamental for understanding water distribution, bonding strength, and functional availability in biological products, which are crucial for designing efficient drying, storage, and preservation strategies. Due to the complexity of sorption phenomena, theoretical prediction is limited, and experimental determination remains essential for each product.

Mint, an aromatic and medicinal plant, has been extensively studied for its drying kinetics and moisture behavior. Müller et al. (1996) and Lebert et al. (1998) examined drying rates under varying air temperatures and humidity conditions, while Tarhan et al. (2005) and Doymaz (2006) investigated

the effect of temperature profiles on drying performance. Dalgıç et al. (2010) compared different drying methods and modeled sorption isotherms using several empirical equations, and later works by Park et al. (2001), Kouhila et al. (2002), and Taoufik et al. (2018) applied gravimetric methods with models such as GAB, Henderson, and Oswin.

Despite these contributions, the literature still presents important gaps. Most studies are limited to narrow temperature ranges, specific drying conditions, or single modeling approaches, making comparisons across studies difficult. In addition, inconsistencies remain in identifying the most reliable predictive models for mint sorption isotherms, which restrict their application in process design and industrial drying optimization.

The objective of this work is to experimentally determine the sorption isotherms of spearmint leaves at 20, 35, 45, and 55 °C using the saturated salt solution method, and to assess the predictive accuracy of the Henderson model. This study contributes by providing a wider temperature-based analysis and clarifying the model's suitability, thereby addressing existing gaps and supporting more reliable drying and storage strategies for mint.

II. MATERIALS AND METHOD

II.1. EXPERIMENTAL PRINCIPLE

The sorption isotherms of mint were determined using the static gravimetric method. Small samples were placed in sealed jars containing saturated saline solutions, which maintained constant relative humidity (RH) at fixed temperatures (T). The mass of each sample was periodically measured until stabilization, indicating equilibrium with the surrounding atmosphere.

The equilibrium moisture content was calculated as: $X_{eq} = (M_h - M_s) / M_s$

where M_h is the humid mass [g] and M_s is the dry mass [g]. Each pair (RH, X_{eq}) defines a point on the sorption or desorption isotherm.

II.2. PREPARATION OF SATURATED SALT SOLUTIONS

Six saturated salts were selected to generate different RH levels: $MgCl_2$, K_2CO_3 , KOH , $NaNO_3$, KCl , and $BaCl_2$. The salts (Fig. 1) were accurately weighed using a precision balance (Fig. 2), dissolved in distilled water, and homogenized by mechanical stirring (Fig. 3). The prepared solutions are shown in Figure 4.



Fig. 1. Salts utilized in the experiments



Fig. 2. Gravimetric Salt Weighing



Fig. 3. Stirring of saline solution



Fig4. Prepared saline solutions

II.3. PREPARATION OF MINT SAMPLES

Fresh mint leaves were cut into small, uniform pieces and pre-dried at 50 °C for desorption studies. Each sample (~0.1 g) was suspended above the saline solutions using a perforated stainless-steel grid placed in the glass jars (Figs. 5 and 6).



Fig.5. Preparation of mint samples

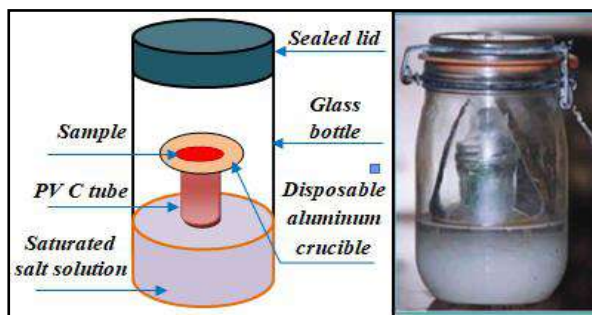


Fig. 6. Experimental setup for sorption isotherm determination

II.4. EXPERIMENTAL DEVICE

The complete experimental setup (Fig. 7) consisted of six airtight one-liter jars, each containing one saline solution and one suspended mint sample.

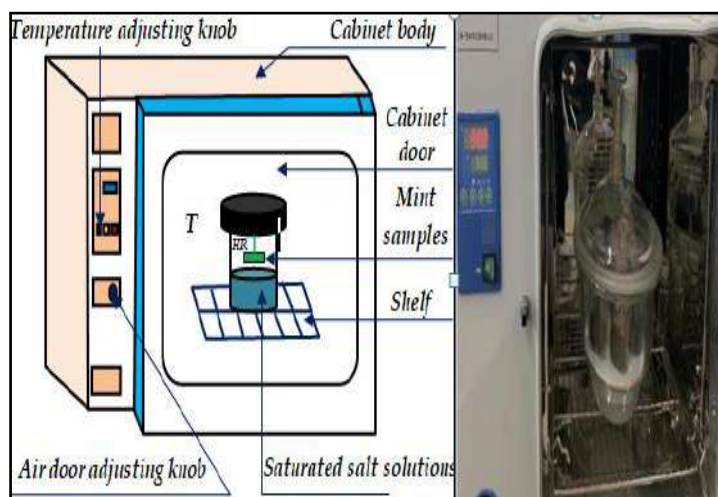


Fig. 7. Apparatus for sorption isotherm determination

The jars were placed in a climatic chamber (BINDER - APT. Line TM KBF – ICH) , equipped with programmable regulation of temperature, humidity, and ventilation. The operating domains of the chamber are summarized in Table I.

Table 1. Adjustment Domains

Parameter	Range
Temperature	–10 °C to +100 °C
Relative humidity	0% RH to 95% RH
Ventilation speed	0% to 100%

II.5. OPERATING PROCEDURE

Before placing the samples, the jars were conditioned for 24 h at the working temperatures of 20, 35, 45, and 55 °C, to allow stabilization of the saturated solutions.

Once stabilized, the samples were introduced into the jars and exposed to controlled RH and T. The mass of each sample was measured every five days, a frequency suitable given that equilibrium generally required 1–2 months depending on the salt type and temperature.

Equilibrium was defined as a mass variation of less than 1% between two successive measurements. After equilibrium was reached, the samples were dried in an oven at 100 °C until constant mass. The dry mass (M_s) was then used together with the humid mass (M_h) to calculate the equilibrium moisture content (X_{eq}).

This procedure was repeated for the four working temperatures (20, 35, 45, and 55 °C) and six relative humidity values, enabling the construction of complete sorption and desorption isotherm curves for mint.

III.RESULTS

III.1. EXPERIMENTAL RESULT

Samples were weighed every five days using a precision balance (± 0.001 g) until a constant mass (M_h) was reached, marking hygroscopic equilibrium. The equilibrium moisture contents (X_{eq}) of mint were experimentally determined at four temperatures (20, 35, 45, and 55 °C). Table 2 summarizes these experimental X_{eq} values together with the corresponding relative humidity (RH) values obtained from six reference salts.

Table.2. Equilibrium Moisture Contents (X_{eq}) of Six Salts at Four Working Temperatures

T (°C)	T = 20 °C		T = 35 °C		T = 45 °C		T = 55 °C	
Salts	HR [%]	X_{eq}	HR[%]	X_{eq}	HR[%]	X_{eq}	HR[%]	X_{eq}
<i>KOH</i>	16,478	0,0825	16,457	0,0674	10,769	0,041	9,974	0,0238
<i>MgCl₂</i>	32,344	0,0971	32,434	0,0832	31,890	0,074	32,434	0,0587
<i>K₂CO₃</i>	45,595	0,1334	45,964	0,1183	44,604	0,102	46,235	0,0804
<i>NaNO₃</i>	74,926	0,2187	75,198	0,2026	74,926	0,186	75,198	0,1649
<i>KCl</i>	88,205	0,3332	88,728	0,3175	90,359	0,301	91,447	0,2783
<i>BaCl₂</i>	94,416	0,3515	94,688	0,3393	94,960	0,329	95,775	0,3059

The experimental values of equilibrium moisture content (X_{eq}) and relative humidity (RH) were used to determine the Henderson constants n and k . These values, calculated for different RH domains at each temperature, are summarized in Table 3.

Table.3. The experimental results used to find the coefficients n and k

T (°C)	HR	Xeq (Experimental)	HR domain	n	k
20 °C	0.15	0.077	0 < HR < 0,3	2.486	0.180
	0.25	0.097			
	0.50	0.130	0,4 < HR < 1	1.075	0.0117
	0.80	0.260			
35 °C	0.18	0.070	0 < HR < 0,35	2.608	0.367
	0.31	0.089			
	0.60	0.146	0 ,35< HR < 1	1.179	0.0159
	0.90	0.319			
45 °C	0.19	0.060	0 < HR < 0,35	2.153	0.156
	0.33	0.081			
	0.64	0.145	0,5< HR < 1	1.347	0.0213
	0.93	0.322			
55 °C	0.16	0.037	0 < HR < 0,35	1.657	0.0694
	0.30	0.057			
	0.67	0.132	0,59 < HR < 1	1.169	0.020
	0.95	0.309			

III.2. ANALYTICAL RESULTS

To model sorption isotherms, several empirical correlations exist. Here, the analytical Henderson model is applied, as it enables interpolation over a wide range of temperature and relative humidity, unlike the G.A.B. or B.E.T. models restricted to low humidity. The Henderson equation is:

$$X_{eq}(T, RH) = \left[\frac{-\ln(1 - RH)}{k(1.8T + 492)} \right]^{\frac{1}{n}}$$

with constants k and n depending on temperature and product properties (e.g., Table 5)

Table.5. Equilibrium water contents were obtained for six salts (**Xeq**) and relative humidities (HR) for the four temperatures obtained by the Henderson model

T (°C)	n	K	HR	Xeq (Henderson)	HR domain
20 °C	2.486	0.180	0.15	0.077	0 < HR < 0,3
			0.25	0.096	
	1.075	0.0117	0.50	0.130	0,4 < HR < 1
			0.80	0.286	
35 °C	2.608	0.367	0.18	0.070	0 < HR < 0,35
			0.31	0.089	
	1.179	0.0159	0.60	0.146	0 ,35< HR < 1
			0.90	0.320	
45 °C	2.153	0.156	0.19	0.060	0 < HR < 0,35
			0.33	0.081	
	1.347	0.0213	0.64	0.158	0,5< HR < 1
			0.93	0.323	
55 °C	1.657	0.0694	0.16	0.037	0 < HR < 0,35
			0.30	0.057	
	1.169	0.020	0.67	0.132	0,59 < HR < 1
			0.95	0.309	

III.3. GRAPHICAL DEPICTION OF EXPERIMENTAL AND ANALYTICAL FINDINGS

Based on both experimental and analytical investigations, a graphical analysis was carried out, followed by a comparative assessment to highlight the consistency and differences between the two approaches.

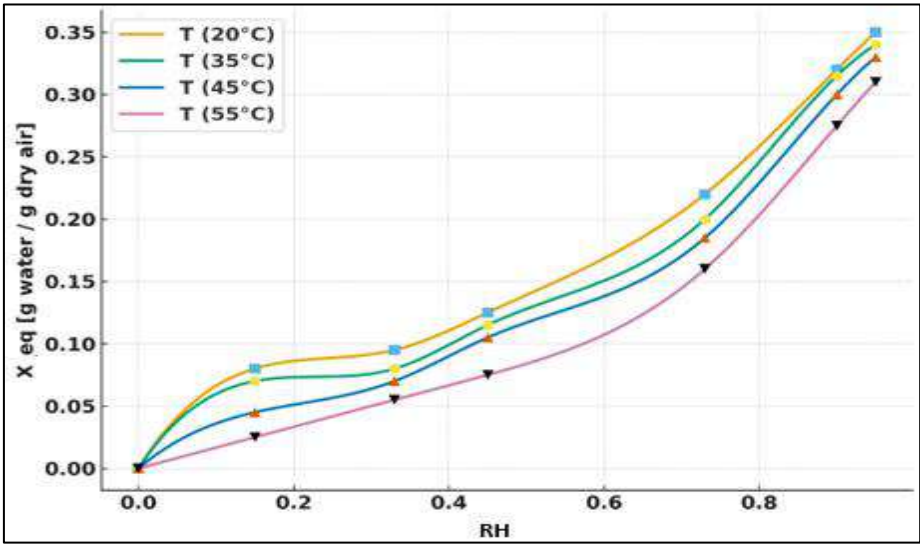


Fig.08 . Experimental Sorption Isotherms of Mint at Different Temperatures

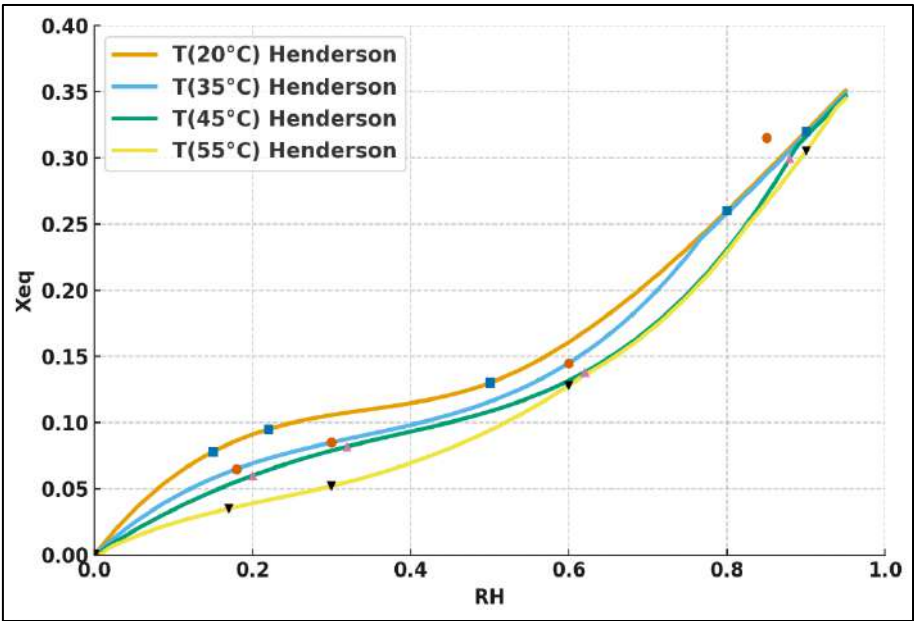


Fig. 09. Sorption isotherms of spearmint (*Mentha spicata*) predicted by the Henderson analytical model

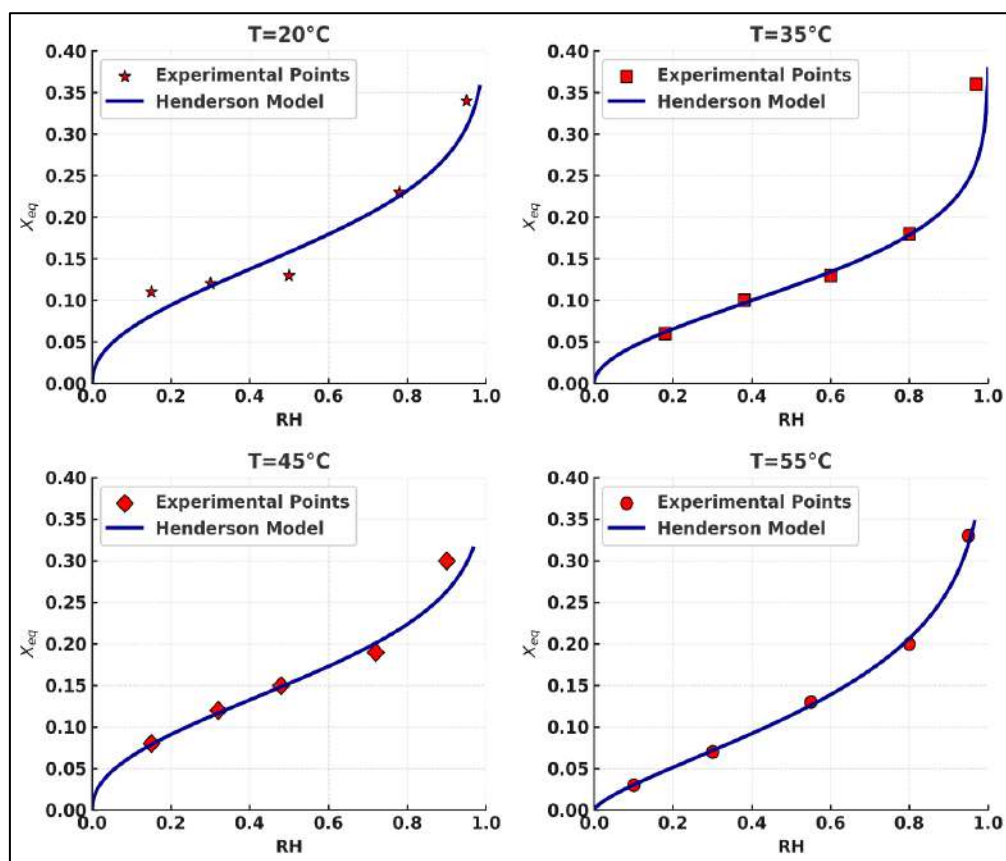


Fig .10. Comparative Analysis of Experimental Sorption Isotherms and Henderson Model Predictions of Mint at Different Temperatures

IV.DISCUSSION

Figure 08 shows the experimental sorption isotherms of mint at different temperatures. The equilibrium moisture content (X_{eq}) decreases as temperature increases for the same relative humidity, reflecting the reduced affinity of the product for water. The curves exhibit the typical sigmoidal shape of hygroscopic agricultural products. This behavior confirms that higher temperatures promote lower water retention, which is important for improving drying efficiency and ensuring safe storage conditions.

For Fig. 9: The Henderson model provides a reliable representation of spearmint sorption isotherms across the studied temperatures. The curves exhibit the characteristic sigmoidal profile, with equilibrium moisture content (X_{eq}) rising sharply at higher relative humidity levels. The observed decline in X_{eq} as temperature increases reflects a reduced hygroscopic affinity, supporting the model's adequacy for describing moisture interactions in mint.

Figure 10 presents a comparative analysis between experimental sorption isotherms of mint and predictions obtained from the Henderson model at four temperatures (20, 35, 45, and 55 °C). The experimental data exhibit the typical sigmoidal trend of food sorption isotherms, with equilibrium moisture content (X_{eq}) increasing non-linearly with relative humidity (RH). A clear temperature effect is observed, where higher temperatures lead to lower X_{eq} , reflecting reduced water affinity of the product.

The Henderson model provides a good agreement with the experimental points across all temperatures, especially at intermediate and high RH values, confirming its suitability for describing the hygroscopic behavior of mint. Minor deviations at low RH highlight possible structural or compositional influences not fully captured by the model. Overall, the strong correlation between

predicted and experimental data validates the use of the Henderson model for practical drying and storage applications of mint.

V.CONCLUSION

The determination of sorption isotherms for mint leaves has proven essential for understanding dehydration mechanisms and defining appropriate storage conditions. Experimental results at four working temperatures (20, 35, 45, and 55 °C) confirmed the inverse relationship between equilibrium moisture content and temperature, particularly at water activities above 0.6. The good agreement with the Henderson model validates its applicability for describing mint hygroscopic behavior. These findings highlight the importance of accurate metrological approaches and provide a reliable basis for optimizing drying and conservation processes. Future work will extend the study to additional temperature ranges and salts to refine the characterization and potentially develop new predictive equations.

NOMENCLATURES

T	Temperature	°C
A_w	Water activity in the product	%
H_r, H_R	Relative air Humidité	%
X_{eq}	Equilibrium water contents	$Kg_{water} / Kg (dry air)$
X	water content of the dry base product	$Kg_{water} / Kg (dry air)$
M_h	Humid mass of the product	Kg
M_s	Dry product mass	Kg
n	Number of layers	
k	Constant which generally depends on the air temperature	

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Fiber-Laser Square Texturing of AA2024-T3: Scale Factor and Scanning Speed Effects on Contact Angle and Surface Profilometry

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Abstract – Laser square texturing of AA2024-T3 was used to tune wetting and topography by varying scale factor (SF = 100, 150, 250 μm) and scanning speed (250, 500, 750 mm s^{-1}). Relative to the untextured reference ($\theta = 92^\circ$), the textured surfaces delivered a broad contact-angle window of $75\text{--}107^\circ$. At SF = 100, θ changed from 94° (250) to 79° (500) and 107° (750); at SF = 150 from 96° (250) to 87° (500) and 85° (750); and at SF = 250 from 78° (250) to 75° (500) and 78° (750). Averaged over speed, increasing SF hydrophilized the alloy (mean θ : 93.3° to 89.3° and 77.0°), while speed showed a non-monotonic, scale-dependent effect: the 500 mm s^{-1} group gave the lowest mean θ (80.3°), and 750 mm s^{-1} enhanced hydrophobicity only at SF = 100. Areal roughness S_a ranged from 1.365 to 2.105 μm : low S_a occurred at SF = 250 with 250–750 mm s^{-1} (1.366–1.365 μm) and at SF = 100 with 500 mm s^{-1} (1.447 μm), whereas the roughest condition was SF = 100 at 750 mm s^{-1} (2.105 μm). Optical images corroborated reduced recast/HAZ and crisper rims at higher speed. Overall, square texturing provides predictable wettability control on AA2024-T3 without chemistry. Future work should broaden the parameter space and assess durability and functional performance.

Keywords – AA2024-T3 Aluminum Alloy, Laser Texturing, Wettability, Contact Angle, Surface Morphology.

I. INTRODUCTION

Aluminum alloy is technologically significant by virtue of its exemplary strength-to-weight ratio. Laser surface texturing can ideally complement its functionality by inducing compressive stresses in a bid to counter stress corrosion cracking, adhesion improvement by way of jointing, and tribological benefit by way of lubrication reservoirs. Its material, however, undergoes a significant thermal input through laser processing, and it can alter its corrosion resistance. The nature of the transformation, negative or positive, heavily depends on the specific alloy composition and the applied treatment parameter utilized [1]. Aluminum alloys are playing a decisive role in aerospace, auto, and marine applications by virtue of their larger strength-to-mass, machinability, and low-price tag. Their use within gear sets, e.g., wind turbine gear sets and car gear set, stimulates weight minimization and efficacy. However, the surfaces are susceptible to wear, corrosion, and icing in extreme conditions and limit widespread usage. The method of surface texturing has been hailed as a promising technique to increase functionality by squarely increasing tribological capability, corrosion immunity, and anti-icing capability by controlled geometries on the micro/nanoscale [2].

Surface texturing, the formation of microscale features on a substrate, has gained universal interest in the tailoring of properties without costly materials. This multifunctional technique enhances hardness, wettability, and wear and friction properties by suppressing wear and friction and enhancing wear

resistance. Its implications broaden into increasing battery efficiency, heat transfer augmentation, and osseointegration induction. Inspired by advances in precise engineering, texturing stands as a powerful tool in engineering surfaces with specific functional demands in a broad range of industries [3]. Qin et al. [4] encapsulates a tough, corrosion-resistant coating by trapping perfluoropolyether oil within a perfluoropolyether oil hydrophobic SiO₂ nanoparticle layer deposited on laser-textured aluminum. Micro-nano composite pores, made up of laser dimples and nanoparticle porosities, form effective oil wells. This arrangement allows effective oil retention, maintaining a water contact angle of $\sim 130^\circ$ after 30 hours of water impact. Tong et al. [5] gives a laser texturing technique in the manufacture of periodic dimple arrays on aluminum alloy, creating case hardening. After stearic acid (STA) treatment, surfaces are characterized by superhydrophobicity, with tunability in wettability by determining dimple sizes. A new fluorescence method visually confirms the air trapping capability, exceeding theoretical estimates by Cassie-Baxter. The air cushion repulsion and improved mechanical stability through surface hardening are confirmed as initial friction hysteresis on the superhydrophobic substrate.

Angell et al. [6] investigates femtosecond laser texturing of AL6061 aluminum alloy in the manufacture of superhydrophobic surfaces. Central composite design and response surface methodology were applied in modeling laser parameter effects (pulse energy, duration, repetition frequency) on morphology and wetting properties of the surface. The optimal parameters ($E = 214 \mu\text{J}$, $t_p = 10 \text{ ps}$, $f_p = 2427 \text{ Hz}$) resulted in a 161° calculated contact angle. Experimental validation reached 168° , demonstrating the efficacy of the method in realizing superhydrophobicity through controlled micro-nano surface structures. Volpe et al. [7] demonstrates that by methodologically optimizing laser texturing, processing time can be reduced by 10% in manufacturing aluminum alloys. Three geometries of lattice groove were taken into account (square, circular, triangular). The results confirm narrow spacing among the grooves results in enhancement in hydrophobicity through air entrapment, and increased spacing emphasizes geometrical dominance. Appropriate choice of texture parameters thus enables efficient production of efficient and cheap superhydrophobic surfaces. Boinovich et al. [8] demonstrates a nanosecond laser texturing and nanoengineered method in transforming aluminum-magnesium alloy into a robust and long-lasting superhydrophobic material. The method generates, in a simultaneous manner, multimodal roughness and modifies the composition in generating nanocavities embedding hydrophobic agents as well as hard oxynitride nano inclusions in the material. The combination of both attendant corresponding topographical and physicochemical transformations generates impressive resistance against pitting corrosion, superheated vapor, abrasive wear, and heat cycles from room temperature and up to liquid nitrogen, without a significant loss in its non-wetting properties.

Xu et al. [9] discusses femtosecond laser texturing in aluminum alloys in producing parallel micro-trenches. The morphology, ascertained by micro-cracks, lumps, and porosity decorated by nanoparticles, was controllable by scanning speed and pulse fluence. The wettability was modifiable by transforming it from hydrophilicity in a broad range of high fluence into hydrophobicity in a narrow range of low fluence. High fluence irradiation was also observed to induce exemplary anti-reflection ability, and reflectance was less than 5% in the 200–1200 nm range. Such multifunctional materials, with adjustable wettability and broad-spectrum anti-reflection, have vast potential in cutting-edge applications in optics and surface engineering. Cholkar et al. [10] employs ultrafast laser texturing in inducing hydrophobicity in aluminum alloy 7075 in ship and aircraft applications. The interface features were ascertained by goniometry, profilometry, SEM, and XPS. The response surface methodology was utilized in the optimization of laser parameters, and water contact angle was optimized. The optimal settings (3W power, 0.08 mm hatch, 3 mm/s speed) produced a 142° water contact angle with certain roughness profiles ($S_a = 0.87 \mu\text{m}$, $S_z = 19.4 \mu\text{m}$), with precise control in interfacial shape and wetting. Divin-Mariotti et al. [11] compares the long-term evolution of femtosecond laser and mechanical knurling texturing on aluminum. Despite comparable initial topographies, their interfacial properties and chemistry significantly differ on long timeframes. Laser-textured interfaces exhibit dynamic wetting properties, which are, by employing the application of XPS, accredited to a dynamic transformation in the C-C/C-O bonded ratio on the extreme interface. Conversely, knurled interfaces are chemically and wettingly stabilized after texturing.

In this paper, AA2024-T3 aluminum alloy was texturized by a fiber laser (1064 nm, 100 W, 100 kHz) under deliberately varied conditions of scale factor (100, 150, 250 μm) and scanning speed (250, 500, 750 mm/s). Such parameter-controlled approach, designed on a nine-level orthogonal array, enables direct exploration into how texture size and energy input dictate contact angle and surface morphology. Unlike earlier work, reliant on chemical modifications or hierarchical architectures, the paper presents an investigation, which uncovers, in isolation, the contribution of laser parameters itself, and thereby elucidates the intrinsic relationship between processing conditions, morphology and wettability. This originality puts into emphasis the capability developed by controlled fiber laser texturing as a practical pathway towards designing the functional surfaces of low-weight structural alloys.

II. MATERIALS AND METHOD

A. Materials

The AA2024-T3 aluminum alloy (Al–Cu–Mg) was selected for this study as a representative aerospace-grade material owing to its high specific strength, excellent fatigue resistance, and good damage tolerance when processed in standard heat-treat conditions (e.g., T3/T351). Chemically, 2024 nominally contains 3.8–4.9 wt% copper (Cu), 1.2–1.8 wt% magnesium (Mg), and 0.3–0.9 wt% manganese (Mn), with minor amounts of iron (Fe), silicon (Si), zinc (Zn), and titanium (Ti), the balance being aluminum (Al). High strength comes essentially through precipitation of the θ' (Al_2Cu) and S' (Al_2CuMg) phases formed during the solution treatment and aging process, and offers a good strength-to-weight ratio that is central to aircraft construction. Though by nature it offers lower inherent corrosion resistance than the 5xxx/6xxx alloys and fusion weldability is limited, the handicaps are generally balanced in service by Alclad coverage, anodize/primer systems, and the use of mechanical fastening or friction-stir joining. The aggregate of the properties has established AA2024-T3 as a workhorse alloy in aircraft construction and widely used in fuselage skins, wing and rib articles, and other significant airframe fits requiring high strength and fatigue life.

B. Laser Surface Texturing

In this study, a fiber laser system was used to create micro-scale square textures on an aluminum surface. The experimental setup is shown schematically in Figure 1. The system consists of a computer-controlled fiber laser and control unit, a galvanometer-based laser scanning head, a theta lens, and an elevation table on which the sample surface is positioned. The fiber laser system is a source operating at a wavelength of 1064 nm, with a maximum output power of 100 W, capable of operating at a repetition frequency of 100 kHz in pulsed mode. The laser beam is focused onto the sample surface via a galvanometer-controlled scanning head, and a homogeneous energy distribution is achieved by keeping the focal spot size constant with the aid of a theta lens.

In experimental studies, square-shaped microtextures were created on the aluminum sample surface. Three different scales were selected for the textures, with edge lengths set at 100 μm , 150 μm , and 250 μm , respectively (Table 1). Among the laser parameters, the power (100 W) and frequency (100 kHz) were kept constant, and the scanning speeds were varied to obtain different trace depths. In this context, the laser scanning speeds were selected as 250 mm/s, 500 mm/s, and 750 mm/s, thus investigating the effects of different energy densities on the surface morphology. A nine-level orthogonal experimental design was applied for experimental planning in this study. In this design, combinations of three different scales (100, 150, 250 μm) and three different scanning speeds (250, 500, 750 mm/s) were tested, creating a total of nine separate experimental sets. For each parameter set, the resulting groove depths from laser processing were measured, and the effects of laser parameters on surface topography were compared. This methodology enabled the systematic evaluation of the texture morphology created by laser parameters on the surface and aimed to determine the most suitable laser scanning conditions.

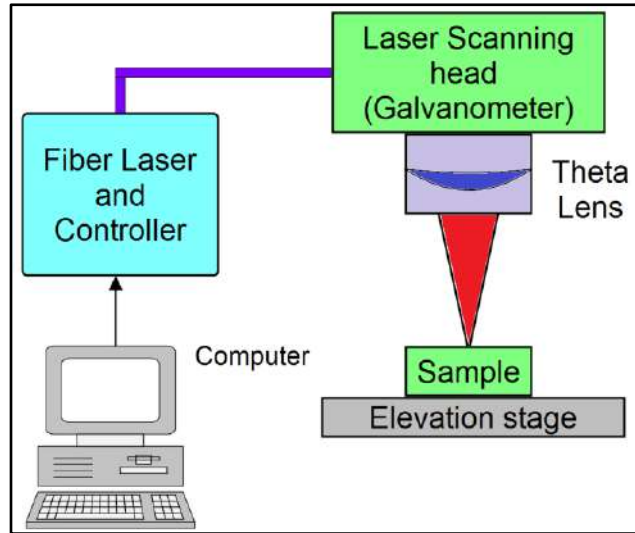


Fig. 1 Surface texturing experimental setup using a fibre laser system

C. Contact Angle Measurement of Laser Surface Textured AA2024-T3 alloy

The surface morphology of fiber-laser square microtextured AA2024-T3 was examined using an Evident-Olympus BX53 MRF optical microscope, whose high-NA, high-resolution, multi-magnification optics enabled scale-aware imaging and quantitative assessment of feature geometry and the local microstructural response. Across the imposed variations in scale factor and scan speed, we systematically evaluated surface topography, grain-boundary expression, and spatial roughness heterogeneity by surveying fields at successive magnifications. Image analysis extracted feature diameter, pitch, circularity, and rim continuity while also identifying laser-induced artifacts such as recast rims, spatter/ejected droplets, and micro-fissures. In AA2024-T3, the intrinsic phase contrast between the matrix and Cu-rich intermetallics enhanced delineation of microtexture perimeters and adjacent heat-affected zones. The resulting micrographs exhibit clear parameter-dependent signatures that provide a robust basis for correlating morphology with wettability (contact angle) and profilometric roughness.



Fig. 2 Contact angle measurement device set-up for laser surface square-textured AA2024-T3 alloy

D. Optical Microscope Surface Characterization of Laser Surface Textured AA2024-T3 alloy

The surface morphology of fiber-laser square microtextured AA2024-T3 was examined using an Evident-Olympus BX53 MRF optical microscope, whose high-NA, high-resolution, multi-magnification optics enabled scale-aware imaging and quantitative assessment of feature geometry and the local microstructural response. Across the imposed variations in scale factor and scan speed, we systematically

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E. Non-contact Laser Profilometer Roughness Analysis

Surface topography was measured using a Nanovea PS-50 optical profilometer equipped with a chromatic confocal (CHR) sensor. For each specimen, a 3.0×3.0 mm area was scanned with the X-axis as the fast scan and the Y-axis as the index, using a lateral step of $5.00 \mu\text{m}$ in both directions (600×600 points; 3.6×10^5 height samples) at a scan velocity of 5.00 mm s^{-1} and a CHR acquisition rate of 1000 Hz, as illustrated in the instrument screenshot. Height maps were leveled by least-squares plane subtraction, de-spiked to remove outliers, and analyzed in accordance with ISO 25178 areal surface-texture procedures. The areal arithmetic mean height, S_a , was adopted as the primary roughness metric for comparison. The system prior to collecting the data had already been calibrated with a traceable step-height standard and the readings taken at the same optical settings to be repeatable.

III. RESULTS AND DISCUSSION

A. Contact Angle Measurements

In Table 1, the untextured AA2024-T3 reference shows a contact angle of 92° , while square texturing enables tuning between more hydrophobic and more hydrophilic states depending on scale factor and scanning speed. At the smallest scale factor (100), the contact angle spans 94° (speed = 250) to 79° ; (500) to 107° (750), with the 750-speed condition giving the study's maximum (107° , $+15^\circ$ or $+16.3\%$ vs. reference). At scale factor 150, wettability shifts downward with speed; 96° (250), 87° (500), and 85° (750); all nearer to or below the reference. The largest scale factor (250) consistently yields the lowest angles; 78° (250), 75° (500), and 78° (750); with the minimum at 75° (-17° or -18.5% vs. reference). Averaged across speeds, increasing scale factor reduces the contact angle from 93.3° (SF 100) to 89.3° (SF 150) to 77.0° (SF 250), indicating a clear scale-driven hydrophilization. Speed effects are condition-dependent: the 500-speed group produces the lowest mean angle (80.3°) across scales, whereas 750 speed enhances hydrophobicity only at the smallest scale factor (107° at SF 100). Overall, the square texture–parameter interaction is non-monotonic with speed but monotonic with scale on average, delivering a tunable range of $75\text{--}107^\circ$ (-18.5% to $+16.3\%$ relative to the reference).

Table 1. Contact angle measurement comparisons of AA2024-T3 aluminum alloy square texture with various scale factors and laser scanning speed

Exp. no	Texture	Scale Factor	Speed	Contact Angle
1	Square	100	250	94
2	Square	100	500	79
3	Square	100	750	107
4	Square	150	250	96
5	Square	150	500	87
6	Square	150	750	85
7	Square	250	250	78
8	Square	250	500	75
9	Square	250	750	78
Reference				92

Figure 3 shows sessile-drop morphologies on square-textured AA2024-T3 for all nine parameter sets, progressing from Figure 3(a) to Figure 3(i). In (a) (scale factor, SF=100; speed=250 mm s⁻¹), the droplet is only slightly taller than the baseline, giving 94°, i.e., marginally more hydrophobic than the untextured reference (92°). In Figure 3(b) (SF=100; 500), the droplet spreads markedly (79°), evidencing hydrophilization relative to Figure 3(a). In Figure 3(c) (SF=100; 750), the droplet becomes distinctly spherical (107°), the most hydrophobic state in the series. Increasing the scale to SF=150 shifts wettability downward across speeds: Figure 3(d) (250) remains mildly hydrophobic at 96°, while Figure 3(e) (500) and Figure 3(f) (750) flatten progressively to 87° and 85°, respectively. At the largest scale (SF=250), all droplets are hydrophilic and visually flatter; Figure 3(g) (250) and Figure 3(i) (750) are both 78°, and Figure 3(h) (500) reaches the minimum of 75°. Collectively, the images corroborate two trends: Figure 3(i) on average, larger scale factors reduce the contact angle (from predominantly >90° at SF=100 to 75–78° at SF=250), and scanning speed has a non-monotonic influence at the smallest scale (hydrophilic at 500, hydrophobic at 750) but exerts a weaker, mostly decreasing effect at SF=150 and is nearly negligible at SF=250. Thus, square texturing enables tunable wetting from hydrophilic ($\theta = 75\text{--}79^\circ$) to hydrophobic ($\theta = 94\text{--}107^\circ$) by co-adjusting scale factor and speed.

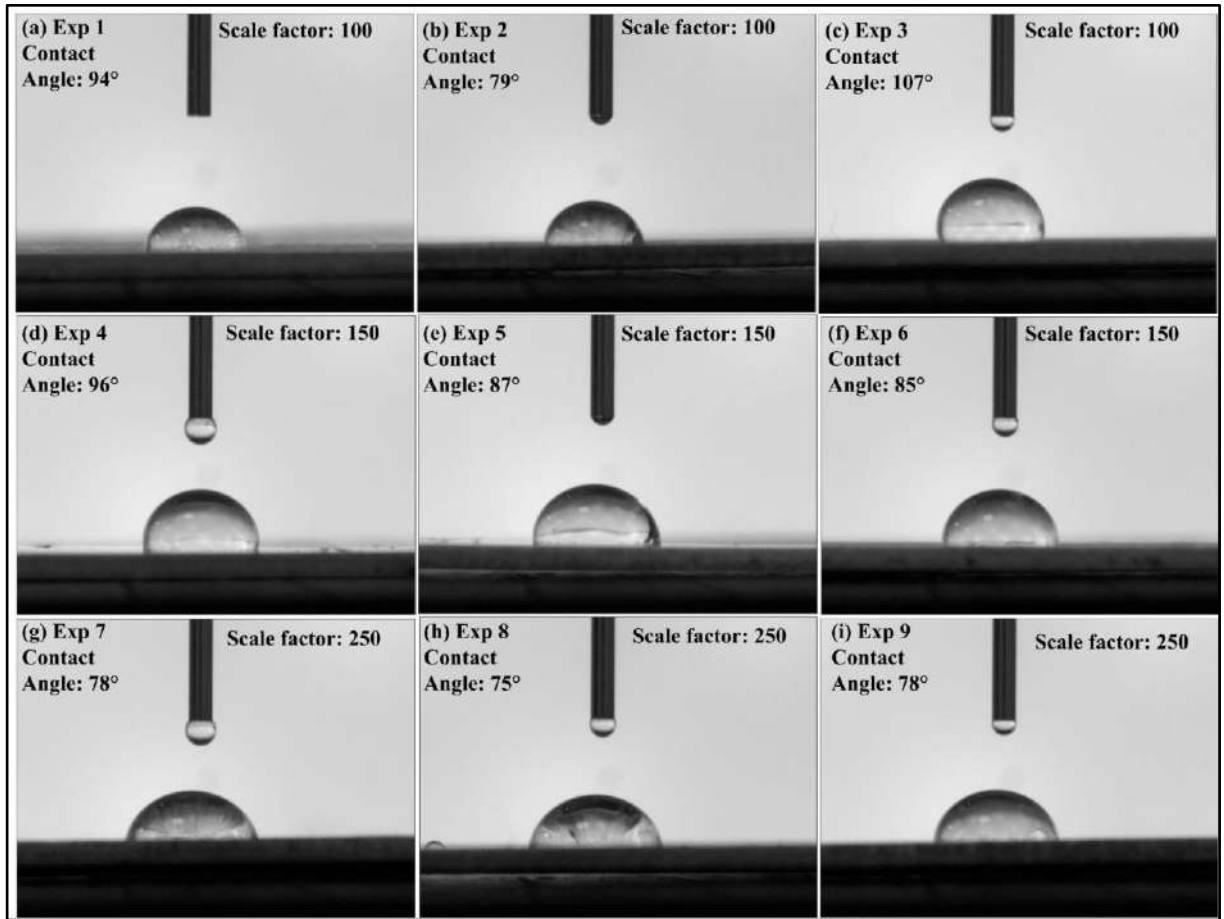


Fig. 3 Contact angle measurement of AA2024-T3 alloy square-textured surfaces (a) exp-1, (b) exp-2, (c) exp-3, (d) exp-4, (e) exp-5, (f) exp-6, (g) exp-7, (h) exp-8, (i) exp-9

B. Laser Surface Texture Morphologies

Figure 4 compares the square-textured morphologies on AA2024-T3 as a function of scale factor (SF) and laser scanning speed. At SF=100, low speed provides heat input and recast; Figure 4(a) 250 mm s⁻¹ has thick resolidified rims, dark burn halos, and partially stitched neighboring squares; Figure 4(b) 500 mm s⁻¹ minimizes heat-affected zone (HAZ) and spatter, generating less ellipsoidal cells with more narrow rims; Figure 4(c) 750 mm s⁻¹ generates the narrowest shape in this size with sharp boundaries and negligible peripheral burn, which implies efficient ablation and low heat accumulation. Increasing to SF=150 enlarges the unit cell and changes heat-sink/overlap conditions; Figure 4(d) 250 mm s⁻¹ again

exhibits pronounced over-melt and corner bulging; Figure 4(e) 500 mm s⁻¹ yields well-defined sidewalls and more consistent aperture area; Figure 4(f) 750 mm s⁻¹ minimizes burn but also shows locally shallower texturing, suggesting borderline energy density at this larger pitch. At SF=250, the interaction of large feature size and heat input is most evident, Figure 4(g) 250 mm s⁻¹ displays the heaviest recast ridges and HAZ with occasional spatter deposits; Figure 4(h) 500 mm s⁻¹ sharpens edges and reduces halo width while preserving feature fidelity; Figure 4(i) 750 mm s⁻¹ provides the cleanest contours at this scale with the least discoloration and debris, though the rims appear thinner, implying reduced melt volume. Overall, increasing speed systematically mitigates surface burn and recast, while increasing scale factor thickens rims and amplifies HAZ at low speeds; the best geometric fidelity (crisp, square apertures with minimal burn) is obtained at higher speeds, particularly for larger SFs.

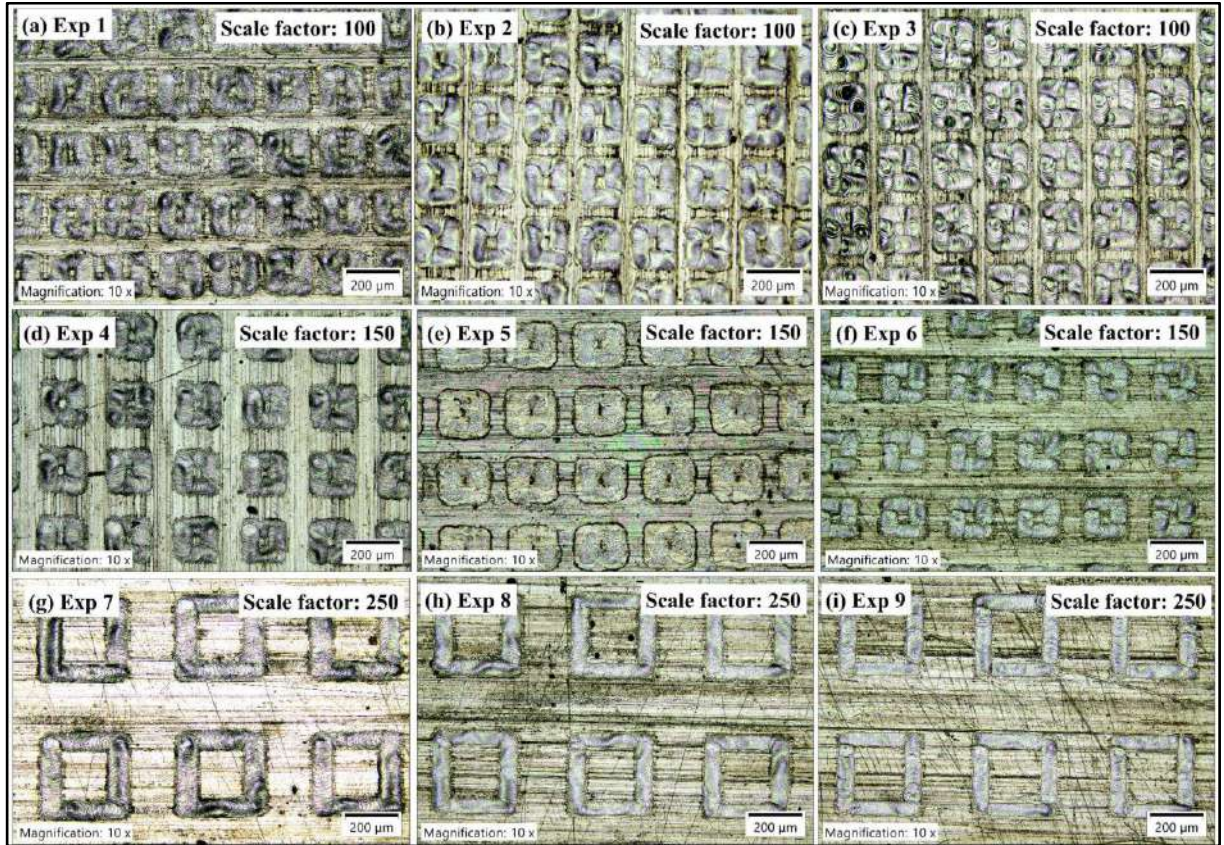


Fig. 4 Optic microscope surface images of laser textured AA2024-T3 alloy square-textured surfaces (a) exp-1, (b) exp-2, (c) exp-3, (d) exp-4, (e) exp-5, (f) exp-6, (g) exp-7, (h) exp-8, (i) exp-9

C. Surface Texture Roughness Analysis

Figure 5 summarizes the 3D areal roughness (S_a) and morphology of the square-textured AA2024-T3 surfaces across all parameter sets. At SF=100, Figure 5(a) 250 mm s⁻¹ yields $S_a=2.013 \mu\text{m}$ with prominent rim peaks and scan-parallel striations; Figure 5(b) increasing to 500 mm s⁻¹ smooths the field ($S_a=1.447 \mu\text{m}$) and produces the most uniform geometry at this scale; Figure 5(c) 750 mm s⁻¹ increases roughness to the series maximum ($S_a=2.105 \mu\text{m}$) with fine ablative pitting and sharper rim asperities. At SF=150, Figure 5(d) 250 mm s⁻¹ is comparatively smooth ($S_a=1.491 \mu\text{m}$) and the squares are well registered; Figure 5(e) 500 mm s⁻¹ roughens the hatch bands ($S_a=1.854 \mu\text{m}$); Figure 5(f) 750 mm s⁻¹ remains high ($S_a=1.821 \mu\text{m}$) with bead-like recast islands superposed on periodic striations. At SF=250, Figure 5(g) 250 mm s⁻¹ gives one of the lowest S_a values ($1.366 \mu\text{m}$) with broad plateaus between features; Figure 5(h) 500 mm s⁻¹ produces a rough outlier ($S_a=1.950 \mu\text{m}$) with thickened rims and re-deposition; Figure 5(i) 750 mm s⁻¹ returns to a low $S_a=1.365 \mu\text{m}$ and the cleanest, most regular squares at this scale. Overall, roughness depends non-monotonically on speed at fixed scale (e.g., smoothest at 500 mm s⁻¹ for SF=100, at 250 mm s⁻¹ for SF=150, and at 250/750 mm s⁻¹ for SF=250), while increasing the

scale factor generally improves texture regularity and lowers Sa when the energy density is either sufficiently low (high speed) or efficiently dissipated (large pitch). The trends indicate competing roughening mechanisms; over-melt/recast at low speeds and fine ablative pitting/striations at very high speeds for tight pitch; leading to scale- and speed-specific optima for geometric fidelity and surface smoothness.

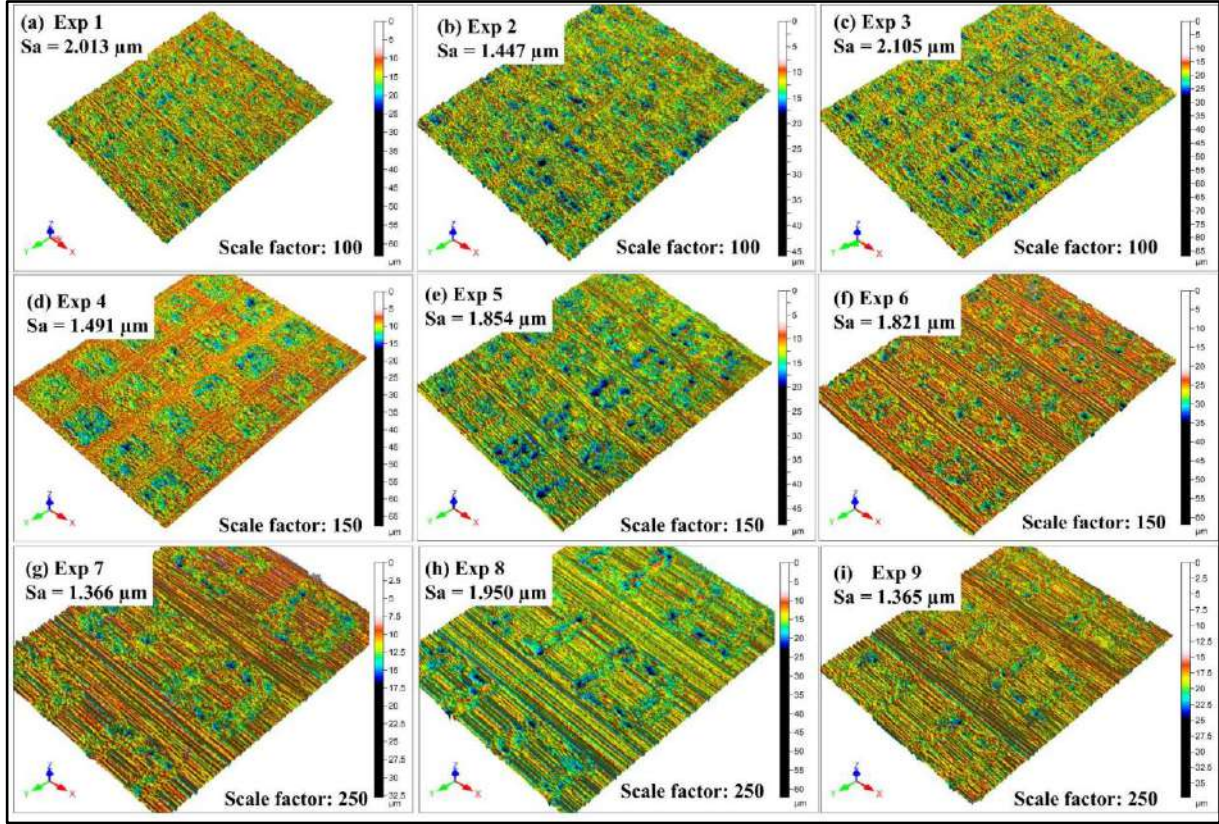


Fig. 5 Surface roughness (Sa) 3D images of laser textured AA2024-T3 alloy square-textured surfaces (a) exp-1, (b) exp-2, (c) exp-3, (d) exp-4, (e) exp-5, (f) exp-6, (g) exp-7, (h) exp-8, (i) exp-9

IV. CONCLUSION

In this study, fibre-laser square texturing of AA2024-T3 (scale factors = 100/150/250 μm ; scanning speeds = 250/500/750 mm s^{-1} ; constant 100 W, 100 kHz) enabled controlled tuning of wettability and topography without chemical modification. Relative to the untextured reference (92°), the contact angle was adjustable from distinctly hydrophilic at 75° (SF = 250, 500 mm s^{-1} ; -18.5%) to maximally hydrophobic at 107° (SF = 100, 750 mm s^{-1} ; $+16.3\%$), with a clear scale-driven hydrophilization on average (mean θ : $93.3^\circ \rightarrow 89.3^\circ \rightarrow 77.0^\circ$ for SF = 100, 150, 250 μm). Speed effects were non-monotonic and scale-dependent: 500 mm s^{-1} produced the lowest mean angle across scales (80.3°), whereas 750 mm s^{-1} increased hydrophobicity only at the smallest scale. Areal roughness Sa spanned 1.365–2.105 μm , with low-Sa, high-fidelity squares achieved at SF = 250 with 250–750 mm s^{-1} and the highest Sa at SF = 100, 750 mm s^{-1} , consistent with the observed transition from recast/HAZ-dominated rims at low speed to sharper, cleaner apertures at high speed. These results demonstrate that wettability on AA2024-T3 can be predictably engineered through the coupled choice of texture scale and scan speed, delivering a practical tunability window of $75\text{--}107^\circ$. Limitations include the single alloy, a fixed laser power/frequency, and short-term characterization (contact angle and 3D profilometry only); future work should map the full energy-density space, link θ to quantitative feature geometry (depth/rim height), and evaluate durability, corrosion, and tribological responses under service-relevant environments.

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Parametric Study of Fiber-Laser Circular Microtextures on AA2024-T3: Influence of Scale Factor and Scan Speed on Wettability and Roughness

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Abstract – AA2024-T3 plates were circularly microtextured using a 1064-nm pulsed fiber laser (100 W, 100 kHz) to examine how scale factor (SF = 100, 150, 250 μm) and scan speed (250, 500, 750 mm s^{-1}) tune wettability and roughness. Sessile-drop tests with $5 \pm 0.5 \mu\text{L}$ DI water and ISO 25178 profilometry (Nanovea PS-50, $3 \times 3 \text{ mm}$, 5 μm step) quantified responses. Contact angle spanned $69\text{--}96^\circ$ relative to the 92° untextured reference. For fixed speed, SF showed a non-monotonic trend: at 250 mm s^{-1} , θ decreased from 96° (SF100) to 77° (SF150), then increased to 87° (SF250); the same pattern occurred at 500 mm s^{-1} (87 to 70 to 77°) and 750 mm s^{-1} (85 to 69 to 86°). The most hydrophilic state was 69° at SF150/750 mm s^{-1} (-23° vs reference). Areal roughness S_a ranged from $0.711 \mu\text{m}$ (SF250/750 mm s^{-1}) to $3.267 \mu\text{m}$ (SF100/750 mm s^{-1}). Optical microscopy revealed parameter-dependent rim continuity, spatter, and HAZ width; SF150/750 mm s^{-1} produced the most homogeneous rings, whereas SF250/750 mm s^{-1} generated shallow, partially discontinuous rims. Correlating S_a and θ indicates that topology plus rim integrity, rather than roughness amplitude alone, governs wetting-enabling targeted tuning of AA2024-T3 surfaces for fluid-contact applications.

Keywords – AA2024-T3 Aluminum Alloy, Laser Texturing, Wettability, Contact Angle, Surface Morphology.

I. INTRODUCTION

Aluminum alloys are universal in industries from automotive engineering up through aerospace and marine engineering. The primary challenge remains designing their surface properties specific for individual extreme environments, e.g., corrosion resistance in ship engineering or anti-icing in aircraft engineering. The implementation of a superhydrophobic state is a promising means of acquisition of multifunctional properties. However, a primary challenge remains in the engineering of mechanically durable and electrochemically durable under hostile in-use conditions coatings [1]. Laser texturing, based on the lotus leaf, has been applied in various materials, including alloys, in order to infuse hydrophobicity and self-cleaning ability by either depositing low-energy chemical layers as fluoroalkylsilane, or creating micro/nanoscale roughness, or both in combination. Industrially dominant chemical processes, however, tend to generate biologically unacceptable wastes and wear-resistant coatings necessitating residue disposal and handling hazardous reactants in a careful and shielded manner [2]. The wettability of a surface is governed by the conditions on a surface, a relationship texturing techniques exploit by means of controlling wetting and spreading characteristics. Predominant processing routes comprise laser direct writing, laser interference, plasma, and mechanical processes. Numerous research works confirmed that designed-in surface geometries are efficient in modulating substrate droplet dynamics in a desired manner, thereby commanding customized wetting functionality [3]. Laser texturing is a most potential

method in generating metallic and alloy substrate material having a superhydrophobic and self-cleaning ability. This method, in a simultaneous fashion, augments important material properties such as corrosion resistance. An understanding in a quantitative basis regarding the interlocked relationship prevailing among resulting chemistry on a substrate material and designed-in micro/nanoscale geometries is a prerequisite in advancing the field [4]. Laser texturing radically alters the functional characteristics in metals by modifying their chemistry and morphology. Although development in a static and dynamic wetting on a material is modeled, that on a smaller quantity of liquids remains scantily explored. The prevailing molecular-kinetic and hydrodynamic theories characterize contact line motion by different energy dissipation mechanisms in different formulations. The results, however, on application on laser-textured material are obscure, since a sharp dependence on a parameter in the former on a heterogeneity and a wettability on a surface remains unresolved in research [5].

The work by Kuznetsov et al. [6] investigates nanosecond laser-textured aluminum-magnesium alloy droplet dynamics of distilled water. Whereas prior work considers targets on wettability, corrosion, and wear, the researchers establish that nanosecond laser texturing creates anisotropic and ordered surfaces. The textures exhibit characteristic wetting modes, time-dependent inversion in wettability, and dynamic angle hysteresis. The hysteresis increases on the ordered textures towards an initial uneven variation in the unevenness in surface wettability, which decreases as the property difference in laser-processed and unprocessed segments decreases as time advances. Laser marking was utilized in creating a superhydrophobic aluminum alloy material, endowing it with a microstructure of irregular pits and protrusions. SEM characterization and contact angle measurement demonstrated exemplary superhydrophobicity ($CA=156.4^\circ$) and hydrophobicity ($CA=147.8^\circ$). Laser-induced anisotropy created different texture scales with characteristic wettability and adhesion. The scalable method provides customized functionality through potential applications in fluid transfer, anti-fouling, and oil transport, thereby significantly broadening the application range in industry on aluminum alloys [7]. Xu et al. [8] investigates a laser surface pre-treatment on aluminium 7075-T6 alloy in a bid to enhance the alloy's wettability and adhesive bonding strength. The optimal parameters were 30 W, 1.2 m/s, and 8 kHz, producing a 17° water contact angle, attributed to an increase in roughness and cavity depth. This pre-heating increased adhesion strength by 45% up to 8.5 MPa, comparable with chemical treatments, and stimulates robust interfacial adhesion. FTIR analysis confirmed effective adhesives' curing with laser pre-heating. Laser pre-heating is a promising, environmental-friendly method as an alternative in producing bonded joints with atraumatically high strengths. Superhydrophobicity, enabled through roughness and low surface energy, gives revolutionary applications. Laser texturing presents a precise, flexible technique in creating the needed roughness on metals without chemical processes. The emphasis by Tong and Xiong [9] continues on direct laser texturing, discussing parameter impact on the geometry and forcing the wetting shift through from a hydrophilic into a superhydrophobic nature. Definitive parameters control laser-textured metals' transformation in wetting into a superhydrophobic phase. First, laser parameters in energy, speed, and repetition rate control geometry on the metallic substrate and its ability in absorbing airborne organics, forcing through the transformation through hydrophilicity. Secondly, through the use of a line-scanning resolution technique in a spot diameter lower than $50\text{ }\mu\text{m}$, it strongly forces through the transformation into a hydrophilicity domain. Thirdly, storage within an argon atmosphere or in vacuum-annealing treatment strongly enhances the superhydrophobicity. Misyura et al. [10] experimentally investigates laser-textured microstructures on an aluminum alloy and their effect on free convection and water droplet evaporation. Compared with an unwrapped substrate, various textures were compared by Micro Particle Image Velocimetry (PIV) and by chemical characterization. The rate of evaporation is determined by competing issues: wetted diameter, drops' height, and thermocapillary and microstructure-driven convection. Textures with $50\text{--}100\text{ }\mu\text{m}$ crater diameter most significantly intensified convection and evaporation. Samanta et al. [11] demonstrates a systematic approach to achieve extreme wettability on laser-textured aluminum alloy by designing chemistry on the surface, a parameter less mature than surface topology. Micro trenches were created by nanosecond laser texturing, followed by chemical immersion modification by introducing specific functional groups. Fluorinated groups yielded superhydrophobicity / superoleophobicity, and polar nitrile groups yielded superhydrophilicity and superoleophilicity. Co-anchoring by fluorinated and carboxylate groups achieved the mutually

contradictory existing property of superoleophobicity and superhydrophilicity, and allowed selective repulsion and attraction by liquids.

In this study, AA2024-T3 aluminum alloy was circularly microtextured using a fiber laser system (1064 nm wavelength, 100 W power, 100 kHz frequency) under systematically varied scale factors of 100, 150, and 250 μm and scanning speeds of 250, 500, and 750 mm/s. A nine-level orthogonal design was implemented to examine how the interplay of texture size and line energy density governs wettability and surface roughness. Unlike many prior works that focus predominantly on achieving superhydrophobicity through hierarchical textures, chemical coatings, or hybrid treatments, the present work isolates the direct effects of geometrical scaling and scanning speed on AA2024-T3 without additional surface modification. By correlating contact angle behavior with topographic metrics such as S_a roughness and rim continuity, this study offers new insight into the mechanisms by which fiber-laser parameters can be tuned to control wetting states. This approach provides a more fundamental and application-relevant understanding of parameter-driven texturing, highlighting its originality and potential for environmentally sustainable tailoring of functional surfaces in aerospace-grade aluminum alloys.

II. MATERIALS AND METHOD

A. Material

The AA2024-T3 aluminum alloy (Al–Cu–Mg) was selected for this study as a representative aerospace-grade material owing to its high specific strength, excellent fatigue resistance, and good damage tolerance when processed in standard heat-treat conditions (e.g., T3/T351). Chemically, 2024 nominally contains 3.8–4.9 wt% copper (Cu), 1.2–1.8 wt% magnesium (Mg), and 0.3–0.9 wt% manganese (Mn), with minor amounts of iron (Fe), silicon (Si), zinc (Zn), and titanium (Ti), the balance being aluminum (Al). High strength comes essentially through precipitation of the θ' (Al_2Cu) and S' (Al_2CuMg) phases formed during the solution treatment and aging process, and offers a good strength-to-weight ratio that is central to aircraft construction. Though by nature it offers lower inherent corrosion resistance than the 5xxx/6xxx alloys and fusion weldability is limited, the handicaps are generally balanced in service by Alclad coverage, anodize/primer systems, and the use of mechanical fastening or friction-stir joining. The aggregate of the properties has established AA2024-T3 as a workhorse alloy in aircraft construction and widely used in fuselage skins, wing and rib articles, and other significant airframe fits requiring high strength and fatigue life.

B. Laser Surface Texturing

In this study, a fiber laser system was used to create micro-scale textures on an AA2024-T3 surface. The experimental setup is shown schematically in Figure 1. The system consists of a computer-controlled fiber laser and control unit, a galvanometer-based laser scanning head, a theta lens, and an elevation table on which the sample surface is positioned. The fiber laser system is a source operating at a wavelength of 1064 nm, with a maximum output power of 100 W, capable of operating at a repetition frequency of 100 kHz in pulsed mode. The laser beam is focused onto the sample surface via a galvanometer-controlled scanning head, and a homogeneous energy distribution is achieved by keeping the focal spot size constant with the aid of a theta lens.

In experimental study, microtextures in a round shape were created on the AA2024-T3 substrate material. The three different scales were selected in the case of textures, and the edge widths were kept as 100 μm , 150 μm , and 250 μm , respectively. Out of the laser parameters, the power was kept as 100 W and the frequency was kept as 100 kHz, and different trace densities were obtained by changing the scanning speeds and obtaining different trace depths by varying the scanning speeds as provided in Table 1. In this context, laser scanning speeds were selected as 250 mm/s, 500 mm/s, and 750 mm/s, and thus considering the effect on the morphology on the surface by different energy densities. Experimental design was performed by utilizing a nine-level orthogonal experimental design in this study. The combinations between three different scales and three different scanning speeds were evaluated in this experimental design, and a total nine different experimental sets were developed. The groove depth generated by laser processing was calculated and compared among all the parameter sets, and different

laser parameter-generated effects on the topography on the surface were taken into account. This was a systematic approach and enabled considering different texture morphology developed on the surface by laser parameters and determining the most suitable laser scanning conditions.

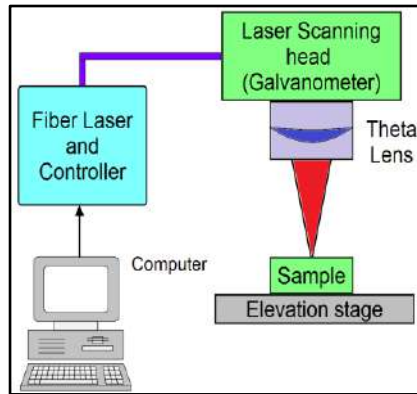


Fig. 1 Surface texturing experimental setup using a fiber laser system

C. Contact Angle Measurement of Laser Surface Textured AA2024-T3 alloy

Wettability of the AA2024-T3 aluminum alloy patterned with circular fiber-laser microtextures was quantified by the sessile-drop method using the in-house contact angle measurement system developed in the Wear Laboratory of the Faculty of Aeronautics and Astronautics, Kocaeli University (Figure 2). Deionized water droplets ($5 \pm 0.5 \mu\text{L}$) were dispensed with a calibrated high-precision micropipette and gently deposited at predefined locations within the textured fields and on untextured reference areas. Immediately upon deposition, the three-phase contact line was recorded by the system's integrated high-resolution camera, and static contact angles were computed by an image-processing algorithm based on Young–Laplace fitting. Measurements were carried out under controlled laboratory conditions ($23 \pm 1^\circ\text{C}$; 40–50% RH). For each scale factor and scan speed condition of processing, at least five independent measurements at non-overlapping locations were taken and averaged to yield statistically robust values. Specimens were ultrasonically cleaned in ethanol before testing, then washed in deionized water and dried by oil-free compressed air to remove adventitious contaminants. The resulting contact angle data permit quantitative assessment of how the surface energy and wettability of the AA2024-T3 surface are changed by the scale of the circular microtexture and the scan speed.



Fig. 2 Contact angle measurement device set-up for laser surface square-textured AA2024-T3 alloy

D. Optical Microscope Surface Characterization of Laser Surface Textured AA2024-T3 alloy

The surface morphology of fiber-laser circularly microtextured AA2024-T3 was examined using an Evident-Olympus BX53 MRF optical microscope, whose high-NA, high-resolution, multi-magnification optics enabled scale-aware imaging and quantitative assessment of feature geometry and the local

microstructural response. Across the imposed variations in scale factor and scan speed, we systematically evaluated surface topography, grain-boundary expression, and spatial roughness heterogeneity by surveying fields at successive magnifications. Image analysis extracted feature diameter, pitch, circularity, and rim continuity while also identifying laser-induced artifacts such as recast rims, spatter/ejected droplets, and micro-fissures. In AA2024-T3, the intrinsic phase contrast between the matrix and Cu-rich intermetallics enhanced delineation of microtexture perimeters and adjacent heat-affected zones. The resulting micrographs exhibit clear parameter-dependent signatures that provide a robust basis for correlating morphology with wettability (contact angle) and profilometric roughness.

E. Non-contact Laser Profilometer Roughness Analysis

Surface topography was measured using a Nanovea PS-50 optical profilometer equipped with a chromatic confocal (CHR) sensor. For each specimen, a 3.0×3.0 mm area was scanned with the X-axis as the fast scan and the Y-axis as the index, using a lateral step of $5.00 \mu\text{m}$ in both directions (600×600 points; 3.6×10^5 height samples) at a scan velocity of 5.00 mm s^{-1} and a CHR acquisition rate of 1000 Hz , as illustrated in the instrument screenshot. Height maps were leveled by least-squares plane subtraction, de-spiked to remove outliers, and analyzed in accordance with ISO 25178 areal surface-texture procedures. The areal arithmetic mean height, S_a , was adopted as the primary roughness metric for comparison. The system prior to collecting the data had already been calibrated with a traceable step-height standard and the readings taken at the same optical settings to be repeatable.

III. RESULTS AND DISCUSSION

A. Contact Angle Measurements

Table 1 shows that circular microtexturing tunes AA2024-T3 wettability over a wide range ($69\text{--}96^\circ$) relative to the untextured reference (92°). At a fixed scan speed, the scale factor has a non-monotonic effect: at 250 mm s^{-1} the contact angle drops from 96° (SF = $100 \mu\text{m}$) to 77° (SF = $150 \mu\text{m}$, -19°), then rises to 87° (SF = $250 \mu\text{m}$, $+10^\circ$ vs $150 \mu\text{m}$). The same trend holds at 500 mm s^{-1} (87° ; 70° ; 77°) and 750 mm s^{-1} (85° ; 69° ; 86°), identifying SF = $150 \mu\text{m}$ as the most wetting (hydrophilic) geometry across speeds, with the global minimum 69° at $150 \mu\text{m}/750 \text{ mm s}^{-1}$ (-23° vs reference). At a fixed scale, increasing scan speed generally lowers the contact angle for SF = $100 \mu\text{m}$ (96° ; 87° ; 85° , -11° from 250 to 750 mm s^{-1}) and SF = $150 \mu\text{m}$ (77° ; 70° ; 69° , -8°), consistent with reduced line energy increasing liquid–solid contact in a Wenzel-leaning state. In contrast, SF = $250 \mu\text{m}$ exhibits a U-shaped speed response (87° ; 77° ; 86°), suggesting a competition between decreased energy input at intermediate speed (500 mm s^{-1}), which maximizes wetting, and feature/rim morphologies at the highest speed (750 mm s^{-1}) that partially re-establish air entrapment and pinning, thereby recovering hydrophobicity. Overall, microtexture scale governs the baseline wetting regime ($150 \mu\text{m}$ most hydrophilic), while scan speed provides a secondary but systematic knob; monotonic for smaller scales and non-monotonic for the largest scale; allowing targeted tuning around the 92° reference.

Table 1. Contact angle measurement comparisons of AA2024-T3 aluminum alloy circular texture with various scale factors and laser scanning speed

Exp no	Texture	Scale Factor	Speed	Contact Angle
28	Circle	100	250	96
29	Circle	100	500	87
30	Circle	100	750	85
31	Circle	150	250	77
32	Circle	150	500	70
33	Circle	150	750	69
34	Circle	250	250	87
35	Circle	250	500	77
36	Circle	250	750	86
Reference				92

Figure 3 compiles sessile-drop images for nine (scale factor, scan speed) combinations on AA2024-T3 and reveals a tunable wetting window of 69–96° relative to the 92° untextured reference. In Figure 3(a), SF = 100 μm at 250 mm s^{-1} yields a tall spherical cap ($\theta = 96^\circ$), whereas at the same scale factor Figure 3(b) and Figure 3(c) show progressively flatter drops as speed increases to 500 and 750 mm s^{-1} ($\theta = 87^\circ$ and 85° , respectively), consistent with reduced line energy producing smoother rims, diminished pinning, and greater solid–liquid contact. At SF = 150 μm , Figure 3(d), Figure 3(e), and Figure 3(f) display a stronger hydrophilic shift with $\theta = 77^\circ$, 70° , and a global minimum of 69° at 750 mm s^{-1} , indicating efficient liquid infiltration into the circular microtextures and minimal contact-line hysteresis. For the coarsest scale, SF = 250 μm , the speed response becomes non-monotonic; Figure 3(g) at 250 mm s^{-1} gives $\theta = 87^\circ$, Figure 3(h) at 500 mm s^{-1} drops to 77° , and Figure 3(i) at 750 mm s^{-1} recovers to 86° , suggesting that intermediate speed optimizes feature fidelity and reduces recast buildup, while the highest speed may generate shallower or discontinuous rims that reintroduce partial air entrapment. Overall, the images substantiate that scale factor sets the baseline wetting regime; with SF = 150 μm most hydrophilic across speeds; whereas scan speed acts as a secondary control, monotonic for the 100 and 150 μm textures but U-shaped for 250 μm .

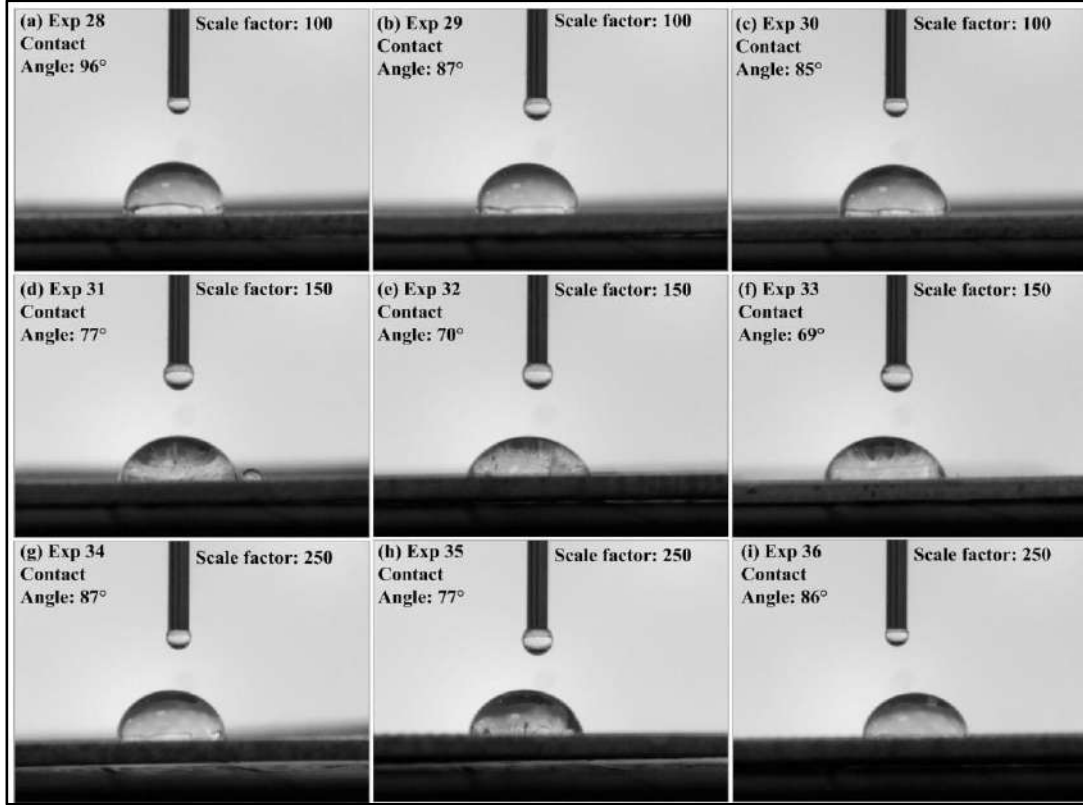


Fig. 3 Contact angle measurement of AA2024-T3 alloy circular-textured surfaces (a) exp-28, (b) exp-29, (c) exp-30, (d) exp-31, (e) exp-32, (f) exp-33, (g) exp-34, (h) exp-35, (i) exp-36.

B. Laser Surface Texture Morphologies

Figure 4(a) shows $SF = 100 \mu\text{m}$ at 250 mm s^{-1} , for which significant recast rims, local spatters, and relatively wide HAZ indicate larger line energy and larger melt ejection. Figure 4(b) at $SF = 100 \mu\text{m}$ and 500 mm s^{-1} shows more uniform circularity with less rims and fewer droplet numbers, confirming lower thermal inputs and improved feature fidelity. Figure 4(c) for $SF = 100 \mu\text{m}$ at 750 mm s^{-1} rounds the perimeter further and narrows the HAZ such that defined shallow ring features with small debris are obtained. Figure 4(d) at $SF = 150 \mu\text{m}$ and 250 mm s^{-1} shows larger rings at thick and sometimes merging rims and isolated spatters and represents large resolidified material at low scan rate. Figure 4(e) for $SF = 150 \mu\text{m}$ at 500 mm s^{-1} shows clearer edges, reduced rim thickness, and better pitch regularity as melt expulsion diminishes. Figure 4(f) at $SF = 150 \mu\text{m}$ and 750 mm s^{-1} displays the most homogeneous morphology at this scale, with continuous, symmetric rims and scarce by-products, a texture quality consistent with the minimum contact angle reported for this condition. Figure 4(g) at $SF = 250 \mu\text{m}$ and 250 mm s^{-1} reveals coarse doughnut-like rims with rough, segmented recast and occasional bridging, suggesting excessive local heat accumulation. Figure 4(h) for $SF = 250 \mu\text{m}$ at 500 mm s^{-1} improves circularity and rim continuity while lowering debris, indicating an optimized balance between ablation and resolidification at intermediate speed. Figure 4(i) at $SF = 250 \mu\text{m}$ and 750 mm s^{-1} shows shallower, partially discontinuous rims with sporadic gaps, implying under-melting of the perimeter that can reintroduce air entrapment and align with the recovered contact angle at the highest speed for this scale.

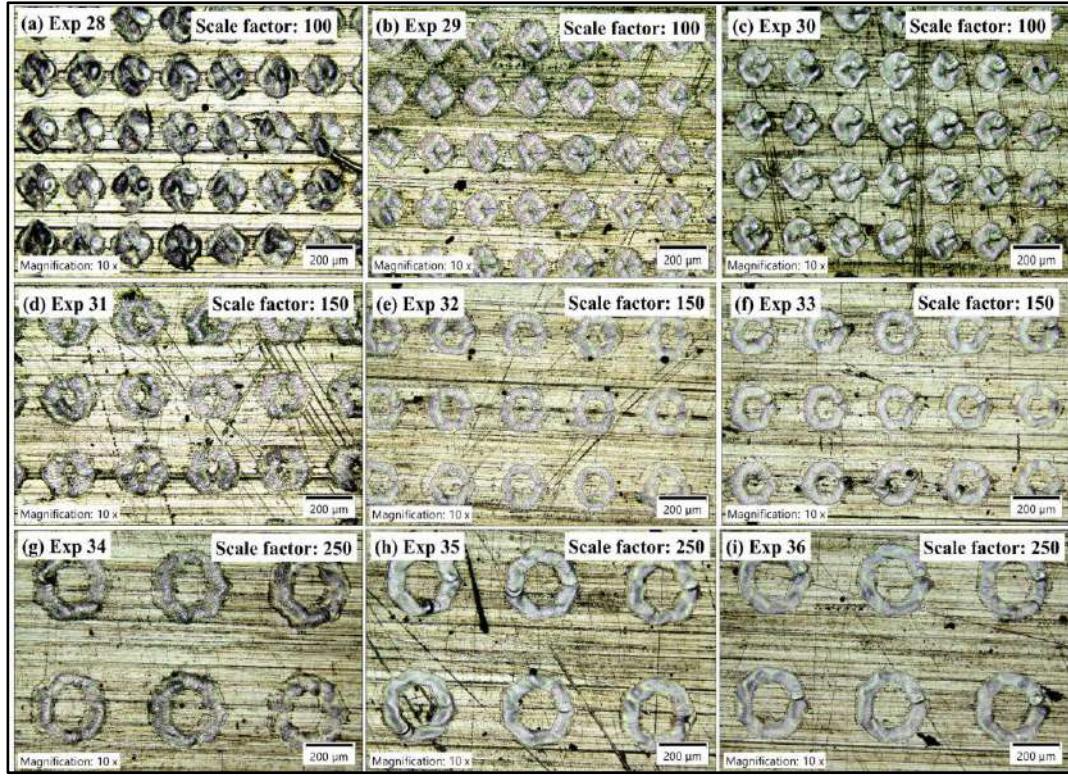


Fig. 4 Optic microscope surface images of laser textured AA2024-T3 alloy circular-textured surfaces (a) exp-28, (b) exp-29, (c) exp-30, (d) exp-31, (e) exp-32, (f) exp-33, (g) exp-34, (h) exp-35, (i) exp-36.

C. Surface Texture Roughness Analysis

Figure 5(a) shows $SF = 100 \mu m$ at 250 mm s^{-1} with a moderately rough field ($Sa = 1.198 \mu m$) and shallow ring relief; Figure 5(b) at $100 \mu m$ and 500 mm s^{-1} remains similar ($Sa = 1.216 \mu m$) with slightly clearer annuli; Figure 5(c) at $100 \mu m$ and 750 mm s^{-1} exhibits the largest roughness of this set ($Sa = 3.267 \mu m$), indicating pronounced topographic modulation despite the refined optical rim seen in 2D images. Figure 5(d) for $SF = 150 \mu m$ at 250 mm s^{-1} yields $Sa = 1.210 \mu m$ with distinct ring depressions; Figure 5(e) at $150 \mu m$ and 500 mm s^{-1} increases slightly to $Sa = 1.257 \mu m$ as recast undulations become more evident; Figure 5(f) at $150 \mu m$ and 750 mm s^{-1} reaches the lowest Sa within this scale ($1.122 \mu m$) while preserving uniform, continuous circular features, representing the best overall circular formation at constant morphology and low roughness. Figure 5(g) at $SF = 250 \mu m$ and 250 mm s^{-1} shows comparatively coarse relief ($Sa = 1.899 \mu m$) with higher-amplitude rims; Figure 5(h) at $250 \mu m$ and 500 mm s^{-1} reduces the roughness to $Sa = 1.508 \mu m$ as the ring edges regularize; Figure 5(i) at $250 \mu m$ and 750 mm s^{-1} produces the smoothest surface among all conditions ($Sa = 0.711 \mu m$) with shallow, partially discontinuous rims, implying under-melting at the perimeter. Overall, increasing scan speed tends to raise Sa at $SF = 100 \mu m$, slightly lowers Sa and improves circular uniformity at $SF = 150 \mu m$ (optimal in Figure 5f), and monotonically decreases Sa at $SF = 250 \mu m$ to a very smooth but less well-defined ring pattern (Figure 5i).

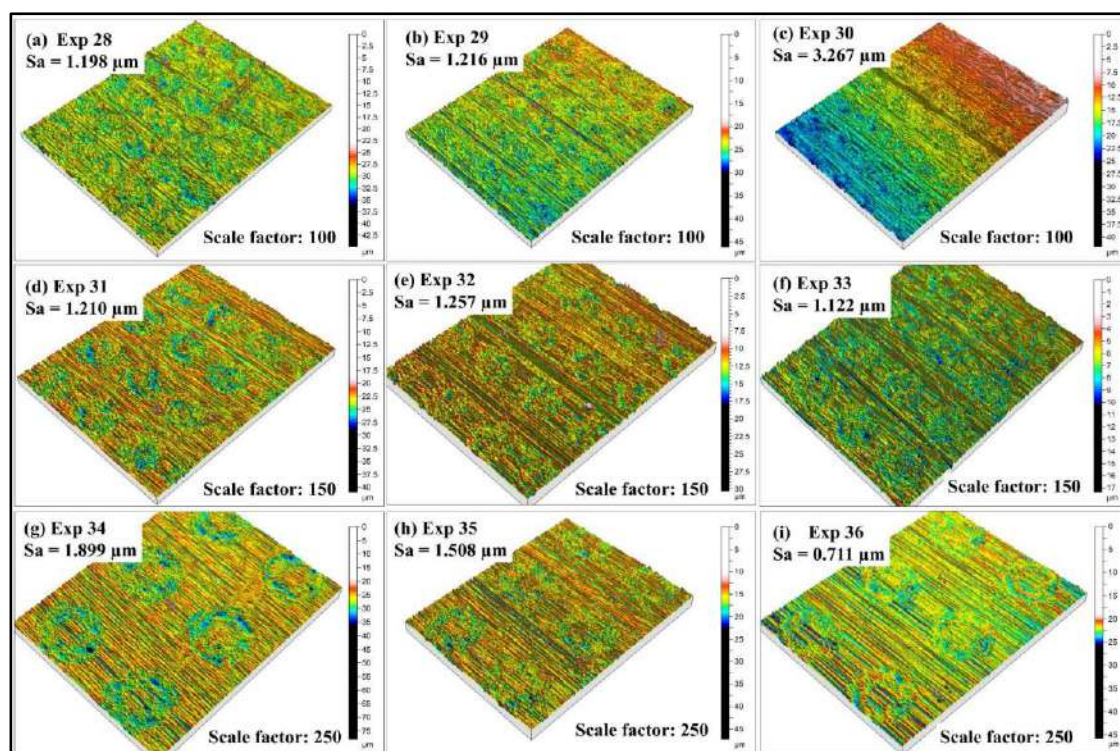


Fig. 5 Surface roughness (S_a) 3D images of laser textured AA2024-T3 alloy circular-textured surfaces (a) exp-28, (b) exp-29, (c) exp-30, (d) exp-31, (e) exp-32, (f) exp-33, (g) exp-34, (h) exp-35, (i) exp-36

IV. CONCLUSION

In conclusion, fiber-laser circular microtexturing of AA2024-T3 enabled controlled modulation of wetting and relief within the tested window of scale factor and scan speed. Static contact angle spanned $69\text{--}96^\circ$ relative to the 92° reference, with a consistent minimum at $SF = 150\text{ }\mu\text{m}$ and 750 mm s^{-1} (69°); at fixed speed the SF response was non-monotonic (e.g., 96 to 77 to 87° at 250 mm s^{-1}), while speed produced a monotonic decrease for $SF = 100$ and $150\text{ }\mu\text{m}$ and a U-shaped trend for $SF = 250\text{ }\mu\text{m}$. Areal roughness S_a ranged from $0.711\text{ }\mu\text{m}$ ($SF250/750\text{ mm s}^{-1}$) to $3.267\text{ }\mu\text{m}$ ($SF100/750\text{ mm s}^{-1}$), and microscopy/3D maps showed that rim continuity and cavity geometry; rather than S_a magnitude alone; govern wetting. This study is limited by the discrete parameter set (three scales, three speeds), a single test liquid and droplet volume, emphasis on S_a as the primary descriptor, and the lack of surface-chemistry and aging assessments, so broader generalization should be cautious. Future work should enlarge the process space, include dynamic contact angles and durability, and integrate chemical analyses to refine mechanisms–property links and application-specific design guidelines.

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Zararlılık etkisi yüksek kimyasalların depolama ve üretiminin yapıldığı tesiste risk analiz çalışma örneği

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Özet – Tehlikeli kimyasal üretimi yapan tesiste, Sodyum lauril glikoz karboksilat, asidite MBS, protectol PE, sodyum benzoat, glikolik asit gibi zararlı H koduna sahip kimyasalların üretimi yapılmaktadır.

Tehlikeli kimyasal üretimi ve depolaması yapılan tesiste mevcut risklerin belirlenmesi Fine-kinney metodu ile yapılmıştır. Risk skoru yüksek çıkan yerlerde önleyici ve koruyucu faaliyetler ile çalışmalar yapılmış ve risk değeri $20 < R < 70$ arasında tespit edilmiş bu da tesiste bu bölümde olası bir risk olduğunu ve gözetim altında uygulanması gerektiği sonucuna varılmıştır. Sodyum lauril glikoz, protectol PE, sodyum benzoat H319, H315, H317, H412, asidite MBS H319 H315, H317, H410, H400, glikolik asit H319 H315 H317 H410 H400 tehlike kodlarına sahip kimyasallardır.

Bu çalışmada mevcut risk puanının 30-70 arası değerler ile ifade edilmiştir. Tesiste riskin yüksek olduğu üniteye öncelikle mevcut tehlike; kimyasalın göze ve deriye teması, yangın meydana gelmesi durumunda müdahalenin doğru şekilde yapılmaması, kaza sonucu dökülmesi veya yayılması durumunda uygun şekilde müdahale edilmemesi, kullanıldığı alanda havalandırmanın yetersiz olması, uygun şekilde depolanmaması, kaza sonucu dökülmesi veya yayılması durumunda uygun şekilde müdahale edilmemesi, uygun şekilde elleçlenmemesi olarak belirlendi. Bu yüksek risk içeren birimde önleyici çalışmalar olarak, Ürün kanalizasyon sistemine girmemeli veya yüzey suyu veya yeraltı suyu ile temas etmemelidir. Cilt, gözler ve kişisel giysinin kirlenmesini önlemek için uygun koruyucu ekipman kullanılmalıdır. Sızan/akan ürünü uygun bir kap içerisine toplanmalıdır. Geri kalanı, inert emici malzeme ile emdirilmelidir. Kaçağın meydana gelmiş olduğu yerin yeterli derecede havalandırılmasını sağlanmalı, kontamine olmuş materyalin bertaraf edilmesi sağlanarak riskin azaltılması sağlanmıştır. Yapılan risk analiz çalışmasıyla dikkat edilmesi gerek risk seviyesi 20-40 seviyesine düşürülmüştür.

Anahtar Kelimeler – Fine-Kinney Risk Analizi, Tehlikeli Kimyasallar, H Kodu, İş Sağlığı Ve Güvenliği.

I. GİRİŞ

Kimyasal üretimin yapıldığı aynı zamanda depolama işleminin de olduğu tesislerde oluşabilecek risklerin boyutu çok önem taşıdığı için İş sağlığı ve güvenliği çalışmalarından öncelikli çalışma konusu olmaktadır. Mevcut tehlike sadece insan değil, çevreye de zarar verebilmektedir. Avrupa Birliği tarafından yapılan çalışmalar ile CLP (Classification, Labelling and Packaging) yönetmeliği ile kimyasalların tehlike özellikleri, H (Hazard) kodları ile sınıflandırılmıştır. Bu tehlike ile tanımlanan kodlar, toksisite, aşındırıcılık, yanıcılık, patlayıcılık ve çevresel zarar olarak belirlenmiştir. Bu tehlikeli kimyasallardan, sodyum lauril glikoz karboksilat, deterjan ve kozmetikte yüzey aktif madde olarak kullanılmaktadır. Mevcut tehlikesi ise, (H315: Cilt tahrişine yol açar, H319: Ciddi göz tahrişine yol açar). MBS (meta-bisulfit), gıda ve kimya endüstrisinde kullanılan bir koruyucu maddedir. Bu maddeyi bulunduğu, (H334: Solunması halinde alerji, astım belirtilerine sebep olmaktadır). Protectol PE'nin yüksek konsantrasyonlarda maruziyeti ciltte alerjik reaksiyonlara sebep olurken, sodyum benzoatın fazla miktarlarda alınması toksik etki yaratabilmektedir (H302: Yutulması halinde zararlıdır). Ayrıca, kozmetik ve farmasötik formülasyonlarda kullanılan Isotearly palmitat, çevresel toksisite bakımından risk taşımakta

ve sucul yaşam için tehlikeli olabilmektedir (H411: Uzun süre kalıcı, sucul ortamda toksik etki). Glikolik asit ise yüksek asiditesi sebebiyle aşındırıcı etkiler göstermekte ve ciddi cilt yanıklarına yol açabilmektedir (H314: Ciddi deri yanıklarına ve göz hasarına yol açar) [1].

Yapılan araştırmalarda ise, bu kimyasalların özellikle yanlış depolanması ve üretimde solunması çalışan sağlığına olumsuz etki edeceği görülmektedir. Almeman (2024) yaptığı çalışmada, glikolik asidin yüksek konsantrasyonlarının kozmetik ürünlerde cilt üzerinde kalıcı hasara yol açabileceğini ifade etmiştir [2]. El-Shennawy ve arkadaşlarının (2020), yaptığı bir çalışmada, sodyum benzoatın insan hücresinde oksidatif stres ve DNA hasarı oluşturabileceğini belirtilmiştir [3]. Salonen ve arkadaşlarının (2024), yaptığı çalışmada ise endüstriyel temizlik ürünlerinde kullanılan yüzey aktif maddelerin iş sağlığı ve güvenliği açısından kritik riskler yarattığı belirtilmiştir [4].

6331 sayılı İş Sağlığı ve Güvenliği yasasına göre tehlikeli işyerinde öncelikli çalışma risk analizi yapmaktır. Bu sebeple, bu tehlikeli kimyasal üretimi yapılan tesiste Fine-Kinney metodu, risklerin olasılık, frekans ve şiddet parametrelerine dayalı olarak hesaplanması açısından yaygın bir şekilde kullanılmıştır. Yapılan literatür taramasında, Yalçın ve Gürün, (2025), bir petrokimya tesisinde Fine-Kinney yöntemi ile yapılan çalışmada, özellikle depolama alanlarında yangın ve patlama risklerinin yüksek olduğunu ve alınan önlemlerle bu risklerin kabul edilebilir seviyelere düşürüldüğünü belirtmişlerdir [5]. Başka bir çalışmada ise, boya üretim tesisinde organik bileşiklerin yarattığı tehlikeleri azaltmak ve en aza indirmek için risk değerlendirme yöntemi olarak Fine-Kinney kullanıldığı bilgisi mevcuttur. Yapılan geniş çapta araştırmada, Fine-Kinney metodunun farklı kimya sektörlerinde etkin bir şekilde kullanıldığı görülmektedir. Örneğin, Özdemir ve Ören (2025), seramik üretim tesisinde Fine-Kinney risk yöntemi kullanarak olası riskleri minimuma indikleri bir çalışma yaptıkları görülmektedir [6]. Singh ve Sharma (2020), Hindistan’da bir ilaç üretim tesisinde yaptıkları analizde, solvent depolama ünitelerinde yüksek risk tespit etmiş ve mühendislik kontrolleri ile risk seviyesinin düşürülebileceğini ortaya koymuşlardır[7]. Yapılan literatür taramasında , özellikle Sodyum lauril glikoz karboksilat, MBS, Protectol PE, sodyum benzoat, isotearly palmitat ve glikolik asit gibi zararlı H koduna sahip kimyasalların üretilmesi ve depolanması süreçlerinde Fine-Kinney metodu kullanılarak yapılan risk analizleri, önleyici faaliyetlerin planlanması açısından önem taşımaktadır.

Bu çalışmada, sodyum lauril glikoz karboksilat, MBS, Protectol PE, sodyum benzoat, isotearly palmitat ve glikolik asit gibi zararlı H koduna sahip kimyasalların üretim ve depolama süreçlerinde ortaya çıkabilecek tehlikelerin sistematik bir şekilde belirlenmesi ve değerlendirilmesidir. Çalışmada Fine-Kinney risk analizi metodu kullanılarak, söz konusu kimyasallarla ilişkili tehlikelerin olasılık, maruziyet sıklığı ve şiddet parametreleri üzerinden hesaplama yapılmış ve yüksek risk taşıyan bölgeler belirlenmiştir.

II. MATERYAL VE YÖNTEM

A. İncelenen Tesis Hakkında Bilgi ve Tehlike Kodları

Tehlikeli kimyasalların üretiminin ve depolama işleminin yapıldığı tesiste, gıda, kimya ve endüstriye alanda kullanımı olan maddelerin üretimi yapılmaktadır. İncelenen başlıca kimyasallar şunlardır:

Sodyum lauril glikoz karboksilat: Yüzey aktif özelliklerinden dolayı deterjan ve kozmetik sektöründe yaygın olarak kullanılmaktadır. Ancak cilt ve gözde bazı rahatsızlıklara sebep olabilmektedir (H315, H319). Asidite MBS (Meta-bisulfit): Gıda katkı maddesi ve kimyasal koruyucu olarak kullanılan bu madde, solunum yollarında hassasiyet ve alerjik reaksiyonlara yol açabilmektedir (H319, H315, H317, H400, H410). Protectol PE: Endüstriyel koruyucu kimyasal olup, özellikle cilt tahrişi ve alerjik reaksiyon riskleri ile bilinmektedir (H315, H317, H412). Sodyum benzoat: Gıda ve ilaç sanayisinde koruyucu olarak kullanılan bu madde, yanlış koşullarda depolandığında toksik etki gösterebilir (H319, H315, H317, H412).

Glikolik asit: Kozmetik ve temizlik ürünlerinde kullanılan organik asit olup, yüksek asiditesi nedeniyle ciddi cilt ve göz tahrişi, ayrıca çevresel toksisite riski taşımaktadır (H319, H315, H317, H400, H410). Tesis, bu kimyasalların üretimi sırasında büyük hacimli reaktörler, depolama tankları, dolum üniteleri ve taşıma sistemleri barındırmaktadır. Özellikle depolama alanlarında yangın, dökülme ve çevresel sızıntı riski yüksek seviyede tespit edilmiştir. Ayrıca üretim hatlarında kullanılan ekipmanların yüksek basınç ve sıcaklık koşullarında çalışması, olası kazaların ciddiyetini artırmaktadır. Çalışmada yöntem olarak Fine-Kinney risk analizi tercih edilmiştir. Bu yöntemle, kimyasalların üretim ve depolama süreçlerinde ortaya çıkabilecek tehlikeler; olasılık, maruziyet sıklığı ve şiddet parametrelerine göre puanlanmış, risk skorları hesaplanmış ve yüksek risk taşıyan noktalar belirlenmiştir. Elde edilen sonuçlar ışığında, önleyici ve koruyucu faaliyetler geliştirilerek risk seviyelerinin azaltılması hedeflenmiştir.

B. Fine-Kinney Risk Analizi Metodolojisi

Bu çalışmada risk değerlendirme yöntemlerinden Fine-Kinney risk analizi metodu kullanılmıştır. Fine-Kinney metodu kaza oluşma olasılığı, zarar/sonuç yani şiddet parametresi ve tehlikeye maruz kalma sıklığını yani tehlike frekansını da içermektedir. Bu nedenle matris yöntemlerine göre daha güvenilir sonuçlar vermektedir. Fine-Kinney Risk Değerlendirme Yöntemi [8-10]. Fine Kinney Metodu, Kinney ve Wiruth tarafından 1976'da geliştirilmiştir. Nicel risk analiz yöntemi olarak bilinir. Yapılan risk analizinde , olasılık (O) , frekans (F) ve şiddet (Ş) olmak üzere üç parametre bulunmakta ve tehlikelerin risk derecesi bu üç parametrenin çarpımı sonucu elde edilmektedir. Daha sonra elde edilen risk skoruna göre durumun kabul edilebilir olup olmadığına karar verilir [11]. Fine-Kinney yönteminde olasılık, zararın zaman içinde meydana gelme olasılığı iken frekans faktörü, tehlikeye maruz kalma sıklığını ifade eder. Şiddet, bir tehlike meydana geldiğinde insanlara, işyerine ve çevreye verilen zararın veya zararın miktarıdır [11].

$$R = \dot{I} \times F \times \text{Ş} \text{ olarak hesaplanır.}$$

Burada $\dot{I}$ = İhtimal,

F = Frekans (Sıklık),

Ş = Şiddet,

R = Risk Skoru olarak tanımlanmaktadır.

Tablo 1 Bir Olayın Gerçekleşme İhtimali Değerleri

OLASILIK	
	PUAN
Tehlikenin gerçekleşmesi kesin-beklenen	10
Gerçekleşme olasılığı yüksek-mümkün	6
Gerçekleşmesi mümkün	3
Gerçekleşebilir fakat düşük olasılık	1
Gerçekleşmesi beklenmez ama mümkün	0,5
Gerçekleşmesi beklenmez, imkânsıza yakın	0,2

Tablo 2. Fine-Kinney metodunda frekans,değerleri

FREKANS	
SIKLIK (FREKANS)	
Sürekli - Bir saatte birkaç defa	
Sık sık – Yaklaşık günde bir defa veya daha fazla	
Ara sıra – Haftada bir/birkaç defa	
Sık değil ayda bir/birkaç defa	
Seyrek – Yılda birkaç defa	
Çok seyrek – Yılda bir/daha az	

Tablo 3. Zarar ve sonuç derecelendirmesi

DERECE			
İNSAN	ÇEVRE	MADDİ KAYIP	PUAN
Felaket – Çok Sayıda Ölüm	Büyük Çevre Kirliliği	1.000.000 USD	100
Öldürücü Kaza	Önemli Çevre Kirliliği	500.000 – 1.000.000 USD	40
Kalıcı Hasar – Yaralanma –Uzuv Kaybı	Yakın Çevreden Şikayet	İş Kaybı, 100.000 – 500.000 USD	15
Önemli Hasar – Yaralanma – Harici İlk Yardım	Sınır Dışına Taşmış Çevresel Zarar	İş Kaybı, 100.000 – 500.000 USD	7
Küçük Hasar – Yaralanma – Dahili İlk Yardım	Küçük Çevresel Etki	1.000 USD Küçük Zarar	3
Hafif – Zararsız - Önemsiz	Çevre Kirliliği Yok	Kabul Edilebilir Zarar	1

Tablo 4. Risk Değerlendirme Sonucu

SKOR		
RİSK PUANI	ÖNEM DERECESİ	EYLEM
400 < R	Tolerans Gösterilemez Risk	Hemen gerekli önlemler alınmalı / veya işin durdurulması, tesisin, binanın kapatılması vb. düşünülmelidir.
200 < R < 400	Esaslı Risk	Kısa dönemde iyileştirilmelidir. “birkaç ay içerisinde”
70 < R < 200	Önemli Risk	Uzun dönemde iyileştirilmelidir. “yıl içerisinde”
20 < R < 70	Olası Risk	Gözetim altında uygulanmalıdır.
R < 20	Önemsiz Risk	Önlem öncelikli değildir.

III. BULGULAR

Tesisin üretim ve depolama birimlerinde yapılan incelemeler sonucunda çeşitli tehlikeler tespit edilmiştir. Kimyasalların üretiminde kullanılan ekipmanların yüksek basınç ve sıcaklık altında çalışması, dökülme ve sızıntı risklerini artırmaktadır. Ayrıca, kimyasalların göze ve deriye teması, kazalar sırasında yangın riskleri, yanlış depolama koşulları ve yetersiz havalandırma ciddi tehlikeler arasında yer almaktadır.

Özellikle Sodyum lauril glikoz karboksilat, Protectol PE ve Sodyum benzoatın cilt ve göz tahrişine yol açması (H315, H319), Asidite MBS ve Glikolik asidin sucul canlılar üzerinde uzun süreli toksik etkilere sahip olması (H400, H410) önemli risk faktörleri olarak belirlenmiştir. Literatürde de benzer tehlikelerin vurgulandığı görülmektedir. Örneğin, Gerster ve arkadaşları (2014), temizlik ürünlerinde kullanılan yüzey aktif maddelerin özellikle çalışan sağlığı açısından ciddi riskler barındırdığını raporlamıştır [12]. Risk değerlerinin hesabında, Fine-Kinney yöntemi ile yapılan hesaplamalar sonucunda, tehlikelere ilişkin risk skorları 30 ile 70 arasında bulunmuştur. Bu değerler, risklerin kabul edilebilir sınırların üzerinde

olduğunu ve dikkat edilerek takip edilmesi gerektiğini göstermektedir. Özellikle yangın, kimyasal sızıntı ve dökülme durumlarında olasılık, maruziyet sıklığı ve şiddet parametreleri yüksek puanlanmıştır. Benzer çalışmalarda da Fine-Kinney metodunun etkin bir şekilde kullanıldığı görülmektedir. Yıldırım (2023). Biyogaz üretim süreçlerinde kullanılacak en uygun risk değerlendirme metodolojisinin analitik hiyerarşi prosesi ile belirlenmesi konulu çalışmasında Finne-Kinney metodunu kullanarak risk değerlendirme çalışması yapmıştır [13]. Ghobakhloo ve arkadaşları (2023), boya fabrikasında solvent buharlarının risk değerlerini hesaplamış ve yüksek seviyede risk tespit etmişlerdir. Bu da, çalışmamızdaki bulgular ile literatürün uyumlu olduğunu göstermektedir. Risklerin yüksek olduğu yerde özellikle kimyasalların depolandığı ve elleçlendiği kısımlarda olduğu tespit edilmiştir. Depolama tanklarında olası sızıntılar, dolum ünitelerinde kimyasalın kazara dökülmesi ve yangın riskleri en kritik tehlikeler olarak öne çıkmıştır. Bu alanlarda risk skorlarının 70 seviyesine yakın olduğu tespit edilmiştir. Singh ve Sharma (2020), tekstil atıkların depolanmasıyla ilgili yaptıkları çalışmada yüksek riskli bölgeler olduğunu ve uygun mühendislik kontrolleriyle risk seviyelerinin azaltılabileceğini belirtmişlerdir. Bu bulgu, mevcut çalışmamızın sonuçlarıyla örtüşmektedir.

IV. TARTIŞMA

Fine-Kinney yöntemi, risklerin nicel olarak değerlendirildiği ve tehlike sınıfı çalışmalarında oldukça sık kullanılan bir yöntem olduğu görülmektedir. Yapılan araştırmalarda, özellikle kimyasal madde üretimin yapıldığı aynı zamanda depolama faaliyetlerinin olduğu tesislerde kullanımının olduğu tespit edilmiştir.

Mevcut çalışmada elde edilen bulgular, söz konusu çalışmalarla benzerlik göstermekte ve risk değerlerinin özellikle yangın, patlama ve kimyasal maruziyet gibi kritik tehlikeler üzerinde yoğunlaştığını ortaya koymaktadır [14-15].

Önceki çalışmalarla karşılaştırıldığında, bu çalışmanın önemli bir katkısı, risk skorlarının sadece belirlenmesiyle sınırlı kalmayıp, aynı zamanda önleyici ve koruyucu faaliyetler aracılığıyla risk değerlerinin düşürülebileceğini ortaya koymasıdır. Bu durum, teorik risk analizlerinin pratik uygulamalara aktarılabilirdiği için önem taşımaktadır. Ayrıca, çalışmada elde edilen $20 < R < 70$ aralığındaki risk değerleri, literatürde raporlanan diğer tesis çalışmaları ile kıyaslandığında orta düzey risk grubuna karşılık gelmekte ve bu da çalışmanın güvenilirliğini artırmaktadır.

Sonuç olarak, bu çalışma, zararlılık etkisi yüksek kimyasalların bulunduğu endüstriyel tesislerde Fine-Kinney metodunun etkin bir şekilde uygulanabileceğini ve risklerin kontrol altına alınmasında önemli katkılar sağlayabileceğini göstermektedir. Bu bağlamda, çalışma hem literatüre katkı sunmakta hem de iş sağlığı ve güvenliği alanında uygulayıcılara yol gösterici nitelik taşımaktadır.

V. SONUÇLAR

Bu çalışma, zararlılık etkisi yüksek kimyasalların bulunduğu endüstriyel tesislerde Fine-Kinney metodunun etkin bir şekilde uygulanabileceğini ve risklerin kontrol altına alınmasında önemli katkılar sağlayabileceğini göstermektedir. Bu bağlamda, çalışma hem literatüre katkı sunmakta hem de iş sağlığı ve güvenliği alanında uygulayıcılara yol gösterici nitelik taşımaktadır.

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Genomic Insights into Antimicrobial Resistance and Prophage Elements of *Lactiplantibacillus plantarum* TOS9 Isolated from the Honeybee Gut

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Abstract – *Lactiplantibacillus plantarum* is a lactic acid bacterium with remarkable ecological adaptability, probiotic potential, and industrial significance. In this study, we performed whole-genome sequencing of *Lpb. plantarum* TOS9, a strain isolated from the honeybee gastrointestinal tract, to evaluate its genomic features, antimicrobial resistance (AMR) genes, and prophage elements. The draft genome comprised 33 contigs, with a total length of 3.67 Mbp, a G+C content of 44%, and 3,463 coding sequences. Genome analysis revealed the presence of glycopeptide resistance genes, including *vanY* within the *vanB* cluster and *vanH* within the *vanA* cluster, suggesting potential resistance to vancomycin and teicoplanin, possibly acquired through mobile genetic elements. Additionally, four incomplete prophage regions belonging to the Siphoviridae family were identified, highlighting the role of phage-derived elements in genomic plasticity. These findings provide valuable insights into the genomic architecture of *Lpb. plantarum* TOS9 and support its potential applications in food biotechnology and probiotic development, while also emphasizing the need for careful assessment of its antimicrobial resistance traits.

Keywords – *Lactiplantibacillus Plantarum*, AMR Genes, Whole Genome, Food Safety, Probiotic.

I. INTRODUCTION

Lactiplantibacillus plantarum is a versatile lactic acid bacterium widely studied for its beneficial roles in food fermentation, gut health, and biotechnology [1]. It occurs naturally in diverse environments, including fermented foods (e.g., sauerkraut, pickles, and yogurt), plant materials, and the human gastrointestinal tract [2]. Owing to its ability to produce antimicrobial compounds, enhance food preservation, and promote probiotic effects, *Lpb. plantarum* has been extensively applied in both food production and therapeutic contexts [3]-[5]. It has strong antioxidant capabilities and helps balance the gut microbiome, promoting digestive health and boosting immunity [6]. Due to its adaptability, *Lpb. plantarum* is used in both food production and therapeutic applications [7].

The pan-genome of *Lp plantarum* refers to the collective set of genes found across different strains of this species, encompassing both the core genome, which is shared by all strains, and the accessory genome, which includes strain-specific genes [8]. This genetic diversity allows *Lpb. plantarum* to adapt to a wide range of environments, from fermented foods to the human gastrointestinal tract [9]. The core genome contains essential genes for basic metabolic functions and survival, while the accessory genome provides functions related to niche adaptation, such as stress resistance, antimicrobial compound production, and carbohydrate metabolism [10]. Studying the pan-genome of *Lpb. plantarum* is crucial for understanding its versatility, probiotic potential, and ability to be used in diverse biotechnological applications [11]. It also

helps in identifying specific genes responsible for its health-promoting properties and industrial benefits [2], [12].

Lpb. plantarum is one of the most extensively utilized probiotics globally [13]. While numerous studies have validated the safety of this strain through microbiological methodologies and bioinformatic analyses, the safety of *Lpb. plantarum* strains cannot be conclusively assured without verification, as certain *Lactobacillus* species have been documented to exhibit antimicrobial resistance (AMR) and may not conform to the European Food Safety Authority (EFSA) guideline criteria [14]-[18]. The intrinsic resistance to vancomycin observed in some *Lpb. plantarum* strains, in particular, underscores this concern [19]. Although intrinsic resistance to antibiotics specific to bacterial species is generally considered relatively safe, it remains a matter of concern. Moreover, non-intrinsic resistance to other antibiotics has been reported in some *Lpb. plantarum* strains. The most critical issue related to AMR is the phenomenon of acquired resistance, which can be transferred to other bacteria via horizontal gene transfer (HGT). To determine whether AMR is intrinsic or acquired, it is essential to investigate the presence of specific regions of mobile genetic elements (MGEs) at the genomic level and to verify the potential function of the genes through microbiological tests [20], [21].

With the rapid advancement of genome sequencing technologies, the comprehensive investigation of bacterial genomes has become feasible, thereby accelerating the identification and in-depth study of prophage prevalence within bacterial genomes [22], [23]. By examining prophage information in bacterial genomes, researchers have overcome the previous limitation of studying only isolated prophages, thus enriching research on prophage genetics and evolution [24]. Studies conducted on 16 genera of lactic acid bacteria have demonstrated that nearly all lactic acid bacterial strains (99.8%) harbor phage-related fragments, and complete prophage genomes have been identified in numerous strains [25]. Notably, the work of Ventura and colleagues revealed that a single strain of *Lpb. plantarum* contains at least four putative prophage regions, highlighting the remarkable richness of phage genomic diversity in this species [26]. However, comprehensive comparative genomic analyses of prophages in *Lpb. plantarum* remain limited. Therefore, future research should focus on large-scale comparative genomic analyses of prophages in *Lpb. plantarum* to further elucidate their significance in microbial ecology and host interactions [27].

Determining the genomic features of *Lpb. plantarum* TOS9 is crucial for investigating both its industrial application potential in dairy products. In this work, we carried out whole-genome sequencing and highlighted analysis of antimicrobial resistance genes of *Lb. plantarum* TOS9 isolated from honeybee gastrointestinal tract.

II. MATERIALS AND METHOD

Bacterial Strain and DNA Extraction

The strain *Lpb. plantarum* TOS9 (SRA: PRJNA792923) was previously isolated from the honeybee gastrointestinal tract. A single colony was cultured in MRS broth at 37 °C for 24 h under aerobic conditions. Genomic DNA was extracted using the EURX Tissue and Bacterial DNA Purification Kit (EURX, Poland). A 150 bp paired-end Illumina library was prepared and sequenced on the Illumina NovaSeq 6000 platform (BM Software Consult. and Lab. Sis. Ltd., Ankara, Türkiye). Reads were trimmed using Shovill v0.9.0, and genome annotation was performed with Prokka v1.14.6.

Detection of Antimicrobial Resistance Genes, and Prophage Regions

AMR genes were identified using the CARD Resistance Gene Identifier database (via Proksee, <https://proksee.ca>), and prophage regions were detected using the Phigaro database [28].

III. RESULTS

Genome Features

The genome of *Lpb. plantarum* TOS9 consists of 33 contigs, with a total length of 3,677,152 bp, an average G+C content of 44%, and 3,463 predicted CDS, along with 9 rRNA, 1,476 tRNA, and 1 tmRNA genes. The assembly data have been deposited in NCBI SRA (PRJNA792923). A circular genome representation was generated using Proksee (Figure 1). Comparable genome sizes and G+C contents have been reported for other *Lpb. plantarum* strains, such as HYY-DB9 (3.39 Mbp, 45.5% G+C) [20], 12-3 (3.40 Mbp, 44.4% G+C) [21], and FCa3L (3.37 Mbp, 44.3% G+C) [22]. Lu et al. reported that *Lpb. plantarum* HYY-DB9 whole genome sequencing revealed a genome size of 3,387,787 bp with a total of 3269 genes spanning 2,827,224 bp in length, accounting for approximately 83.45% and the average Guanine + Cytosine (G + C) content was determined to be 45.47% of the total genome length [29]. Aziz et al. found the G+C content of the 3,403,608 bp *Lpb. plantarum* 12-3 whole genome to be 44.4% within 8 assembled contigs. A total of 3,234 genes were predicted, with typical lengths ranging from 1,020 to 2,500 base pairs. Closer examination of the *Lpb. plantarum* 12-3 genome revealed a wide variety of tRNA, tmRNA, and rRNA sequences. There are several different types of tRNA, including tRNA-Val, tRNA-Met, and tRNA-Ala genes [30]. In another study it was reported that *Lpb. plantarum* FCa3L isolate had a circular chromosome of 3,365,929 bp with 44.3% GC content and a cyclic phage phiX174 of 5386 bp with 44.7% GC content [31].

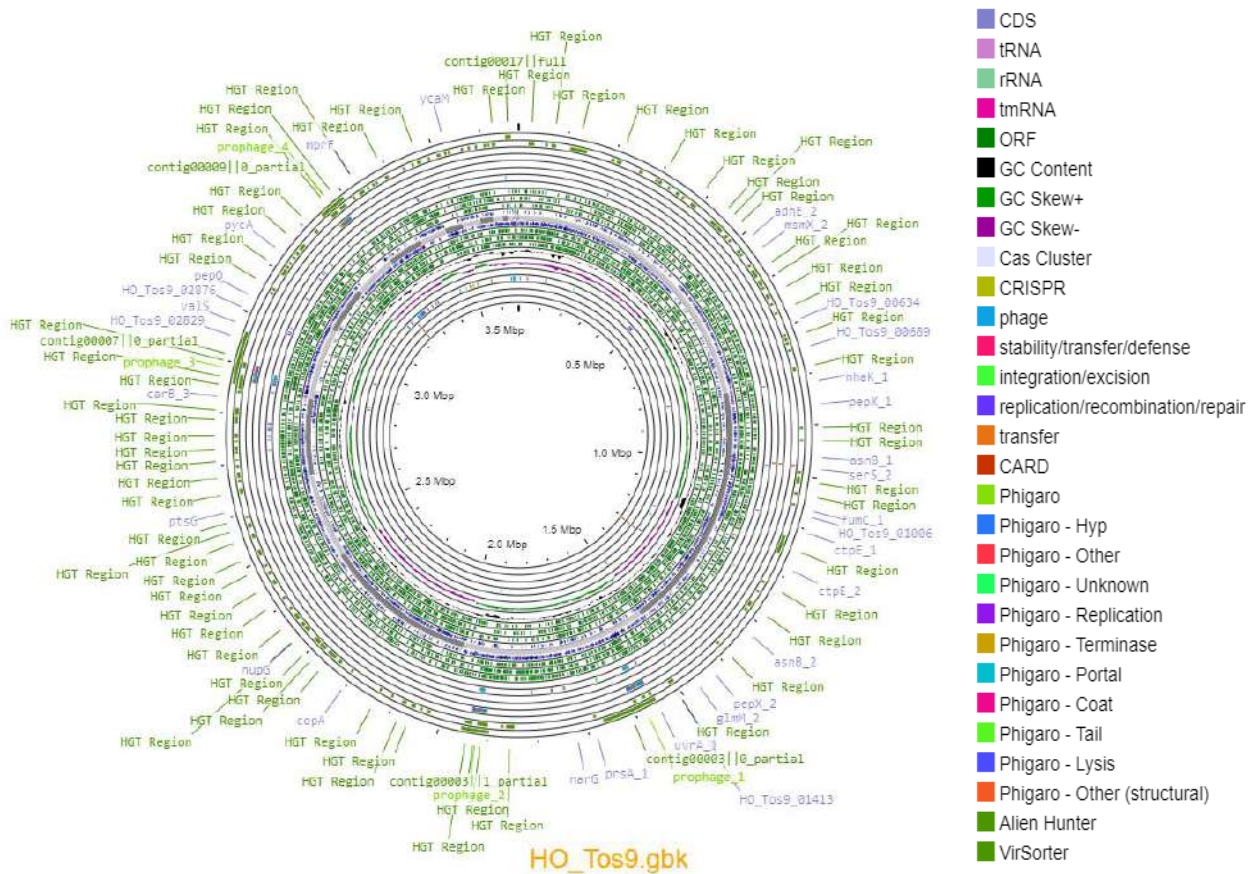


Fig 1. Circular genome representation of *Lpb. plantarum* TOS9

Detection of Antimicrobial Resistance Genes, and Prophage Regions

Analysis of the *Lactiplantibacillus plantarum* TOS9 genome revealed the presence of glycopeptide antibiotic resistance gene clusters (Table 1). Specifically, the *vanY* genes are located within the *vanB* cluster, while the *vanH* gene is part of the *vanA* cluster, all of which confer resistance through antibiotic target alteration mechanisms. The GC content of the *vanB* cluster genes is approximately 46%, whereas the

vanA cluster gene exhibits a slightly lower GC content (~42%), suggesting the possibility of horizontal gene transfer or a different origin. Additionally, the genes are situated on different contigs and on opposing strands (+/-), indicating the potential involvement of mobile genetic elements and intra-genomic diversity. The high sequence identity (95–103%) and scores ranging from 89 to 201 indicate reliable annotation, with *vanH* displaying particularly high confidence. These findings suggest that *Lpb. plantarum* TOS9 may exhibit a potential resistance phenotype against glycopeptide antibiotics such as vancomycin and teicoplanin and that these resistance genes may have been acquired through mobile genetic elements. Pell et al. conducted a screening against known resistance genes for vancomycin (*ddl*), tetracycline, and ciprofloxacin (*gyrA*). They identified an internal active site mutation (F261Y) in the *ddl* gene conferring vancomycin resistance in the *Lpb. plantarum* ATCC 202195-A genome. In addition, a single partial match was found with the tetracycline resistance gene *tetM*, and the *gyrA* gene was found to be present in the *Lpb. plantarum* ATCC 202195-A genome, but no mutations conferring fluoroquinolone resistance were identified [32]. In another study, the presence of potential antibiotic resistance genes in the *Lpb. plantarum* FCa3L genome was examined, and genes encoding tetracycline resistance, oxytetracycline resistance (*otrA*), fluoroquinolone resistance, and multidrug resistance (*cmeA*, *cmeB*, *cmeC*, *macA*, *macB*, *mtrF*, *acrB*, *mexD*, *mexC*) were detected [31]. Ruiqi and Chongpeng performed a comparative genomic analysis of 324 *Lpb. plantarum* strains and examined the ARGs present in the genome. A total of six ARGs were identified in the study. Two of these (*vanH* and *vanY*) were present in almost all strains except plant-derived samples. Another ARG conferring vancomycin resistance, *vanT*, was detected in 10.7% animal-derived strains and 28.6% of environmental strains. In addition to vancomycin resistance genes, the *Tet(M)*, *ANT(6)-Ia*, and *mdeA* genes, which mediate tetracycline, aminoglycoside, and multidrug resistance, respectively, were also identified in these strains [33].

In the analyzed genome, four prophage regions were identified, all taxonomically classified within the Siphoviridae family (Table 2). These prophages varied in length between ~27 kb and ~40 kb, but were predicted to be incomplete, suggesting that they represent defective or remnant prophages rather than intact, functional bacteriophages. The annotated pVOGs within these regions included genes encoding structural components (capsid, tail, portal), replication-associated proteins, and various phage-related enzymes. The presence of these prophage remnants highlights the contribution of phage-derived mobile genetic elements to the genomic architecture and potential evolutionary adaptation of the host bacterium. Previous studies have shown that more than 92% of 213 *Lactobacillus* genomes harbor prophages [34–36]. The study by Lv et al. aimed to systematically reveal the distribution characteristics of prophages in this species and their potential effects by conducting an in-depth analysis of the genome sequences of 1497 *Lpb. plantarum* strains. Specifically, phage-associated sequences were detected in 99.9% of the strain genomes (1496/1497), with a total of 5618 phage fragments identified, with only one exception. This highlights the high prevalence of phages in *Lpb. plantarum* and their central roles in the genomic architecture of the strain [24]. Another study investigating phorages revealed the presence of five phorage regions in the *Lpb. plantarum* JS21 genome, including three complete and two incomplete phorages [37]. Peng et al. identified three intact prophage regions in the *Lpb. plantarum* VHProbi P06 genome with a total length of 133.6 Kbp (3.92% of the genome), which were reported to contain 53, 59, and 57 coding genes, respectively, named Phage1, Phage2, and Phage3. The prophage region of VHProbi P06 was found to be shorter than that of other *Lpb. plantarum* strains [38]. For example, the total length of the prophage elements in *Lpb. plantarum* DMDL 9010 is 279.6 Kbp, constituting 8.15% of its genome [39]; the prophage elements in *Lpb. plantarum* NCU116 also constitute 4.37% of the genome [40].

Table 1. *Lactiplantibacillus plantarum* TOS9 antimicrobial resistance genes (Proksee CARD RGI software).

Contig ID	Start	End	Strand	GC content	Identity (%)	Score	Gene Cluster	Annotation	Protein model	Function (Mechanism)	Antibiotic(s)	Notes
KEYWORDS-2_166	177036	177809	+	0.461	95.90	89.35	vanY vanB	vanY gene in vanB cluster	Protein homolog model	Antibiotic target alteration	Vancomycin	Glycopeptide resistance gene cluster
KEYWORDS-2_463	500212	500985	-	0.461	95.90	89.35	vanY vanB	vanY gene in vanB cluster	Protein homolog model	Antibiotic target alteration	Vancomycin	Glycopeptide resistance gene cluster
KEYWORDS-9_52	54239	55237	-	0.420	103.11	201.45	vanH vanA	vanH gene in vanA cluster	Protein homolog model	Antibiotic target alteration	Vancomycin; Teicoplanin	Glycopeptide resistance gene cluster

Table 2. *Lactiplantibacillus plantarum* TOS9 Prophage Regions

Contig ID	Prophage ID	Start	End	Length (bp)	Complete	Taxonomy	Example pVOGs (subset)
3	prophage1	75,538	115,387	~39,849	False	Siphoviridae	VOG4602, VOG8520, VOG1563, VOG8222, VOG8925
3	prophage2	425,972	456,474	~30,502	False	Siphoviridae	VOG0535, VOG6545, VOG4713, VOG1329, VOG9640
7	prophage1	11,676	45,322	~33,646	False	Siphoviridae	VOG7298, VOG4566, VOG4713, VOG1330, VOG8294
9	prophage1	73,701	100,940	~27,239	False	Siphoviridae	VOG4599, VOG4605, VOG5904, VOG8239, VOG4553

IV. CONCLUSION

In this study, whole-genome sequencing of *Lactiplantibacillus plantarum* TOS9, isolated from the honeybee gut, provided comprehensive insights into its genetic features, antimicrobial resistance determinants, and prophage elements. The genome revealed the presence of glycopeptide resistance genes, including vanY within the vanB cluster and vanH within the vanA cluster, suggesting potential resistance to vancomycin and teicoplanin and indicating the possible involvement of mobile genetic elements in their acquisition. Moreover, four prophage regions belonging to the Siphoviridae family were identified, emphasizing the role of phage remnants in shaping the genomic architecture and contributing to genetic plasticity.

These findings highlight the dual importance of *Lpb. plantarum* TOS9 as a promising candidate for probiotic and food biotechnology applications, while also underscoring the necessity of careful evaluation of its antimicrobial resistance traits to ensure compliance with food safety regulations. Future research should include functional validation of resistance phenotypes, as well as large-scale comparative analyses of prophages in *Lpb. plantarum* to further elucidate their ecological and evolutionary roles. Overall, this work contributes valuable genomic data that can guide both applied and fundamental studies on *Lpb. plantarum*.

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Detection of Bone Fractures in X-ray Images with Machine Learning Methods Using InceptionV3 Deep Features

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Abstract – This research investigates the integration of deep learning-based feature extraction with classical machine learning techniques for the detection of bone fractures in X-ray images. In particular, the InceptionV3 architecture was employed within a transfer learning framework to extract rich, multi-layered, and distinctive feature representations directly from original radiographic images. These extracted features were subsequently classified using two widely adopted machine learning algorithms, namely Support Vector Machines (SVM) and Naive Bayes (NB). To rigorously assess the classification performance, standard evaluation metrics such as accuracy, precision, recall, and F1-score were employed, in addition to confusion matrix analysis to better understand class-specific strengths and weaknesses. The experimental results demonstrate that the SVM model achieved an accuracy of 76.8%, outperforming the NB model, which reached 67.3%. These findings highlight the effectiveness of combining deep learning-driven feature extraction with conventional classifiers and suggest that architectures such as InceptionV3 can serve as powerful tools for complex medical image analysis tasks, particularly in supporting the reliable and automated detection of bone fractures.

Keywords – Bone Fracture Detection, Deep Learning, Inceptionv3, Support Vector Machines, Naïve Bayes.

I. INTRODUCTION

The complex structure and variety of shapes of the 206 bones in the human body make it difficult to diagnose fractures resulting from physical blows [1]. This situation creates a high workload for radiologists and also carries the risk of incorrect or delayed diagnoses [2]. Traditional X-ray image analysis is a process that requires expertise and is time-consuming, potentially leading to diagnostic delays, especially in situations where radiological expertise is limited [3]. In this context, machine learning and deep learning techniques offer significant potential for the automatic detection and classification of bone fractures in X-ray images [4]. This study investigates the integration of deep learning-based feature extraction and machine learning methods for bone fracture detection in X-ray images. In the study, the InceptionV3 architecture was used with a transfer learning strategy to obtain rich and distinctive feature vectors from the original X-ray images. These obtained features were then classified using traditional machine learning algorithms such as Support Vector Machines and Naive Bayes. In this process, the 10-fold cross-validation method was applied to evaluate the model's generalizability and the robustness of its performance [5]. This approach has the potential to significantly improve patient care by increasing diagnostic accuracy, especially in cases where radiologists are insufficient or in clinical settings where rapid diagnosis is needed

[6]. The transfer learning strategy used in this study aims to achieve high accuracy even with limited medical image datasets by leveraging the ability of deep learning models trained on existing large datasets to transfer knowledge to a new domain [7, 8]. This optimizes diagnostic performance, particularly with complex visual data like X-ray images, by enhancing the models' ability to generalize [8]. Using pre-trained networks like InceptionV3 offers an effective solution for preventing overfitting in small and limited medical image datasets [9]. Additionally, this method can increase clinical efficiency by speeding up the diagnostic process while reducing the workload for radiologists [8, 10]. In this context, this study investigates the effectiveness of deep convolutional networks based on transfer learning for bone fracture detection, highlighting the strong potential of popular architectures like InceptionV3 in medical image analysis [8]. Using the InceptionV3 network is critically important for its ability to capture features at various scales and achieve high performance, which is a significant advantage, especially considering the heterogeneous nature of medical imaging [7]. The main objective of this study is to evaluate the impact of integrating deep features extracted from the InceptionV3 architecture with machine learning classifiers such as Support Vector Machines (SVM) and Naive Bayes (NB) on diagnostic performance for bone fracture detection. [11].

II. RELATED WORKS

In recent years, numerous studies have been conducted on bone fracture detection and classification, and various deep learning approaches have been proposed. However, a method that can universally classify all fractures in the human body has not yet been found. In this study, selected articles using different deep learning techniques were examined. Additionally, important points to consider in achieving the goal have been identified. Deep learning, particularly CNNs, has been shown to achieve human-level results in bone fracture classification. It is believed that a well-designed computer-aided diagnostic system will assist doctors, saving time and reducing misdiagnoses [12].

Lindsey et al. (2018) developed a deep learning model for fracture detection using the annotations of 18 orthopedic surgeons on 135,409 radiographs and tested this model on the diagnostic performance of emergency medicine physicians. The findings revealed that with model support, sensitivity increased from 80.8% to 91.5%, specificity from 87.5% to 93.9%, and the misinterpretation rate decreased by 47%. These results indicate that artificial intelligence-based decision support systems can significantly improve clinical accuracy [13].

Dimililer et al. (2017) developed a method for classifying bone fractures in X-ray images. In the study, the images were first compressed using the Haar wavelet transform, and then scale, rotation, and compression-resistant features were obtained using the SIFT method. With these features, a classification performed using a three-layer neural network with 1024 input neurons reported an accuracy rate of 94.3% on 30 training and 70 test images. The results obtained show that strong preprocessing techniques increase classification success; however, it is emphasized that the small dataset size and training-test imbalance, as well as data augmentation methods, could provide additional contributions [14].

Chung et al. (2018) used 1891 shoulder radiographs (1376 fractured, 515 healthy) in their study aimed at categorizing proximal humerus fractures according to the Neer classification. The images were scaled to 256×256 pixels, and data augmentation techniques increased the training set to over 40,000 samples. The ResNet-152-based deep learning model achieved over 95% accuracy in distinguishing healthy and fractured fractures and 65–86% accuracy in classifying fracture types, thus exceeding the performance of general physicians and orthopedists [15].

Olczak et al. (2017) studied 256,458 hand, wrist, and ankle X-rays to evaluate fracture detection in orthopedic trauma X-rays. Five different pre-trained networks on ImageNet (BVLC Reference CaffeNet, VGG CNN S, VGG16, VGG19, and Network-in-Network) were used. The images were divided into 70% training, 20% validation, and 10% test sets and resized to 256×256 pixels. The VGG16 model showed the highest performance with 83% accuracy. In a comparison with two senior orthopedic surgeons on 400 test images, the model's performance was found to be similar to that of experts [16].

Kim and MacKinnon (2018) investigated fracture detection in wrist X-rays using transfer learning. 1389 images (695 fractured, 694 intact) based on radiology reports were used in the study. Various data

augmentation methods (horizontal flip, 0° – 25° rotation, pan, shear, and zoom) were used to increase the number of images eightfold and split them into training, validation, and test sets at an 80:10:10 ratio. After converting the images to JPEG format, the pre-trained InceptionV3 network on ImageNet was retrained and trained for fracture/intact classification. The model achieved an AUC of 0.954, demonstrating that transfer learning can be effective in fracture detection even with relatively small datasets [17].

Yahalomi et al. (2019) used the Faster R-CNN approach for the detection and localization of distal radius fractures. The dataset, which initially included 55 fractures, 40 normal hand images, and 25 negative test images, was expanded to 4476 images by data augmentation (reflectance, sharpness, brightness, contrast) after removing some lateral images, and the fracture regions were labeled with bounding boxes. The VGG16-based Faster R-CNN model successfully classified the presence of a fracture with 96% accuracy, achieving a localization value of 0.866 mAP. The findings demonstrate that the method can achieve higher accuracy compared to physicians and radiologists [18].

Rajpurkar et al. (2017) developed a baseline model that can classify radiographs as normal or abnormal. The study used a MURA dataset (14,863 upper extremity studies, 40,561 images) labeled by radiologists. The images were normalized to 320×320 pixels, and data augmentation methods were applied. The model was evaluated using DenseNet-169-based CNN, sigmoid-exit classification, and CAM-based visualization. The model achieved 81% sensitivity, 89% specificity, and 0.929 AUC, achieving results close to the best radiologist performance for finger and wrist fractures [19].

Chen (2019) developed a deep neural network to distinguish atypical femur fractures (AFF) and normal femur fractures (NFF) associated with long-term bisphosphonate therapy. Data augmentation (-10° – $+10^{\circ}$ rotation, pan, zoom) and standard preprocessing techniques were applied to 796 X-ray images (397 AFF and 399 NFF) after quality control. Models based on VGG19, ResNet50, and InceptionV3 were tested with two different strategies. The fully automatic approach achieved 82.7–90.5% accuracy, while the manual intervention method achieved 92.2–94.4% accuracy. CAM analyses showed that the model initially focused on DICOM notations and then directed to fracture sites [20].

Sahin (2023) investigated image processing and machine learning methods for fracture detection and classification on 176 long bone X-rays (105 normal, 71 fractured) obtained from Al-huda Digital X-ray Laboratory. Grayscale, thresholding, Canny/Sobel edge detection, Hough spline, and Harris corner detectors were used for feature extraction, and then 12 different algorithms were evaluated using grid search and 10-fold cross-validation. The accuracy rates in the results ranged from 73.58% (Gaussian NB) to 88.67% (LDA), with the best performance being obtained with the LDA model (88.67% accuracy, 0.89 AUC). Additionally, QDA showed the shortest training time (0.0066–0.0070 s), and MLP showed the fastest testing time (0.0027 s) [21].

Ma and Luo (2021) developed a two-stage method for fracture detection in computer-aided telemedicine systems. In the first stage, 20 different bone regions were automatically identified using Faster R-CNN, and in the second stage, fracture status in these regions was classified using a Crack-Sensitive Convolutional Neural Network (CrackNet). Tested on 1052 X-ray images (526 fractured and 526 intact) obtained from Haikou People's Hospital, the system outperformed existing two-stage approaches, achieving 90.11% accuracy and a 90.14% F-measure [22].

III. MATERIALS AND METHOD

This research presents an innovative approach for detecting bone fractures in X-ray images by combining deep learning for feature extraction with classical machine learning for classification. In this study, the model is employed exclusively as a feature extractor, capturing detailed and meaningful representations directly from the original X-ray images. These extracted features are subsequently classified using Support Vector Machines (SVM) and Naive Bayes (NB) to differentiate between various types of fractures, as illustrated in the general workflow diagram of the study (Figure 1).

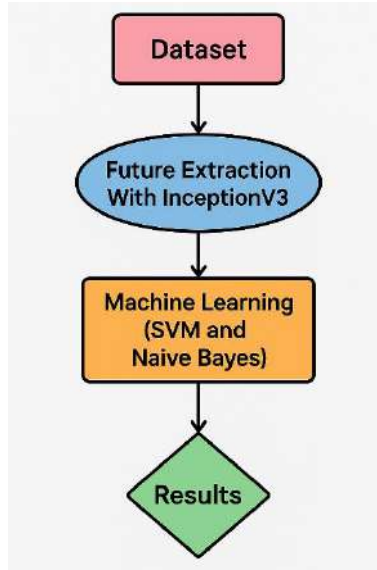


Figure 1. General flow diagram of the study

A. Dataset

The dataset used in this study consists of X-ray images prepared for the automatic detection of bone fractures [23]. The dataset consists of two classes: Comminuted Bone Fracture and Simple Bone Fracture. There are a total of 2384 X-ray images. Of these, 1173 belong to the complicated fracture class and 1211 to the simple fracture class. Each image is labeled according to its fracture type, and the balanced distribution between classes provides a significant advantage in the learning process of the algorithms.

The separation of the dataset into two classes focused the study on distinguishing simple and complex fractures. Thus, the ability of the classifier algorithms to accurately distinguish different fracture types was evaluated.

B. InceptionV3 Feature Extraction

InceptionV3 architecture has a very deep and complex structure in the field of image processing and has modules that can capture features at different scales simultaneously [24]. When employed within the framework of a transfer learning strategy, this architecture adapts the pre-trained weights acquired from large and diverse datasets such as ImageNet to X-ray images, thereby generating multi-layered and enriched feature vectors.

Specifically, the convolutional layers of InceptionV3 are capable of capturing not only fundamental features such as edges, textures, and shapes, but also higher-level and abstraction-based representations. The outputs obtained from the intermediate and final layers of the model are subsequently reduced into a more compact and discriminative form through a global average pooling operation [25]. This process allows the preservation of critical structural and visual information about the bone structure in X-ray images, while obtaining meaningful feature vectors that can be submitted as input to classification algorithms (SVM and Naive Bayes). In this way, the model's deep learning-based feature extraction constitutes an effective preliminary step in examining complex medical conditions such as bone fractures and firmly supports the basis of the classification process [26].

C. Classification

In this study, feature vectors extracted by InceptionV3 were classified using two different machine learning algorithms, Support Vector Machines (SVM) and Naive Bayes (NB), to determine bone fracture types.

Support Vector Machines (SVM): SVM aims to separate instances by the widest possible margin by determining the most appropriate boundary line or hyperplane between classes in a high-dimensional data space. This method is particularly effective in cases with complex and multidimensional feature vectors [27, 28]. In our study, we aligned the model with the intrinsic nature of the data distribution by selecting

an appropriate kernel function (e.g., linear or RBF kernel), thereby enhancing the separability between classes. Moreover, the hyperparameters of the SVM model were optimized using methods such as cross-validation, ensuring that the classification performance was maximized.

Naïve Bayes (NB): Naive Bayes is a probabilistic classification method built upon Bayes' theorem and based on the assumption of conditional independence among features. This approach models the distribution of features for each class and calculates the probability of an instance belonging to a particular class. Large-scale datasets particularly favor the NB algorithm due to its high computational efficiency and low memory requirements [29]. In our study, the extracted feature vectors were utilized to compute class-specific probabilities, with the aim of effectively distinguishing between different types of bone fractures.

Both algorithms were independently applied to the feature vectors extracted from InceptionV3, and the resulting outcomes were comparatively evaluated. The performance of the models was assessed using metrics such as accuracy, precision, recall, and F1-score; in addition, confusion matrix analysis was conducted to examine in detail the classes where the models performed strongly or weakly. This versatile classification approach integrates the powerful feature extraction capability of deep learning with the precise discriminative abilities of traditional machine learning algorithms, thereby offering a reliable and effective solution for bone fracture detection.

D. Performance Measures

In our study, various performance metrics were used to evaluate the classification success of the model. These metrics provide a detailed overview of the model's overall performance, its discrimination ability across each class, and its error distributions [30].

Confusion Matrix: A detailed representation of the model's classification results is given in Figure 2. This matrix contains the number of correct and incorrect classifications for each class [31]. This allows us to observe which classes the model makes errors in and which types of errors (false positives or false negatives) are most common. This analysis is an important tool for identifying model weaknesses and developing improvement strategies [32].

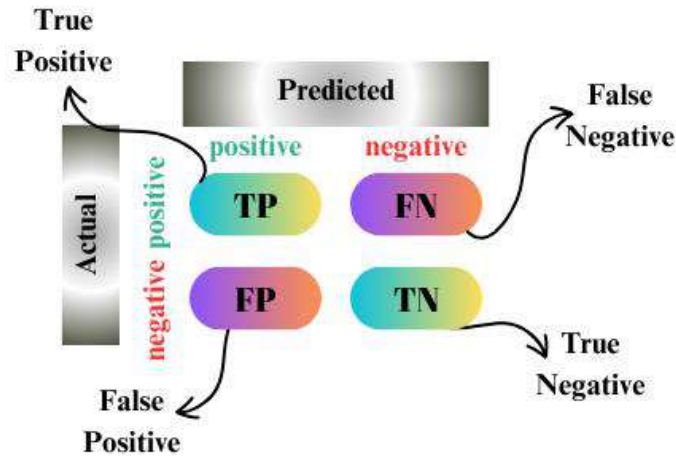


Figure 2 Confusion Matrix

Accuracy: It indicates the proportion of correct predictions the model makes across all predictions. This is calculated by dividing the number of correctly classified examples by the total number of examples. This metric reflects overall performance on balanced datasets, but can be misleading when there is an imbalance between classes [33, 34].

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

Precision: It indicates how many of the predictions made for the positive class are actually positive. In other words, it measures how accurate the model is in its positive predictions. Precision plays a critical role, especially in applications where false positives are a concern [35].

$$Precision = \frac{TP}{TP + FP}$$

Recall: It expresses how many positive samples can be correctly detected. It measures sensitivity by considering the number of positive samples missed by the model. This metric is especially important in situations where false negatives can have serious consequences [36].

$$Recall = \frac{TP}{TP + FN}$$

F1-Score: It summarizes the model's performance under a single metric by taking the harmonic average of precision and recall. This metric is particularly preferred when a balance between precision and recall is required [37].

$$F1 - Score = 2 \times \frac{Precision \times Recall}{Precision + Recall}$$

The combination of these metrics allows you to evaluate model performance multidimensionally. Especially in medical image analysis, it is critical to consider metrics such as precision, recall, and F1-score rather than focusing solely on overall accuracy, as false positives and false negatives can impact clinical outcomes [38].

IV. RESULTS

In this study, the integration of deep learning-based feature extraction and machine learning methods was addressed for the detection and classification of bone fractures from X-ray images. The InceptionV3 architecture was employed through a transfer learning approach to obtain rich feature vectors, which were subsequently evaluated using SVM and Naïve Bayes classification algorithms. The results presented in Table 1 numerically demonstrate the classification performance of the SVM and Naïve Bayes algorithms.

Table 1. SVM and Naive Bayes classification performance results

Model	Accuracy	F1-Score	Recall	Precision	AUC	MCC	Specificity
SVM	0.768	0.768	0.768	0.768	0.859	0.536	0.768
Naive Bayes	0.673	0.672	0.673	0.673	0.740	0.347	0.671

Performance measurements obtained from experimental analyses provide a detailed comparison of both classifier models. The SVM model achieved an accuracy rate of 76.8%, along with an F1-score of 0.768, recall of 0.768, precision of 0.768, Area Under the Curve (AUC) of 0.859, Matthews Correlation Coefficient (MCC) of 0.536, and specificity of 0.768. The NB model accuracy rate was calculated as 67.3%, and in addition to this value, F1-score of 0.672, recall of 0.673, precision of 0.673, Area Under the Curve (AUC) of 0.740, Matthews Correlation Coefficient (MCC) of 0.347, and specificity of 0.671 were obtained. Thus, the classification performance of both algorithms is presented in detail in line with the criteria given in Table 1.

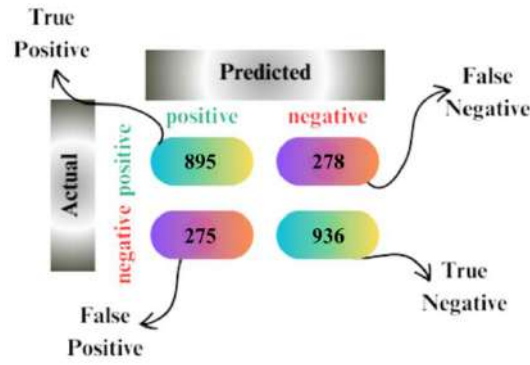


Figure 3. Confusion matrix of SVM algorithm

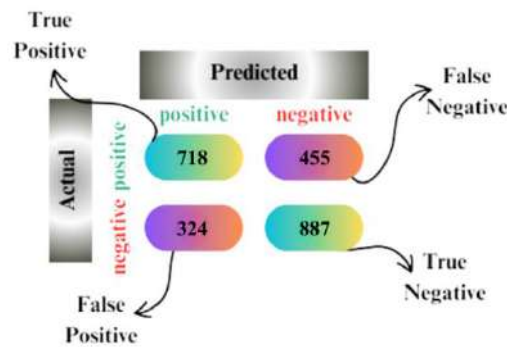


Figure 4. Confusion Matrix of Naive Bayes algorithm

When the confusion matrix presented in Figure 3 is examined, it is seen that the SVM model correctly classified 895 complicated fractures and 936 simple fractures; however, it incorrectly classified 278 complicated fractures as simple fractures and 275 simple fractures as complicated fractures. When the confusion matrix presented in Figure 4 is examined, it is determined that the Naive Bayes model correctly classified 718 complicated fractures and 887 simple fractures; however, it incorrectly classified 455 complicated fractures as simple fractures and 324 simple fractures as complicated fractures.

V. DISCUSSION

The results indicate that the SVM algorithm achieved higher classification performance compared to Naïve Bayes. This can primarily be attributed to the ability of SVM to model non-linear decision boundaries, which enables a more effective separation of fracture patterns in X-ray images. In contrast, the relatively lower performance of the Naïve Bayes algorithm may stem from the violation of the independence assumption among features in the real dataset.

An examination of the confusion matrices further revealed that both algorithms exhibited limited success in classifying complex fractures. While the SVM model correctly classified 895 complex fractures, it misclassified 278 cases; the Naïve Bayes model, on the other hand, correctly identified 718 complex fractures but misclassified 455 cases. Similar errors were also observed in the classification of simple fractures. These findings suggest that the morphological variability of fracture types and the structural complexity of X-ray images directly influence classification performance.

The findings demonstrate that although classical machine learning algorithms can process deep features extracted through transfer learning to a certain extent, they remain limited in achieving accuracy levels

sufficient for clinical applicability. Therefore, future studies employing more advanced deep neural networks, hybrid approaches, and large-scale balanced datasets are expected to contribute to more reliable and clinically applicable outcomes.

VI. CONCLUSION

This study employed InceptionV3-based transfer learning for feature extraction, followed by classification using SVM and Naïve Bayes. The results indicated that SVM achieved higher performance (76.8% accuracy, 0.859 AUC) compared to Naïve Bayes, although both algorithms had limitations in classifying complex fractures. Overall, classical machine learning methods provided only moderate discriminative power, suggesting that it takes future research with advanced deep learning models, hybrid approaches, and large-scale datasets to achieve clinically reliable fracture detection.

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The heading of the Acknowledgment section and the References section must not be numbered.

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Molecular Approaches to Determining Male Sterility in Carrots

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Abstract – Carrots (*Daucus carota* L.) are a significant vegetable species, extensively cultivated across the globe, and renowned for their high nutritional value. Hybrid seed production is of great importance in modern carrot breeding, and male sterility systems, particularly cytoplasmic male sterility (CMS), are used as one of the fundamental tools in this process. The use of CMS has been demonstrated to prevent self-pollination, thereby ensuring genetic homogeneity and concomitantly reducing labour costs in the context of hybrid production.

The most prevalent type of petaloid CMS in carrots manifests when male floral structures metamorphose into petal-like organs, a phenomenon that is predominantly favoured for its application in hybrid production, owing to its inherent stability.

In recent years, molecular markers have been integrated into breeding studies, resulting in the more efficient and reliable identification of CMS lines and restorer of fertility (Rf) genes. PCR-based markers, particularly those associated with mitochondrial genes (atp6, atp9), along with SSR and SNP technologies, are being effectively used in the identification of male sterility and genetic diversity studies in carrots. These developments shorten the breeding period and contribute to the development of high-quality hybrid varieties.

Keywords – Carrot, Cytoplasmic Male Sterility, Hybrid Breeding, Male Sterility, Molecular Markers.

I. INTRODUCTION

The genus *Daucus*, which includes the carrot, has many wild forms found in the Mediterranean basin and South-West Asia. The carrot is believed to have originated in Central Asia, where purple and yellow carrots were first found, and these colours later evolved into the orange varieties commonly cultivated today [1], [2]. It is known that carrots were used as a vegetable with edible roots in Afghanistan, Pakistan, Iran, and Anatolia around 900-1000 AD [3]. Carrots have a wide variation in root colour, including white, yellow, orange, red, black, and purple [4].

According to the FAO [5], 41,393,537 tons of carrots and turnips are produced worldwide on 1,127,948 hectares of land. China accounts for 45% of this production. In Turkey, 892,155 tons of carrots are produced across 14,765 hectares. Carrots are grown in many regions of Turkey, with the main production areas being Konya (638,800 tons), Ankara (159,917 tons) and Hatay (72,886 tons) [6].

The carrot plant generally flowers in its second year and has a hermaphrodite flower structure. Carrot flowers are compound umbels, formed by numerous flowers clustered together. The first flowering begins in the main umbel at the top of the plant. Each umbel consists of smaller umbels, and each umbel contains numerous individual flowers [7].

Male sterility can be observed in carrot flowers, and this structure is a mechanism used in hybrid seed production. The use of CMS systems is crucial in preventing self-pollination and ensuring genetic homogeneity [8]. By employing CMS in hybrid seed production, the success of modern carrot breeding programs is enhanced, and commercial production costs are reduced [9].

This study describes the identification of male sterility in carrots using molecular markers.

II. THE MECHANISM OF MALE STERILITY OBSERVED IN CARROTS

Male infertility is the inability of the male organs to function and produce viable pollen. The formation of hereditary male sterility is controlled either by certain genes on the chromosomes or by the interaction of genes in the cytoplasm and cell nucleus [10]. These types of male sterility are referred to as genetic male sterility, cytoplasmic male sterility, and cytoplasmic-genetic male sterility, respectively.

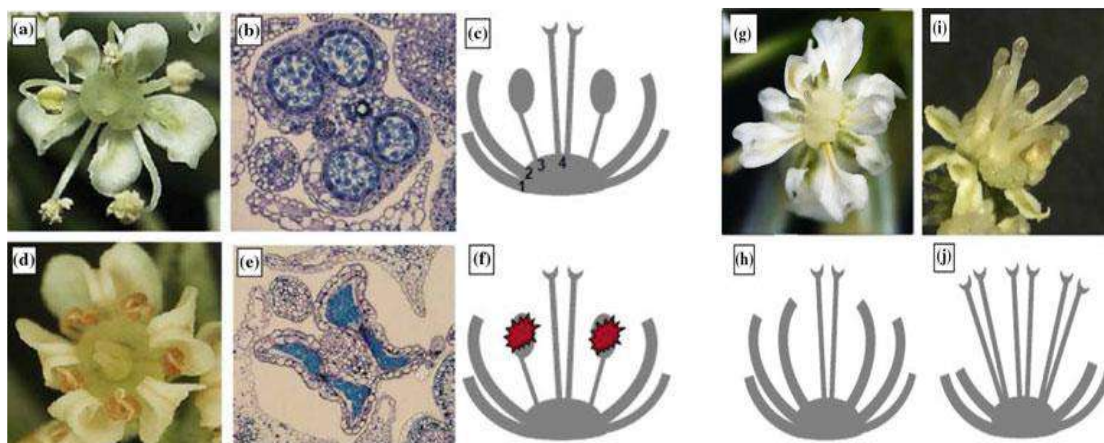


Figure 1. Flower types exhibiting normal and cytoplasmic male sterility in carrots (a–c: fertile flowers; d–f: Brown anther sterility; g–j: petaloid male sterility) [7]

CMS, the most common form of male sterility in carrots, is a trait that arises from the plant's inability to produce pollen and is widely used in hybrid seed production. This trait is inherited from the maternal parent and, due to its stability and ease of use, has become the preferred type of CMS in commercial carrot breeding [11]. CMS, particularly the 'petaloid' type, is of great importance in carrot breeding. Petaloid CMS is a condition in which the male organs (stamens) in carrots transform into petal-like structures, resulting in the inability to produce pollen [12], [13]. Petaloid CMS arises from the interaction of specific cytoplasmic factors with nuclear genes. This trait is cytoplasmically inherited, and fertility can be restored through dominant nuclear genes [14]. The CMS in carrots is primarily associated with mitochondrial open reading frames (ORFs) created by genomic rearrangements. In petaloid CMS, the mitochondrial *atp9* gene is significantly altered; the open reading frame is longer and is expressed at higher levels in sterile lines [11], [12]. These mitochondrial genes typically affect energy production or disrupt normal pollen development by causing cytotoxic effects in reproductive tissues [15]. CMS can generally be suppressed by restorer of fertility (Rf) genes encoding pentatricopeptide repeat (PPR) proteins [16]. Rf genes exert their effect by binding to CMS-associated mitochondrial transcripts and promoting their processing or degradation, thereby restoring pollen fertility [17]. This Rf gene, which is crucial for pollen production in carrot breeding, has been mapped to chromosome 9 in the carrot genome [8], [18].

When the final stage of division is reached in the brown anther male sterility type, meiosis is blocked, preventing the anthers from completing their development. They shrivel and take on a brown colour [19], [20]. The shriveled anthers fall off without bursting and lose their function [21]. The use of petaloid male sterility in the development of hybrid carrot varieties is around 70%. Brown anther male sterility is used in the production of the remaining varieties [22]. The reason brown anther male sterility is used less frequently in the breeding process is that it is less stable than petaloid male sterility [23]. Transferring sterility to self-pollinating carrot lines and producing hybrid seeds with this system is carried out in stages similar to other species. This process begins in the F₂ or F₃ generation, and sterility is crossed with selected fertile genotypes. The suitability of male fertile lines formed in subsequent generations for use as maintenance lines is determined through test crosses [24].

III. THE USE OF MOLECULAR METHODS FOR DETECTING MALE STERILITY IN CARROTS

Molecular markers play an important role in plant breeding, and various techniques and applications are used at different stages of the breeding process. The greatest advantage of using molecular markers is that they enable faster and more effective results compared to traditional breeding methods. In particular, the marker-assisted selection (MAS) method allows for the rapid selection of plants with desired traits. This method bypasses the process of examining phenotypic evaluations, enabling the much faster identification of plants carrying specific genetic traits [25], [26]. As with all plants, molecular markers in carrots facilitate the identification and selection of desired traits and play an important role in the development of new varieties. Another contribution of molecular methods to the carrot breeding process is the identification of male sterility. The molecular identification of male sterility in carrots is a complex process involving the identification of genetic factors contributing to male sterility, particularly CMS. CMS is an important trait in carrot breeding because it facilitates hybrid seed production. Iorizzo et al. [27] emphasised the importance of SNP markers in assessing genetic diversity in modern hybrid carrot varieties and understanding the genetic architecture of CMS. SNP markers are also frequently used in high-resolution genotyping and population structure analyses [28]. SSR markers are among the most commonly used markers in genetic mapping and diversity analyses in carrots due to their high polymorphism and codominant properties [29].

Bach et al. [30] studied the nucleotide sequences of genes located in the carrot genome to distinguish sterile petaloid cytoplasm from fertile normal cytoplasm. As a result of these two separate studies, the researchers developed 14 PCR-based molecular markers from the nucleotide sequences of the *atp1*, *atp6*, *atp9*, *atp8*, *nad6*, or *cob* genes to distinguish petaloid cytoplasm from normal cytoplasm.

Robison and Wolyn [31] found that the expression of the *atp8* gene was not related to petaloid cytoplasmic male sterility. Tan et al. [32] examined the expression of the *atp6* gene in different lines with male sterile and male fertile traits at different stages of flowering in carrots. They found that the copy number of the *atp6* gene was one in lines with male sterility and two in male fertile lines, and determined that the *atp6* gene was expressed differently in male fertile and male sterile plants.

Kalia et al. [11] investigated the relationship between the *atp9* gene and the morphological characteristics of Asian-origin carrots exhibiting petaloid male sterility, with the aim of distinguishing petaloid cytoplasm from male-sterile cytoplasm. They determined that characteristics related to flower structure, such as colour and shape in carrot flowers, were used to distinguish lines exhibiting cytoplasmic male sterility traits; they developed five molecular markers based on PCR associated with the *atp9* gene. In the gel image of the A + B primer combination included in the study, two bands of 260 bp and 350 bp were observed in all breeding lines carrying cytoplasmic male sterility, while two bands of 300 bp and 390 bp were observed in all lines carrying fertile lines (Figure 2). The results of the study confirmed that male sterile lines can be detected using molecular methods.

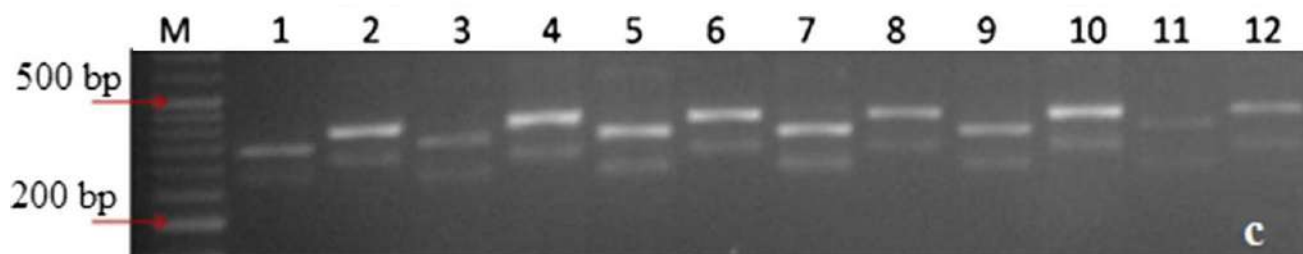


Figure 2. Gel pictures of primer combination A + B [11].

The utilisation of molecular methods is an unavoidable necessity in identifying carrots used as restorer parents to ensure the maintenance of male sterile lines. Cytoplasmic male sterile lines can be detected post-flowering in field conditions, although this is difficult. However, the restorer lines cannot be detected because it has a fertile flower structure. In this regard, molecular methods are used to identify the *Rf* gene mapped to the 9th chromosome in carrots [8],[18].

IV. THE USE OF MALE STERILITY IN CARROT BREEDING AND THE ROLE OF MOLECULAR METHODS

Carrots, due to their floral structure, are a vegetable species that makes hybridization and selfing very difficult. Using the male sterility system, carrots with flowers bearing nonfunctional male organs are identified as the parent and can be easily crossed with parents possessing the desired superior traits. This eliminates the need for emasculation [11], [13]. Furthermore, the use of male-sterile lines eliminates the possibility of self-pollination during crossbreeding, allowing for the successful production of hybrid seeds across large areas [11], [33]. The incorporation of molecular methods into the breeding process can accelerate the breeding process. Analysis performed at each generation allows for the elimination of undesirable genotypes and the rapid transfer of target genes [34].

V. CONCLUSION

In carrots, male sterility, particularly cytoplasmic male sterility (CMS), is a widespread method in modern hybrid variety development. Among petaloid and brown anther sterility types, petaloid CMS is particularly stable, making it a preferred method in hybrid production. This feature prevents self-pollination and enables the production of genetically homogeneous hybrid varieties across large areas. The advent of molecular markers has rendered the identification of male sterile lines and restorer genes a far more expeditious and dependable process than was previously the case with conventional methods. Researchers have developed markers for mitochondrial genes such as *atp6* and *atp9*, where male sterility is inherited in carrots. These markers reveal polymorphisms associated with CMS. SSR and SNP-based approaches have been shown to make significant contributions to the fields of genetic mapping, diversity analysis, and the identification of CMS lines. This has the effect of reducing both the time taken for breeding and the financial costs involved.

In anticipation of forthcoming research, it is hypothesised that a more comprehensive investigation of the molecular mechanisms underlying CMS in carrots is required. In addition, it is anticipated that genome editing techniques and bioinformatics-based approaches will facilitate a more profound comprehension of CMS mechanisms and present novel opportunities in breeding programmes. Consequently, the reliable determination of male sterility using molecular methods will continue to play a strategic key role in the development of hybrid carrot varieties, both scientifically and economically.

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Machinery-Related Marine Casualties in European Waters: Insights from the EMSA 2024 Report

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Abstract – Maritime safety has long been a priority in international shipping due to the severe consequences of accidents for human life and the marine environment. Within the spectrum of maritime casualties, machinery-related failures remain a frequent and disruptive category. They compromise propulsion and auxiliary systems, often leading to blackouts, collisions, groundings, or secondary events such as fires. Although international conventions, Safety Management Systems, and technological advances have contributed to reducing certain categories of accidents, machinery-related failures continue to persist at a significant and relatively stable frequency. Prior research has extensively examined collisions and groundings, while machinery-related casualties have received comparatively less systematic academic attention despite their consistent statistical presence in official reports. This study addresses this gap by conducting a focused analysis of machinery-related marine casualties in European waters, using the European Maritime Safety Agency’s Annual Overview of Marine Casualties and Incidents 2024. Drawing on EMSA’s 2024 overview, the Loss of control – Loss of propulsion power casualty event type accounts for 21.4% of ship occurrences and is virtually tied with Collision (21.3%) as the largest single category. The results confirm that machinery-related casualties constitute one of the most frequently reported categories of accidents, with cargo ships, passenger vessels, and fishing vessels all significantly represented. EMSA data further indicate that 650 fatalities and 7,604 injuries were reported across all marine casualties, with collisions and flooding/foundering identified as the primary fatality drivers. Machinery failures, while not the dominant cause of fatalities, are shown to act as initiating or compounding factors within escalation chains. The study emphasizes the need for preventive engine room strategies, enhanced predictive sensor monitoring technologies.

Keywords – Maritime Safety; Machinery Failures; EMSA 2024; Marine Casualties; Ship Machinery Systems.

I. INTRODUCTION

Maritime transport constitutes the backbone of international trade, carrying the majority of global cargo volumes by sea [1,2]. While shipping is widely acknowledged as the most energy-efficient and economically viable mode of transport, its operational safety continues to face significant challenges [3,4]. Maritime casualties, ranging from minor operational disruptions to catastrophic accidents, have long-standing implications for vessel safety, crew welfare, environmental sustainability, and the economic resilience of supply chains [5]. Among these, machinery-related incidents hold particular importance, reflecting both the technical complexity of shipboard systems and their central role in ensuring safe navigation and continuous operations [6-8].

The International Maritime Organization (IMO) has established a comprehensive framework of conventions and codes designed to enhance maritime safety and minimize accident risks. Conventions such as SOLAS (Safety of Life at Sea) and MARPOL (Marine Pollution) set global standards for vessel design, construction, equipment, and operation. The International Safety Management (ISM) Code mandates the implementation of Safety Management Systems (SMS) onboard vessels, emphasizing proactive risk identification, incident reporting, and continuous improvement [9,10]. Complementary to these instruments, the Standards of Training, Certification and Watchkeeping (STCW) Convention defines the minimum qualifications and competencies for seafarers. In the context of machinery-related accidents, STCW provisions on engine-room watchkeeping, maintenance practices, and emergency response are particularly relevant, as they directly influence the crew's ability to prevent, detect, and mitigate machinery failures before they escalate into casualties [11]. Within the European Union, the European Maritime Safety Agency (EMSA) plays a central role in supporting the implementation of IMO standards and in monitoring safety performance across EU waters. EMSA's Annual Overview of Marine Casualties and Incidents has become a key reference for policymakers, researchers, and practitioners, providing systematic statistics on accident types, contributing factors, ship categories, and human consequences. According to the 2024 report, between 2014 and 2023 a total of 22,343 ship-related occurrences were recorded, corresponding to 19,023 marine casualties with ship involvement. The most frequent casualty event types were loss of propulsion (21.4%) and collision (21.3%), together representing over two-fifths of all ship occurrences. Importantly, between 2018 and 2022, loss of propulsion overtook collisions as the leading casualty event type, underscoring the persistent vulnerability of ship machinery [12].

Ship machinery systems are inherently complex, consisting of propulsion engines, diesel generators, shafting systems, fuel and lubrication circuits, pumps, boilers, compressors, and auxiliary equipment. Failures in these systems may compromise propulsion, power generation, or steering, thereby creating immediate navigational hazards. For instance, loss of propulsion during restricted manoeuvres such as port approaches, canal transits, or congested waters can rapidly escalate into collision or grounding scenarios. Moreover, machinery failures often act as initiating events for secondary accidents: fuel system leaks may lead to engine-room fires; generator failures may disable emergency systems; and loss of steering control may render collision avoidance impossible [13-15]. EMSA data further indicate that while 650 fatalities and 7,604 injuries were reported across all marine casualties during 2014–2023, collisions and flooding/foundering were the primary fatality drivers, whereas machinery failures mainly contributed indirectly as initiating or compounding events [12]. Analytical studies of maritime accidents suggest that machinery-related failures are not isolated technical events but rather the outcome of complex socio-technical interactions. Maintenance policies, spare parts management, crew workload, training quality, and organizational culture all influence the probability and severity of machinery casualties. Inadequate implementation of preventive maintenance schedules or overreliance on “maintenance-free” components can leave critical vulnerabilities undetected until a failure occurs. Likewise, lapses in situational awareness, insufficient familiarity with emergency protocols, or delayed decision-making can exacerbate the consequences of a relatively minor malfunction. Therefore, machinery-related accident analysis requires an integrated approach that combines technical reliability assessment with human factors and organizational dimensions.

Over recent decades, maritime safety research has advanced from purely descriptive analyses toward structured methodologies capable of capturing this complexity. Probabilistic methods such as Fault Tree Analysis (FTA), Event Tree Analysis (ETA), and Bayesian Networks have been applied to quantify the likelihood of machinery failures and their potential escalation paths. Meanwhile, systems-theoretic models such as the Systems-Theoretic Accident Model and Processes (STAMP) have emphasized the role of inadequate controls, unsafe constraints, and feedback failures in accident causation [16,17]. Hybrid approaches that integrate probabilistic and systems-theoretic perspectives are increasingly employed to capture both technical failure pathways and organizational deficiencies. These developments highlight the potential of modern risk analysis methods to complement traditional accident investigations and improve

the resilience of ship machinery systems. Despite these methodological advances, there remains a notable gap in focused academic research on machinery-related casualties at a fleet-wide scale. Much of the existing literature concentrates on high-profile accident types such as groundings, collisions, or oil spills, while machinery damage is often addressed only in passing. EMSA's statistical reports, by contrast, regularly record the significant presence of machinery failures among casualties in European waters. Yet these reports remain primarily descriptive, providing counts and distributions without extending to deeper analytical interpretation or integration with systemic safety perspectives.

The present study addresses this gap by conducting a detailed examination of machinery-related casualties in European waters based on EMSA's 2024 dataset. Specifically, the paper aims to: (i) quantify the prevalence of machinery-related accidents relative to other casualty types; (ii) analyze their distribution across ship categories, severity levels, and temporal patterns; and (iii) discuss implications for preventive maintenance, Safety Management Systems, and risk assessment methodologies. By integrating empirical evidence with conceptual insights from accident analysis literature, the study contributes to a more comprehensive understanding of machinery-related risks in shipping operations.

II. MATERIALS AND METHOD

The present study relies on the Annual Overview of Marine Casualties and Incidents 2024 published by the European Maritime Safety Agency (EMSA). This report compiles data submitted by EU Member States through the European Marine Casualty Information Platform (EMCIP), ensuring a standardized and harmonized classification of accidents within the European maritime domain. The dataset covers the period between 2014 and 2023 and includes information on the number of casualties, affected persons, vessel categories, accident types, severity levels, and contributing factors.

A crucial methodological clarification is needed regarding EMSA's taxonomy. The overview distinguishes between "marine casualties and incidents" and "occurrences with ships." The former refers to casualty records, while the latter can exceed the number of casualties since a single accident may involve multiple ship occurrences. Between 2014 and 2023, EMSA reported 22,343 occurrences with ships and 19,023 marine casualties with ship involvement. Within this classification, the most frequent casualty event types were "Loss of control – Loss of propulsion power" (21.4%) and "Collision" (21.3%), which together accounted for over two-fifths of ship-related occurrences. Notably, between 2018 and 2022, propulsion loss outnumbered collisions, indicating a persistent systemic risk factor. For the purposes of this study, machinery-related casualties are operationalized through the "Loss of control – Loss of propulsion power" event type, supplemented by EMSA's broader accident event taxonomy where "System/equipment failure" represents 25.9% of all recorded accident events (2014/2023). This dual approach ensures both casualty-event and mechanism-based perspectives are considered.

The analysis combines descriptive statistics with comparative indicators derived from EMSA's aggregated data. Descriptive analysis establishes the proportion of propulsion-loss events within total marine incidents, as well as their temporal evolution across the ten-year period. Yearly changes and multi-year trends allow an assessment of whether machinery-related risks are increasing, decreasing, or stabilizing. Comparative indicators, such as the proportion of very serious incidents or ship losses among propulsion-loss cases, are used to highlight severity differences across vessel types. In addition, exposure-adjusted measures are integrated by referring to EMSA's EU ship occurrence indicator, which averaged 131 for all vessels, with 250 for passenger ships, 147 for cargo ships, and 63 for service and fishing vessels. Limitations of EMSA's aggregated dataset are acknowledged. First, the overview does not provide a detailed cross-tabulation of fatalities and injuries by specific casualty event type; instead, it supplies overall totals (650 fatalities and 7,604 injuries during 2014–2023). Second, variations in reporting practices among Member States may affect the consistency of less severe cases. Third, exposure data such as operational hours or fleet age distributions are incomplete, which constrains precise accident rate calculations. To address these issues, the present study interprets EMSA data descriptively and

supplements it with a Severity Index (SI) that weights outcomes (minor=1, serious=3, very serious=9, ship lost=12, fatality=15). The SI is applied at the occurrence level, with rules to avoid double counting when multiple outcomes (e.g., fatality and ship loss) co-exist. Sensitivity checks ($\pm 25\%$ on weightings) were also performed to ensure robustness of the rankings across ship types.

III. RESULTS

The findings of the EMSA 2024 Annual Overview confirm that machinery-related casualties, operationalized here as “Loss of control – Loss of propulsion power,” represent one of the most persistent categories of marine accidents in European waters. Over the reference period 2014–2023, EMSA recorded 22,343 occurrences with ships and 19,023 marine casualties with ship involvement. Within this dataset, propulsion-loss events accounted for 21.4% of ship occurrences, virtually tied with collision (21.3%) as the leading event type. Notably, between 2018 and 2022, loss of propulsion outnumbered collisions, reversing the trend of earlier years.

A. Temporal Trends and Stability of Occurrence

Across the ten-year period, machinery-related events demonstrated a stable presence, with fluctuations corresponding to global operational conditions. A marked decline occurred in 2020–2021, coinciding with the COVID-19 pandemic and reduced shipping activity. However, the number of events increased again in 2022–2023, returning to pre-pandemic levels. This persistence suggests that underlying technical and organizational risk factors have not been substantially mitigated, even as overall shipping activity has evolved.

B. Distribution by Ship Type

Propulsion-loss events are distributed across vessel categories with notable differences. According to EMSA’s EU ship occurrence indicator, the average across all vessels was 131. Passenger ships exhibited the highest indicator at 250, followed by cargo ships (147), while service vessels (63) and fishing vessels (63) recorded the lowest values. Cargo ships, given their numerical prevalence and intensive operating cycles, dominate the absolute number of machinery-related incidents. Passenger ships, despite fewer absolute cases, demonstrate higher exposure-adjusted risk levels. Fishing vessels show comparatively smaller counts but continue to appear in propulsion-loss statistics, raising concerns about maintenance practices and aging fleets.

C. Severity Distribution and Human Consequences

Most machinery-related casualties fall within minor or serious classifications, indicating that they are generally manageable. However, EMSA data confirm that a share escalates into very serious casualties or ship losses. Although EMSA’s aggregated statistics do not provide a precise breakdown of fatalities and injuries attributable solely to propulsion loss, the broader dataset reports 650 fatalities and 7,604 injuries across all marine casualties between 2014 and 2023. The majority of fatalities are linked to collisions and flooding/foundering. Machinery failures, while not the dominant fatality driver, frequently act as initiating or compounding factors that can escalate into severe outcomes when redundancy and emergency response are insufficient.

D. Types of Failures and Cascading Effects

The “Loss of propulsion power” category encompasses failures in propulsion engines, auxiliary systems, and control mechanisms that directly impair manoeuvrability and power supply. These failures can cascade into secondary events: for example, propulsion loss in congested waters may culminate in collisions or groundings; generator blackouts may disable navigation and emergency systems; and fuel or

lubrication leaks can lead to engine-room fires. EMSA's aggregated data, while not offering subsystem-level detail, reinforce that propulsion-related failures often serve as initiating points in wider accident chains.

E. Comparative Risk Indicators

To better capture the relative impact of machinery-related casualties, this study applied additional comparative indicators derived from EMSA's aggregated dataset. A central limitation of the Annual Overview of Marine Casualties and Incidents is the absence of exposure denominators such as fleet size, vessel age, or operating hours, which prevents the calculation of precise accident rates. For this reason, the present analysis employs relative comparisons within the dataset and supplements them with EMSA's EU ship occurrence indicator. This indicator provides a normalized measure of occurrence frequency by vessel type, reported as 131 overall, with significant variation across categories: 250 for passenger ships, 147 for cargo ships, and 63 for both service and fishing vessels. These values underline the comparatively high exposure-adjusted risk of propulsion-loss events for passenger ships and the lower but non-negligible burden for fishing vessels. On the basis of severity distributions, the proportion of very serious casualties and ship losses among machinery-related cases was examined across vessel types. The results indicate that fishing vessels and tankers may face higher severity ratios when propulsion loss occurs, despite contributing fewer cases in absolute numbers. Fishing vessels often operate with small crews and older tonnage, which reduces redundancy and increases vulnerability to critical failures. Tankers, although generally subject to stringent technical standards, face high-consequence risk profiles because propulsion or power failures in these vessels can escalate into environmentally significant incidents. By contrast, cargo ships, which dominate in absolute frequency due to their prevalence and operational intensity, show a broader spread across minor and serious categories, while passenger ships though fewer in propulsion-loss events carry higher potential for human consequences because of the large onboard populations.

This study developed a Severity Index (SI) that assigns weighted values to different casualty outcomes: minor = 1, serious = 3, very serious = 9, ship lost = 12, fatality = 15. This weighting system was applied to propulsion-loss events to produce a composite indicator reflecting both frequency and consequence. Using this approach, cargo vessels ranked highest overall, reflecting their large number of reported events. Fishing vessels ranked disproportionately high when severity was considered relative to fleet scale, confirming their elevated vulnerability in proportion to operational capacity. Passenger ships also scored highly, primarily due to their potential for mass casualties and significant human consequences even when machinery failures were contained before escalating into vessel loss. Tankers, while lower in frequency, displayed high severity indices in the relatively small number of cases where machinery failures occurred, underlining their potential to trigger cascading technical or environmental emergencies. Taken together, these findings demonstrate that supplementary analytical tools such as the SI can meaningfully extend EMSA's descriptive statistics. By weighting outcomes and incorporating exposure-sensitive indicators, the analysis provides a more differentiated picture of machinery-related risks across vessel categories.

F. Summary of Findings

Taken together, these results indicate that machinery-related casualties in European waters are systemic and persistent. They consistently represent about one-fifth of all ship-related occurrences, and in several recent years surpassed collisions as the leading casualty type. Cargo ships dominate in absolute frequency, passenger ships show high exposure-adjusted risk, and fishing vessels reveal disproportionate severity. A non-negligible proportion of these cases escalate into very serious incidents or ship losses, demonstrating their potential for significant operational and human consequences. The cascading nature of propulsion failures confirms that machinery reliability remains a central determinant of maritime safety

and supports the case for more predictive maintenance, redundancy measures, and STCW-compliant crew preparedness.

IV. DISCUSSION

The results of this study confirm that machinery-related casualties, operationalized as loss of propulsion power, remain a structurally embedded risk factor in European maritime operations. Despite decades of regulatory evolution and technological advances, propulsion-loss events accounted for 21.4% of ship-related occurrences between 2014 and 2023, placing them virtually equal with collisions (21.3%). In several years, particularly between 2018 and 2022, propulsion-loss events even surpassed collisions, underscoring the systemic and persistent nature of machinery-related risks in the shipping industry.

A central finding concerns the distribution across ship types. Cargo vessels dominate in absolute terms, reflecting both their prevalence in the fleet and their intensive operational cycles. Passenger vessels, although fewer in number, register the highest occurrence indicator (250 vs. 147 for cargo ships), which indicates greater exposure-adjusted risk. Their large onboard populations also create higher potential for human consequences even when machinery failures are contained. Fishing vessels, by contrast, represent a smaller share of total cases but display disproportionately high severity relative to fleet size. This can be linked to aging fleets, lower redundancy in technical systems, and more variable maintenance practices. Tankers, though less frequent in propulsion-loss incidents, reveal higher severity ratios when failures occur, as even limited machinery disruptions can escalate into environmental emergencies. These distinctions suggest that risk mitigation strategies must be tailored by vessel category, with emphasis on redundancy, preventive monitoring, and crew preparedness in passenger and fishing segments, and environmental safeguards for tankers. The types of failures highlighted in EMSA's casualty event classification propulsion loss, auxiliary engine blackouts, steering gear malfunctions, and pump/boiler breakdowns demonstrate how machinery damage can act as initiating events in cascading accident scenarios. A blackout resulting from auxiliary engine failure can simultaneously disable navigation, communication, and emergency systems, increasing the risk of collision in congested waters. Similarly, a leak in a fuel or lubrication system can escalate into an engine-room fire upon contact with hot surfaces. These patterns reveal that effective safety management requires not only component-level reliability but also system-level resilience through redundancy, shielding, and rapid detection mechanisms.

The persistence of machinery-related failures raises critical questions about the adequacy of existing maintenance regimes. The continued high frequency of propulsion-loss incidents suggests that time-based or condition-based approaches alone may not be sufficient to prevent critical degradations. Past investigations cited by EMSA also note cases where reliance on so-called "maintenance-free" components delayed inspections and allowed hidden defects to accumulate until failure occurred. This underlines the necessity of transitioning toward predictive and data-driven maintenance strategies. Real-time condition monitoring, vibration and thermal analysis, and automated fault-detection systems could provide earlier warnings and reduce the likelihood of escalation.

Human and organizational dimensions remain equally central. While the STCW Convention emphasizes the ability of engine-room watchkeepers to identify and respond to machinery anomalies, EMSA records indicate that delayed recognition and inadequate emergency response remain recurring contributory factors. This finding supports the case for enhanced training programs, realistic simulator exercises, and periodic emergency drills covering blackouts, propulsion loss, and engine-room fire scenarios. Organizationally, although the ISM Code requires companies to implement Safety Management Systems, the recurrence of machinery casualties suggests that many SMS frameworks do not fully integrate machinery vulnerabilities into hazard identification and control processes. Stronger auditing and oversight from classification societies and flag administrations may be required to ensure

that machinery-related risks are systematically embedded in company safety practices. From a methodological perspective, EMSA's dataset provides valuable descriptive insights but remains limited in terms of probabilistic dependencies and causal analysis. Future applications of advanced risk modeling methods such as Fault Tree Analysis (FTA), Bayesian Belief Networks (BBN), and Systems-Theoretic Accident Model and Processes (STAMP) could better capture the escalation pathways, feedback failures, and barrier breakdowns that descriptive statistics alone cannot reveal. Hybrid approaches that combine probabilistic and systems-theoretic perspectives appear particularly promising for extending EMSA's aggregated statistics into explanatory frameworks that can inform proactive interventions.

The persistence of machinery-related casualties, even as other accident categories such as collisions and groundings have shown relative stabilization, suggests that these events may be less responsive to conventional safety interventions. Navigational errors, for example, have been partially mitigated through digital systems such as ECDIS and AIS. Machinery failures, by contrast, are often rooted in material degradation, physical wear, and complex socio-technical interactions that are harder to eliminate through standard regulations or technologies. Long-term solutions will require not only regulatory compliance but also fleet renewal, modernization of propulsion systems, integration of alternative fuels (e.g., LNG, hydrogen, ammonia), and predictive maintenance technologies. EMSA's 2024 data confirm that machinery-related casualties represent a persistent and systemic challenge shaped by technical, human, and organizational factors. Their recurrence indicates that existing maintenance regimes, training programs, and SMS frameworks must be strengthened.

V. CONCLUSION

This study has provided a focused examination of machinery-related marine casualties in European waters, based on the EMSA 2024 Annual Overview of Marine Casualties and Incidents. The results confirm that machinery damage, categorized primarily as "loss of propulsion power," is among the most frequent types of maritime accidents, consistently accounting for about one-fifth (21.4%) of all ship-related occurrences between 2014 and 2023. In several years, particularly between 2018 and 2022, propulsion-loss events even outnumbered collisions (21.3%), highlighting the persistence of machinery failures as a leading accident category. Despite regulatory advances and technical improvements, such failures remain recurrent and impactful, leading to significant operational disruptions and, in a share of cases, escalating into fatalities, injuries, or total vessel losses.

The findings demonstrate that machinery-related accidents are not confined to a single vessel category but are distributed across the fleet. Cargo ships dominate in absolute numbers, reflecting their prevalence and intensive operating patterns. Passenger ships show the highest occurrence indicator (250 compared to 147 for cargo ships), indicating greater exposure-adjusted risk and higher potential human consequences due to large onboard populations. Fishing vessels exhibit comparatively severe outcomes relative to fleet scale, often linked to aging tonnage, limited redundancy, and variable maintenance practices. Tankers, while less frequent in propulsion-loss cases, display higher severity when failures occur, given the potential for environmental consequences. The analysis further shows that propulsion loss, auxiliary engine blackouts, steering gear malfunctions, and pump or boiler failures often act as initiating factors in cascading accident chains that may escalate into collisions, groundings, or fires. From a safety management perspective, these results underline the urgent need to strengthen preventive maintenance regimes, predictive monitoring, and redundancy strategies. Over-reliance on scheduled or so-called "maintenance-free" components risks leaving hidden vulnerabilities undetected, underscoring the importance of integrating data-driven condition monitoring and predictive maintenance practices. Human factors remain equally critical: timely detection, appropriate decision-making, and adherence to STCW-mandated watchkeeping and emergency protocols are decisive in preventing escalation. Organizationally, Safety Management Systems must better integrate hidden machinery vulnerabilities into hazard identification, crew training, and verification processes. Methodologically, this study shows that descriptive accident statistics such as those provided by EMSA can be extended through structured risk

assessment methods. Approaches including Bayesian Belief Networks and Fault Tree Analysis can capture dependencies, uncertainties, and systemic failures that descriptive counts alone cannot reveal. Their integration with accident datasets offers potential to identify high-risk combinations of vessel type, operational condition, and machinery subsystem, thereby supporting more targeted regulatory and operational interventions. Machinery-related casualties thus represent a systemic and persistent challenge for the European maritime sector. Their prevention requires an integrated approach combining technical reliability, human competence, and organizational resilience.

This study is limited by its reliance on EMSA's Annual Overview, which provides aggregated statistics rather than case-level microdata. As such, the analysis cannot reconstruct detailed causal chains or isolate specific technical or organizational failures. Reporting practices may vary across EU Member States, leading to possible inconsistencies or underreporting of less severe incidents. Furthermore, exposure data such as vessel operating hours or fleet age distributions are not systematically available, constraining the ability to calculate precise accident rates and normalize risks across ship categories. Future research should build on these findings by linking EMSA casualty data with fleet exposure information (e.g., ship age, tonnage, operational hours) to enable more robust rate-based comparisons. In addition, as the shipping industry transitions toward alternative fuels and propulsion systems (LNG, hydrogen, ammonia), further studies should assess how machinery-related risks evolve under these technologies. Comparative analyses beyond Europe could also establish whether the patterns observed in EU waters are globally representative or shaped by specific regulatory and operational contexts.

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Remarks on Extension of Common Models for Studying Legislation Coherence and Effectiveness

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Abstract – In order that legislation packages would fulfil their purposes regarding establishing standards, resolving disputes, guaranteeing sustainable progress, the facts-gathering processes and post-ex evaluation activities need for accurate measurement and appropriate analysis based on them. This technical requirement becomes particularly important for transiting democracies due to the elevated rate of legislation's amendments and reviews, and for affording the challenges concerning legislative suitability and their juridical completeness. Also, the adequacy of sociometric measurement is helpful for civic organizations to advance their analysis, contribute to a better generalization for observed behaviors, and become supportive for official agencies to implement cost-effective legislative procedures. An additional benefit from enhancing direct and indirect sociometric measurement is related to the management of the elevated AI and networking activities and volatility of the opinion dynamics and beliefs. On the other side, a direct measurement of desired quantity is very difficult and questionable, which can be overwhelmed by considering the mirroring portrays in the public perception., due to high dimensions of the system, by considering general perception in the role of latent variable In this framework we have presented herein some arguments for improving the measurement in heterogeneous and evolving mediums, and their measurement through . We highlight the interdisciplinary approaches for achieving this goal by contemplating the use of indexes theory and the Rasch models in an adaptive context, reviewing distribution's identification in order to refine statistical calculation, and by adopting sequential sampling for measuring small size sociometric systems where classical procedures are difficult to implement or costly.

Keywords – Legislation, Statistical Analysis, Modelling, Sociometric Measurements.

I. INTRODUCTION

The analyses of legislation coherence and effectiveness throughout ex post evaluation, auditions and other reviewing instruments have highlighted the prerequisite of improving measurements and advancing quantitative analysis in political studies. It is in line with nowadays approach of advancing quantitative analyses in sociometry, political science and modern sociology. The elevated requirements for legislative-normative quality and productive policies, for audition efficacy and the need for continuous evaluation of the institutions' performance, prompted the need for extended and accurate measurement in the framework of ex post evaluations. It is highlighted especially from frequent amendments in developing countries and transiting democracies such as Albania for example. Meanwhile, ex-ante and ex-post evaluation alongside *asquai commentaire* are common political approaches nowadays. However, measuring those quantities is not easy, nor a straightforward standard procedure. In fact, the direct measurement of the corresponding quantities would result too noisy for consideration, whereas by modelling them as latent variables and using a few more numerical calculation, reliable results would be found. Notice that political science has

sanctioned in principles research techniques and methodologies with typologies like econometric or sociometric studies of all natures and levels, see [2], [3], [1] [4], etc., but considering the complexity imposed from behavioural variables such as attitudes, perceptions, etc., in order to evaluate indirectly another variable such as a performance, an profitability, an audit outcome, a policy, success of a reform etc., additional precaution is required. Thus, whereas the public or community support for an issue can be measured directly, the ex-ante evaluation of a legal norm is more difficult, because the measurable quantity herein behaves like a latent variable, which expressed in public perception but is not identical to it. In this context, ex-post evaluation, auditing, performance evaluation, etc., are attracting the attention of researchers in interdisciplinary fields, in addition to dedicated analyses of political science and monitoring agencies. Quantitative methods and the level of precision required by them are conditioned by the analytical framework, which implies the need for purpose-oriented research guidelines, in addition to statistical protocols. In this regard, there is a set of good practices, and regulatory acts of the European Community institutions, see [5], that can be directly implemented by audit or monitoring agencies, especially for ex post evaluations. Meanwhile, if the analyses are theoretically oriented, as discussed in [3], etc., interdisciplinary approaches would be helpful. On the other cases, such as the ex-ante analysis, where a norm or legislative act is projected to a desired future situation or to an intended effect, quantitative techniques became complicated and implementing straightforwardly protocols or methodologies become questionable. In response to similar demands for efficient quantitative methods, sociometry has evolved towards interdisciplinary treatments and complex systems approaches. So, from simple techniques for measuring connections in social groups [6], it has improved its research capabilities to the level of exact science because of methodological exchange with network disciplines initiated by [7], with sociophysics [8] etc. Furthermore, sociologists are using sociometric experiments as a research tool for testing their hypotheses, [9], or for analysing specific structures as in [10]. Thus, in [11] network techniques have been used in legislative research, and today, computational political science has become a reality, [12]. In this context, there exists a solid theoretical basis and a variety of methods for conducting measurement and performing quantitative analysis for systems of legislation' evaluation a public perception regarding their efficiency. Moreover, these arguments indicate that conducting detailed analysis like those of exact sciences, especially regarding measurement accuracy and modelling adequacy, is very important. Meanwhile, such systems are typically behavioural-based entities, hence, heterogeneous and dynamic, that allocate them apart from theoretical assumption for conducting measurements or employing modelling. Consequently, discussing the conditions of measurement turns out to be a procedural step to guarantee the quality of the product. When it comes to activities with such a great impact on society such as laws, norms and general regulation or policies, even small improvements in predictive capabilities or measurements would bring tangible results. An accurate measurement means a realist knowledge that reduces political pressure on the legal norm, amortizes the tendency of expansive interpretation by executing bodies and promotes the culture of law. Bearing in mind this contextual approach, through this paper we aim to contribute to a substantive debate on the quality of measurements and reports for law implementation and efficiency in the country, by advocating the culture of numbers over theorized arguments for explaining political issues for our system but not limited to. Improving the quality of data and direct or indirect measurements, the calibration of measuring instruments in a broad definition of them, is seen herein as a requirement for scientific correctness and a general regulatory imperative that must be taken into consideration by public agencies that gather data and elaborate them in the framework of official or nonofficial statistics.

II. MATERIALS AND METHOD

The classical instruments for direct measurements of social systems are mainly surveys and questionnaires, while for indirect measurements, this role is executed by the model itself. The data collecting analyst apprehend the fulfilment of conditions under which standard the instrument is considered calibrated and guarantee the sensitivity, validity and reproducibility of the measurement, whereas methodologist concern on the associating capability the concept under consideration with a numerically measurable variable. In addition, the systems of perception of norms are dynamic in time, have

spatial heterogeneity, which implies the need for the adaptation of measurement instruments, reassessment of statistical procedures, etc. Socio-political measurements are more complicated than physical or technical ones due to the emergence of additional dimensions or freedom degree related to entities where the measurement is carried out, such as respect for ethical principles, voluntariness, non-harm, anonymity and confidentiality. For example, voluntary participation in a survey limits the randomness of the selection, the principle of non-profit or non-harm, can damage the rigor of the response. Addressing these limitations requires special care in probability sampling, which is the starting stage in these measurements. Also, the data can be involuntarily contaminated by the person that admit answering the survey. To deal with those problems, an intriguing idea comes from the analysis of the conceptual knowledge in schooling, by using the so-called Concept Inventory test (CI) and methodologies. In those analysis, the ground paradigm is that the answering are based on a latent variable, the conceptual knowledge, and that the probability for giving a certain answer depend on individual knowledge and items' difficulty, $P \sim f(Individual.Knowledge, Difficulty.Question)$. we will elaborate this procedure later, but for now, we notice that a CI approach is a good alternative for measuring latent variables such as the efficacy of norms, etc. The result would be apparently bolded for measurement in political issues or more complex cases, the perception of the legislative efficiency, which require deeper knowledge rather a simple perception. The problem becomes harder if we try to build a questionnaire. A contribution to overcoming these difficulties is the piloting of questionnaires, the guarantee of statistical conditions on which the calculation formulas are based, and the calibration of measuring instruments. Other elements such as guaranteeing randomness in probabilistic selection and the justification of the unique distribution of the variable of interest will be addressed subsequently. In the case of surveys with the aim of measuring complex issues such as those related to the expression of attitudes or individual views, the issues of survey validity, reproducibility and reliability are related to both the validation of the method and the calibration of the survey itself. In this regard, pilot measurements are a recommended step in the literature. If the variable has specifics of complexity, then the effects of nonlinear dynamics, etc., should be considered, see [13] etc. The need for calibration is related to the intended accuracy of the measurement and the matching of the methodology with the system we are measuring, and in practice, both components are interconnected. Thus, if we focus on the systematization of basic research rules and steps as analysed in [14]), the measuring instrument is presumed calibrated and the research interest focuses on the system itself, so a relaxed state and sufficient homogenization are aimed for. But if the questionnaire is not standardized or certified, piloting is a very important step, especially to avoid burdensome numerical calculations, or more advanced techniques such as bootstrapping (sampling resampling), [15], etc. Piloting or measuring in a small sample is highly advisable for the statistical practice of surveys and questionnaires. Through the piloting process, researchers are provided with ensuring firstly the validity of the measurement, consisting of (1) content validity by determining the validity of the questionnaire content, (2) construct validity of the questions (i.e. the answer is directly related to the intended question, not other elements), and (3) face validity (i.e. the interviewee clearly understands what he or she is supposed to answer). Validity is measured by taking the judgment of the evaluators with the CVR index (content Validity Index) $CVR = \frac{N_e - 0.5N}{0.5N}$, where N is the number of evaluators and N the number of those who have assessed a question as 'content'. Second, for guaranteeing reliability. Through retesting in the pilot phase, the consistency of the responses is identified throughout internal consistency and external consistency, i.e. different measures find the same answer. In this analysis, alpha Chronbah $\alpha = \frac{n}{n-1} (1 - \frac{\sum_{i=1}^n \sigma_{x_i}^2}{\sigma_x^2})$ is a widely used estimator (called an index). Here n is the number of questions in the questionnaire, σ_{x_i} is the variance associated with question (i) and σ is the total variance. High value of the alpha-chronbah coefficient at the pilot stage is a good premise that the measuring instrument is functional. Experts can also perform a second filter, after carrying out the full-scale measurement. In the following, we will bring an adaptation of this ideain detail the materials and methods used when conducting the study. The citations you make from different sources must be given and referenced in references.

A. Adapting indexes for certifying the drafting questionnaire

Researcher can improve testing but cannot influence the system itself, which may be non-homogeneous, non-isotropic and unrelaxed. It might happen that a person demonstrates biased judgments, do not provide rational thoughts, or chose an answer without knowing the issue. When conducting a survey for measuring the performance of a law, a norma, regulation or entirely governance quality, these effects become harshly for the data integrity, entreating a preliminary evaluation of questionnaire reliability. It followed that before fixing a test prototype, we need to calibrate it as an instrument for measuring a variable which in general, could be hidden ore latent one. For this procedure, we can initially consider the fulfilling of general conditions for a test reliability: Starting by calculating the CVR index is mandatory but does not suffice. It contemplates a professional or expert review of the test, but when going to employ it in a community, the above-mentioned issues become decisive. After a careful analysis of formulation of the items being questioned, several shortcomings could harm the measurement. Good practices suggest piloting the questionnaire, but when discussing the result, quantitative assessment is indispensably needed. In this regard, we have borrowed an idea for checking Concept Inventory tests, which might consist to analysing the test itself, or to verify the adequacy of sampling. For this procedure we have proposed a step-by-step analysis for the data analysis; we propose to consider also an adaption with advanced procedures for test analysis. Meanwhile, for similar situations we might borrow the index theory analysis introduced by J. Ding, in analysing Concept Inventory tests. A rude representation of this idea is represented in Table 1.

Table 1. Ad hoc extension of Indices

Index	Formula *	Desired Rank*	Possible explanation, if the index is outside the target range
Difficulty Suggestion: In understanding	$\delta_i = \frac{n_{\text{Correct}}^{\text{answer}}}{N}$ $\delta_{\text{test}} = \frac{1}{n_i} \sum_{i=1}^{n_i} \delta_i$	0.3-0.9	Confusing question or unclear content
Discriminati on	$d = \frac{(N_{\text{Succses}}^{\text{highestScore}} - N_{\text{Succses}}^{\text{lowestScore}})}{N} p\%$ $D_{\text{Test}} = d_{\text{avg}}$	>0.3	Question not suitable for distinguishing very supportive from very rejecting attitudes
Cronbach alpha	$r_i = \frac{\tilde{x}_i - \bar{x}}{\sigma(x)} \sqrt{\frac{\delta_i}{1 - \delta_i}}; r_{\text{avg}} = \frac{1}{n_i} \sum_{i=1}^{n_i} r_i$	>0.2	Responses are not based on solid knowledge of procedures. Re-doing the survey may yield different results
Discriminati ve power	$\rho_{\text{test}} = \frac{n_i}{n_i - 1} (1 - \frac{\sum_{i=1}^{n_i} \sigma(x_i)}{\sigma^2(x)})$	>0.7	Question/Questionnaire does not distinguish attitudes well as a whole
Self- consistency index	$\Delta = \frac{N^2 - \sum_{i=1}^{n_i} f_i^2}{N^2 - \frac{N^2}{n_i + 1}}$	>0.7	Questionnaire is not self-consistent; questions do not assess the whole

Legend. *The desired rank corresponds to the original CI indices, and further adjustments may be needed. **The explanation is based on a factual attempt, i.e. the researcher can reformulate according to the meaning of the answer.

B. Facilitating indirect measurement by the Rasch model approach

For assessing public perception or judging regarding complex social issues such as governance performance or legislation effectiveness a similar procedure such as Conceptual Knowledge test for

understanding in science can be proposed straightforwardly. When disusing governance performance, employing classical surveys is associated with immense effort to avoid political biased respondents who tend to pronounce partisanship rather than an objective thought. On the other side, the assessment of legislation efficacy is more complex. Firstly, one needs for very careful formulation of the questions, and next, we might address the questionnaire to experts only, in order to have meaningful response. To avoid those complications, we propose to use an indirect measurement of key quantities by considering them as latent variable. In this case, by formatting the questions in an appropriate way, we might use the capability of the Rasch model for calibrating the model and for identifying symptomatic deviances which can be treated further by the model. In order to clarify the procedure, we are introducing very shortly the key parameters of the Rasch model used in original application of analysing students' conceptual knowledge in science. Original CI analysis is based on a CI test which contain a set of question that can be answered correct or incorrect, hence a binary assignment (0,1) is logical. So, after conducting the test in a sample of students, the answers are transformed in numerical values (0,1) and are recorded in a matrix V . Now, the classical grade or knowledge for student (i) is estimated by the fraction $a_i = \frac{1}{n_{questions}} \sum_j V(i,j)$, and the result for the entire group and also the perceived ease for question (j) $b_j = \frac{1}{N_{students}} \sum_i V(i,j)$. Next, we observe that a_i represents also the probability that students (i) resolve the whole test and b_j the probability that all students resolve question (j). While those parameters are final in a classical test, we might doubt that they accurately express respective probabilities. So, if the student (i) was only 51% certain for the answer but nevertheless he has concluded, i.e. $V(i,j) = 1, P_{real}(i,j) = 0.51 \neq V(i,j)$! Further, it turns out that the quantities a_i and b_j do not guarantee the homogeneity or linearity of the scale, which can be seen directly if we compare the abilities of students A, B, C and D who received 90%, 80%, 30% and 20% of the points. Thus $a_A - a_B = a_C - a_D = 10\%$ but student (A) solved a difficult exercise by more than B while C solved an easy exercise by more than D, i.e. the real differences between the abilities are different! Detailed analysis regarding those arguments can be found in original works of [17],[18] or in application observation of [19], etc. We conclude that according to IRT assumption which we are skipping herein, the exact estimators should be based on the logistic function of the response, namely on the new 'logit' units:

$$\alpha_i = \ln \frac{a_i}{1-a_i} ; \delta_j = \ln \frac{1-b_j}{b_j} \quad (3)$$

The quantities (3) are global, representing the answer to the set of all questions and the reaction of the whole group to a question respectively. After this linearization step, the Rasch method proposes to re-estimate the probability of giving the correct answer, by using a trade-off idea. In the logistic model approximation this quantity is estimated:

$$P_{estimate}(i,j) = P(V_{real}(i,j) = 1 | \alpha_i, \beta_j) = \frac{e^{\alpha_i - \beta_j}}{1 + e^{\alpha_i - \beta_j}} \quad (4)$$

Next, the model proposes to replace (4) successively starting from $V(i,j)$, until an estimator of the deviation falls below a threshold, [17-19]. After this procedure, the products are analysed. For example, if the test is ideally good, the spectrum of difficulties and abilities matches; the discrepancy is studied and interpreted. The quantities α_i^{final} and δ_j^{final} not only are better estimators than the initial ones (3) but behave as special projections of the latent trait. 'Pathological' cases are also identified, e.g. if $V(i,j) = 1$ and $\alpha_i < \delta_j$, from (4) $P(i,j) < 0.5$ then the difficult question was answered by a low skill student, which does not make sense, i.e. we have an event that needs to be inspected. Similarly in the other case. Finally, the method identifies bad statical events called outfits and infits that also, report heterogeneity, failure of fulfilling assumptions and many more. Thus, the Rasch model offers a true radiography of the test/survey/questionnaire, as it highlights latent elements, invisible to the optics of ordinary measurements. This methodology can be directly extended to the Polythmous Rasch model where the variable of interest is measured with h levels, such as the Likert scale. Now, following this model, and by arguing the fulfilment of assumptions and thetical prerogatives of this model, we could use it to measure our latent variables. It starts by editing a questionnaire with N_q questions in some important issues and collecting the answers of all N_r respondents $a(i,j)$ that can be evaluated by 1 or zero for supportive or non-supportive attitude. In this scenario, the sum of the supportive values for a certain respondent divided by number of question

$S_{individual} = \frac{1}{N_q} \sum_{i=1}^{N_q} V(i, j)$ and $S_{comunty} = \frac{1}{N_{respondents}} \sum S_{individuals}$ is the preliminary estimator for the overall support. We might assume that this feature behaves like a latent variable. Next, a Rasch model procedure can be conducted for final evaluation. However, this is not enough. In order that this model could be used the questionnaire itself must be certified and standardized and testing process must be calibrated and denoised by the Rach procedure and contemplating the analogy with original application in Concept Inventory analysis. In [20-23], the reader can find alternative applications of this technique ins sociometric measurement and analysis. From a general point of view, for surveys where skill-difficulty trade-off approximation make sense or can be adapted, this model can be applied straightforwardly, otherwise one needs for more arguments. For practical purposes within this proposal might ensure that questions of the survey are related to an integral attitude that behaves as a latent factor, and to some extent, every item complements each other. We note that for applying this idea for ex-post evaluation or audit analyse, the answering of these questionnaires requires knowledge of the field of interest, i.e. they can be applied only in communities of relevant expertise. Following features of original use of the Rasch model, through the proposed technique one can perform the calibration of the survey itself, the evidencing of guessing events and filtering them, the identification of individuals who are not competent in the field of the questionnaire and also, we can discover poorly constructed questions. As a result, the estimation of the latent trait would outperform classical measurement, opposite to a commonsense that a direct measurement would has better accuracy. Notice that in the ongoing stage of this work and contemplating additional remarks regarding heterogeneity issues in our systems, presented in previews analyses [24-26], we have identified supportive arguments for adapting the CI Rasch model for successfully analysing the responses regarding legislative evaluation etc. For example, we concluded that for acceptable measurement, smaller but impartial samples provide better result than bigger samplers based on random sampling. Detailed results for this application are to be presented in a dedicated work, but by detecting pathological events using Rasch analysis in piloting stage we shed some lights in unusual results reported from several surveys which were based on direct evidence.

C. Reviewing sampling and employing sequential sampling

Unexpected outcomes from some surveys conducted in our country might rely on the failure of the IID features (independent and identically distributed) for measured variables. Following this argument, in [25] has been claimed that a very low real in PISA has resulted from non-rigor sampling issues, considering statistically identical against the tests students who have a PC computer at home and those who do not have e.g., do not know to use it appropriately. When discussing preferences and attitudes, we might parallelize with political ones, for illustration. In [24] it has been shown that the nature of the distribution of candidates who gather a certain fraction of the votes depend on the parties' group, indicating that political preferences are not IID. The heterogeneity of the distribution of electoral preferences been recognised also in [27], etc. When this is true, corollary of the Central Limit Theorem, do not hold and therefore the distribution of the mean is not normal. It followed that the sample size assessed by balancing errors I and II provided the normality distribution under the null and alternative hypothesis, must be

reviewed in such cases. Empirically, a bigger sampling, e.g., $N_{sample} > \frac{\left(\frac{z_{\alpha} + z_{1-\beta}}{2}\right)^2 \sigma^2}{(\mu_1 - \mu_0)^2}$, could be the solution, but increasing the sample size to reduce the type 2 error not only increases the cost of the survey, but can also lead to ethical problems in several applications [27]. In this case, sampling and resampling or bootstrapping technique and simulation would help, and practical solution depends on the real problem. In this context, the analyses of legislation efficacy, audit performance and similar quantities which are characterized by such inadequacies and impurities, should be based on careful sampling and refined questionnaires. We believe that purposive sampling could compete random sampling for those situations. But in all tentative, the cost of realizing adequate sampling for measuring thorny quantities are much higher than it might be predicted when suing classical random sampling. Next, for some specific cases an opportune solution could be the use of sequential sampling. To explain the idea, let's assume that the time lag for a procedure is A time units. Afterwards new legal measures, we claim that this time will decrease to less than B units of time. From previous measurements it results that the standard deviation of is C units of time. For measuring the efficacy of the new regulation, we must know whether the new regulation has produced the intended effect. These scenarios can be projected into a variety of applications of audits, ex post evaluation etc, provided that

experts have identified the parameters that can be measured. To avoid sampling inadequacy or costly which seems to be common for those analyses, it is very intriguing using sequential sampling.

III. SOME PRELIMINARILY FINDINGS

Following the arguments for correcting statistical analysis of a highly complexity measurement concerning ex post evaluation, audits and legislation efficacy, we have started with a simple application, measuring the perception for governance performance. In this procedure there are several elements related to legislative improvement efficacy embodied in the wide-ranging questionnaire. The idea is not to purely hidden them behind a general target survey, but to diagnose natural association of responses regarding them with a generalised public perception, using a step-by-step procedure. In order to clarify where to conduct the questionnaire and how to construct a reliable instrument for measuring quantities of the category ex post or efficacy evaluation, we must evidence in what degree respondents would be biased on their final opinion. For this purpose, we will gather information from a pilot study of the questionnaire itself, letting the implementation phase for a future reference. So, initially we have tried to construct a questionnaire for evaluating the perception of the success for the Reform of Justice (implemented in 2016), but it was more complicated than assumed. We observed that the answers of our pilot drafting were based on a general perception, rather in thorough and realistic analysis. It has compromised the nature of latent variable and consequently the use of Rasch model. This preliminary observation has suggested to consider a purposive sampling, based only in expert's communities, but in this case, we observed that respondents were focused on their own analysis and prior arguments regarding the reform or law amendments, rather than in the product observed after implantation of a new law. Therefore, a check of target terms in the framework of a generalised product that can be verified by people's perception on governance quality can be useful. In the line of the core idea of this work, we try to employ an interdisciplinary approach for the very first stage, the drafting of the measuring instrument. It consists of using indirect measurements for quantities that characids complex systems, under the physical paradigm that to much simplification in order to perform a direct measurement may lead to an idealistic state of the system or to an unrealistic system! Based on the goal of this work, we are not trying to measure a feature, but to improve the techniques of measurement in a certain system or condition. So, the goal of piloting and reviewing the questionnaires were to elaborate the method, and to produce an acceptable exemplar for measurement.

A. Analysing a generalised questionnaire ability to evidence distinct issues

In this session we will discuss the result of the certification procedure for a general questionnaire based on a latent variable indirect measurement where several items represent a direct measurement of the feature under investigation. The piloting survey would be focused on governance quality, and several items measured our specific variables. Notice that the perception for governance goodness might be affected by several issues, but for most of the questions the people do have the needed knowledge based on real life and development, regardless of the expertise. So, we drafted a raw set of questions to initiate the drafting stage. The draft consisted of 30 statements for evaluating the supportiveness regarding govern policies, that can be approved or rejected. The piloting survey has been conducted to a small sample of employees having at least a master's degree and being engaged for at least 10 years in public service. We observed that the supportiveness for overall governance was too low, around 22% (contradicting the result of the elections of 2025, that is an indicator to be counted). It is also a projection of the success of the legislative amendment also! When discussing this low support, we obtained that respondents were based in a sole argument, the one that impacted them directly at the moment of filling the form to assign their score! On more variable to be stored! It supports our idea for switching to a modelling or indirect measurement for complicated quantities in the framework of latent traits. It seems that peoples' beliefs are very volatile and the measurements concerning legislation efficacy that should be very careful. For this reason, an empirical observation is considered interesting. Regardless it is out of modelling and statistical nature, it brings some realistic bases to our core arguments, the need for preliminary evidence of the contextual evidence. To figure the perturbation effects let explore some facts. So, the distrust in parliament which involve both side

of the politics is very high and so should be the estimation for their product, norms and legislation. The results of the survey conducted in 2023 based on as much as 79 questions has concluded in the graph of figure 2. The OECD survey represented in Figure 2 has targeted a latent variable which coincide with our interests. It evidences a high distrust that is quite probable to influence answering of common questions, revealing the need for a careful drafting of the questionnaires to avoid the prejudices. Bearing in mind this observation and similar ones, we proposed to employ the above-mentioned procedure for achieving a good measurement instrument. Thus, the draft-survey is conducted initially in a small community, mostly our mates, to identify its content issues. Notice that those finding are very explanatory because the small number of respondents do not permit statistical feature of the indexes calculated, and we have showed it here to demonstrate the methodology activated. Based on the perquisites or a similarity with CI test mentioned above, we tried to compose a set of questions whose answers would be aligned to the responder's position regarding the whole questionnaire. In this regard, a classical survey cannot fulfil this condition, but we might arrange the questions as to report a knowledge-like quantity rather roughly an attitude. When discussing for ex post evaluation or evaluation of the quality of very important Reform in Justice, we obtained several obstacle starting from uneasiness for formulation and following with limited number of individuals who can answer to very technical questions. Consequently, we drafted a CI -like questionnaires based on empirical proposal and ad hoc formulation, based on a bounce of questions consisting of various projections of the people's perception of the quality of governance.

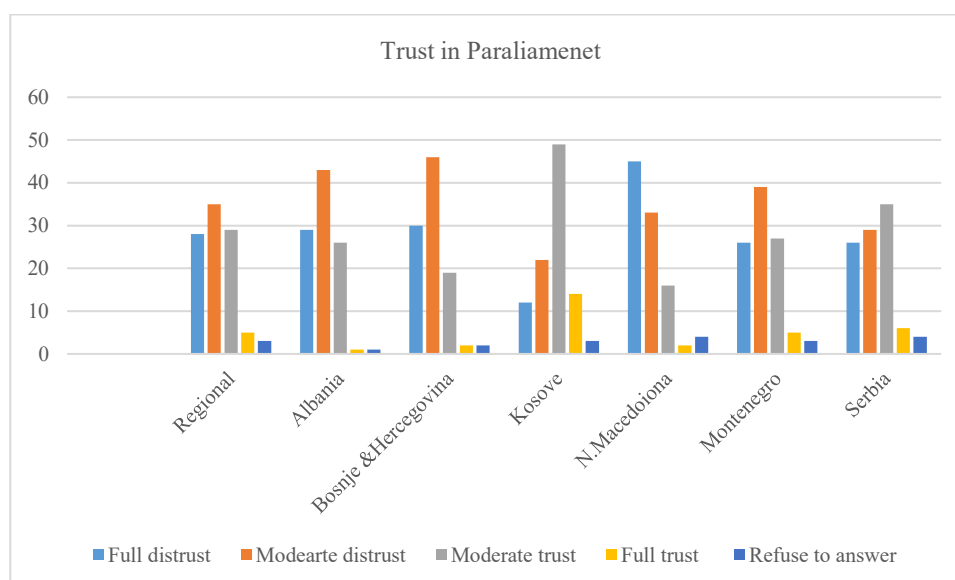


Figure 1. Illustration of the measurement of a latent variable

Based on the above discussion regarding the consistency of measurement procedure, for drafting the questionnaire, we have administered several common recent surveys and composed the very initial questionnaire with 30 questions. We tried to keep our intended variable integrated in the full questionnaire. This draft has been subjected to our colleagues asking them if: (a) the items will be answered based on a general perception of government policies and good conduct, (b) the answer will be based on a trade-off balance between individual *attitude and perception regarding governance* and global perception of *the clearness of the question*. Finally, we proposed the questionnaire which start with 'Answer the following based on your best knowledge and belief or leave blank if you lack the needed expertise'. And the statement: *There has been improvement*) in the Government policies regarding', followed by the list of categories such as '1. Taxes' policies; 2. Education development and strategies...*

B. A model-based check for observing the correlation

The initial questionnaire has been verified for the consistency and reliability. The indexes would provide direct evidence for the nature of correlation of hidden variables expressed on a general knowledge-

perception issues. Firstly we evaluated our instrument based on very basic procedures. After asking colleagues to redact it, we got 9 answers from regarding the completeness and reliability of our draft, from whose 6 estimated it as good instruments, and 3 showed comments or even rejection for some items. We removed 5 items that appear suspicious in many comments. After this check, the experts were more confident that this instrument is capable for measuring the intended quantity, but again, there were comments and remarks on at least one of the items giving the content validity ratio $CVR(item) = \frac{N_{confirm} - \frac{N}{2}}{\frac{N}{2}} \sim (0.33 \div 0.77)$ which is considered good. We chose to keep 25 items for piloting. The draft is sent for answering in a group of our mates, a purposive sampling, just to explore if indexes will report something objective. We realised 43 responses for this preliminary certification of the method. The responders were graduated and all of them confirm that they have voted in the last elections. This detail is irrelevant in general, but here is helpful to confirm us that they have had interest to know the content of the questionnaire and, they have expressed their thought by the vote. It resulted that when indexes fall out of the validity region, respondents admit also the existence of the problem with the questionnaire. This suggests reformulating the content of cells in last column of Table 1, in the final form presented in the second row of the Table 2. In this check, we might confirm that our idea is workable and succeed with using it as filtering stage quite similarly with the original use.

Table 2. Elaborated table of indexes

Indexes	Difficulty-like index: un-supportiveness	Discrimination index	Reliability index (Cronbach alpha)	Discriminatory power	Self-consistency index
Concluded for the feature of 'Description' for out of range	The responder showed that has been biased voluntarily	Item(s) is not effective to discriminate well between high and low supportive scores.	Responses are not based on solid beliefs and uncertainties are influent.	Similar questions have implicated similar responses, so real information remain hidden from the survey	The questionnaire is poorly edited and conflicting ideas are involved

By evaluating indexes and their explanation, the draft has been edited and reviewed based on the indicators of the indexes out of the range, e.g., if self-consistency was found out of range, we reformulated them, if discriminatory index it was found out of range, we have avoided using similar questions, and so on. Note that this procedure was repeated only once, but to be fruitful, more trials are needed. Finally, the drafted questionnaire presented in Table 2.

Table 1. Draft questionnaire: Pronounce your support or rejection for policies during 2016-2025

Formulation of the survey Items	Yes/No	Indexes/Rasch Check
1. Taxes' policies		Questionable
2. Education development and strategies		<i>Usable in current form</i>
3. Crime convictions and general order		<i>Usable in current form</i>
4. Environment care and management		<i>Usable in current form</i>
5. Youths' perspective and employment		<i>Usable in current form</i>
6. Law enforcement		Questionable
7. Elderly support and policies		<i>Usable in current form</i>
8. Military advance in the framework of recent development.		<i>Usable in current form</i>
9. Health and medicine		<i>Usable in current form</i>
10. Foreign affairs performance and straightening the role of the country		<i>Usable in current form</i>
11. Financial stability		<i>Usable in current form</i>
12. Social care and projects		<i>Usable in current form</i>
13. Wages sectors improvement		Questionable
14. Legislation in general (completeness)		Questionable
15. Rule of law		<i>Usable in current form</i>
16. Justice and reforms		<i>Usable in current form</i>
17. Free market guarantees and medium of doing business		Questionable
18. Accuracy of Legislation for Proprieties and public terrains		<i>Usable in current form</i>
19. Effectiveness of implementation of legislation for assets and		<i>Questionable</i>
20. Management of political mediums and democracy		<i>Questionable</i>

This shortened draft has been used as pilot test in a small group for initial evaluation. After calculating indexes based on Table 1, 3 questions have been eliminated too, and question 1,6,13,14,17,19 and 20 are tagged for reformulation. Using a step-by-step control based on the above arguments, we have dropped from 20 questions to only 12 questions which are unstable, but to be concise, only on the community where we employed it, because the survey does not meet statistical requirements. The result is clear; we obtained a 18/30 rejection rate for our questions which were formulated by senior expertise however! The good news is that if we were to organize a full survey, surely, we would follow this strategy to improve the questionnaire, and a bad one is that several surveying bodies do not take such a care at all! Just for elaborating the main idea, the answers of this draft have been passed to the Rasch procedure. Interestingly, the supportive attitude for government policies as measured by Rasch modelling herein has resulted at around 0.28, which is far smaller than evaluations based on direct measurement and published continually in the country. Despite statistical limitations, this is an indicator that indirect measurement performs better than a classical measurement for those systems, reinforcing the idea of implementation of the above-mentioned procedure. Note that the set of Table 2 we have tried a full-scale piloting, but the procedure has taken a little longer than scheduled so we do not have enough data for the moment. However, we observed that guessing behaviour and blank-left boxes present in this case. While this hampered achieving conclusions for supportiveness under scrutiny, it indicates that our idea for following a multistep preparatory analysis works. To go further on and waiting for more results from piloting on a random sample, we realized an opportunity sampling procedure, in a small number of responders, but again with good education and expertise background. The answers administrated from the mini-pilot testing indicates that again, the questions that were identified for reformulation remain still exposed to misunderstanding, appearing with high difficulty-like parameter. By this example, and from the fact that, despite we have tried 3 times, again

our questionnaire is not good enough for measuring the variable aimed, and alternative we may use multiple level variable or polytomous model. But before going to calculation stage we observed that almost all questions that indirectly measure the efficacy of the legislation reforms do not lie along with general perception of other governance goodness. It signifies a separation point on methodological investigation for those components. In a generalised view, we observed that following our procedure proposed in this work, it resulted that a measurement of the legislative or reform efficacy require several analytical steps based in statistical, modelling and judiciary expertise. It cannot be trustworthy nor realistic by using direct perception's responses or evidencing expert opinions solely. In this case, an interdisciplinary approach could be the solution. For very special case where the result can be assigned directly by the numerical variable, the direct measurement is indispensable.

c. A case example of using straight verification

To illustrate the idea of the prevalence of direct measurement for cases where a representative variable can be assigned numerically, let consider an example. It reveals also the importance of interdisciplinary analysis, because prior to arrive at the implantation stage, several advanced statistical analysis for the nature of the state must be concluded. Suppose that the lifespan of a protected species should not be less than 38-time units. After the new legal measures are enacted and have been employed, this time is found over 40 units of time. We want to know whether the new regulation has produced the intended effect, if the standard deviation of lifespan is 8 units. Then the hypotheses are: $H_0: k_0 \leq 38$ and $H_1: k_1 > 40$. Also, one takes $\alpha = 0.05$ and $\beta = 0.1$ just for reference. Theoretically, see [29], we must proceed as follows: initially ones set two directional lines $Y_{upper} = bn + p_2$ and $Y_{lower} = bn + p_1$, where $b = \frac{k_1+k_0}{2}$ and $p_1 = B * \frac{\sigma^2}{k_0-k_1}$; $p_2 = A * \frac{\sigma^2}{k_1-k_0}$; $A = \ln(\frac{1-\alpha}{\beta})$; $B = \ln(\frac{1-\beta}{\alpha})$. Nex, one calculates the cumulative value of the variable being measured and when this value goes outside the area between the two lines, we have an answer. Using the data from the example we have $b = \frac{k_1+k_0}{2} = 39$; $A \cong 2.3$, $B \cong 4.5$ so $h_1 = 4.5 * 4.5 * \frac{4^2}{-2} = -144$ and $p_2 = 2.3 * \frac{4^2}{2} = 18.4$ so the equations of the bounding lines of the 'other measurements are needed' area are respectively $Y_{lower} = 39 * n - 36$ and $Y_{upper} = 39 * n + 76.4$.

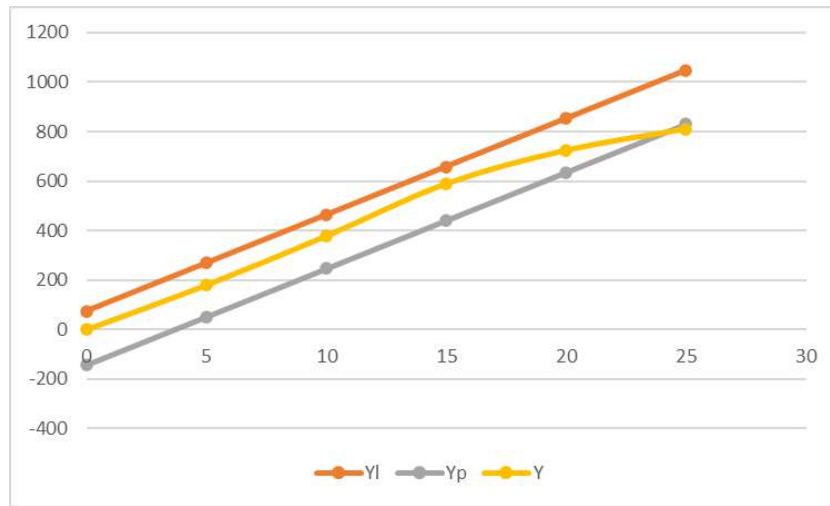


Figure 2. Illustration for Indirect measurement of policies performance

In this example, after having data from 75 measurements we have a conclusion, H_0 must be accepted i.e. we do not have a significant improvement from the adjustment (or application of the adjustment) made. Notice than using random sampling one have need nearly four times more measurements. With a little effort for enhancing meaningful adaptation, this technique offer solution by a much smaller sampling.

IV. RESULTS

By this review and a procedural discussion, we have underlined the importance of a detailed analysis of methods and instruments before conducting measurements in some typical sociological systems based on beliefs and attitudes. For the very special case of analysing legislative performance, audits and other operations of this category, we have proposed a revision of all steps starting from the fulfilling of theoretical statistical assumptions. In this case, a pragmatic technique would be the adaption of indexes that are used elsewhere in the framework of testing of the Conceptual Inventories and removing the items that do not coney to the standard desired indexes' values. Next, a Rasch analysis could be useful for identifying pathological events that mostly are based on partisanship behaviour. Finaly, we suggest reformulating the measurement goals, to enable a sequential sampling procedure for avoiding costs and time needed for a random sampling, and also, to skip the unknown optimal sampling due to the lack of IID feature for the random variable under scrutiny. Finally, but not less relevant, the success of such analyses is guaranteed if interdisciplinary approach has been established in every stage of the analyses. Based on this last, we can discriminate between indirect or direct measurement alternative.

V. DISCUSSION

Notwithstanding that the idea elaborated herein do not touch something new in the general contexts, it brings a realistic approach, and a careful extension of the classical tools used elsewhere in the framework of the relationships causes-responses in a civic behaviour, when we try to perform delicate designment such as legislative performance and efficacy, which by nature is not measured directly. In this case, we must seek for a logic and meaningful functional relationship between the probability of a certain answer with a trade-off between individual attitude and a general perception for a certain issue, and if this can be arranged by a careful organization of the survey, the Rasch model can be used successfully for calibrating the instrument, and for conducting more detailed measurement. Considering the quality of measuring latent traits by the Rasch techniques, we would conduct a sequential sampling and analysis in the near future, for discovering peoples or experts' judgment on the legalisation performance and efficacy. Note that direct measurement of those quantities is considerable fuzzy due to several interferences and factors that conditionate individual attitudes.

VI. CONCLUSION

In this paper, a descriptive methodological analysis is presented regarding the measurement process for high complexity analysis such are ex post evaluation, audits etc. This work constitutes a summary presentation of our ongoing work motivated by the growing interest in quantitative analysis in the field of audit and auditing, assessment of legislative performance and regulatory efficiency for our country. Considering the multiplicity of factors and hidden variables in those systems, we have presented a general framework of the problem and next, we proposed some simplified for a trustworthy surveys and adequate analysis. This methodology seeks to adopt the indexes theory and Rasch analysis borrowed from Conceptual Knowledge analysis for realizing a qualitative questionnaire. Positioned in the midway of a measurement procedure we have illustrated the idea with few realizations on opportunity and purposive sampling and proposed a sequential sampling for the further step. We believe that the expansion and development of quantitative computational capacities in the fields of political science, applied econometrics, and sociometrics in matters of legal performance assessment, ex post evaluation, and audit methodologies will shorten the time between the appearance of problems and their cure, as well as the cost of normative enterprises in general. In this regard, after having the full survey data of the piloting stage, we pretend to achieve a calibrated instrument to be used successfully for our system. We indicated by few examples that the success of measuring complex variables such as legislative evaluation necessities the interdisciplinary to discriminate between indirect or direct measurement alternatives.

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Ablation-Driven Model Selection for Eating Disorder Prediction from Neurobehavioral Data

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Abstract – Classifying eating disorders is a complex process requiring a multidisciplinary approach. Eating disorders (anorexia nervosa, bulimia nervosa, binge eating disorder, etc.) are complex psychiatric illnesses that seriously threaten an individual's physical and mental health. Traditional diagnostic methods, based on clinical interviews and self-report questionnaires, are among the classic methods used to identify eating disorders. While valuable, these methods can be subjective, time-consuming, and can miss subtle signs in the early stages. In this regard, machine learning algorithms offer an objective, data-driven, and potentially faster approach that can support the diagnostic process. Furthermore, methodological factors such as data quality, sample size, feature selection, and model validation are considered crucial in the application of machine learning-based neurobehavioral analyses to the field of eating disorders. The primary goal of machine learning is to create a model that can learn from a set of data points and predict whether a new individual falls into a healthy or a specific eating disorder category. In this study, Random Forest, Support Vector Machine (SVM), and XGBoost algorithms were subjected to various ablation tests on a dataset containing neurobehavioral factors associated with eating disorders. As a result of the experimental studies, the sigmoid kernel variant of the SVM algorithm achieved higher performance than other experimental results, maintaining its position as a competent machine learning algorithm.

Keywords –Anorexia Nervosa, Bulimia Nervosa, Binge Eating Disorder, SVM, XGBoost, Random Forest.

I. INTRODUCTION

Individuals with eating disorders generally experience problems with their body weight and appearance. Even if their weight is within the recommended range, they perceive themselves as overweight and constantly strive to be thinner. In some cases, the opposite occurs. The individual cannot control their urge to eat and constantly desires to eat [1]. Feeding and eating disorders are defined in the literature as abnormal food consumption behaviors, disruption in eating-related behaviors that lead to deterioration in physical health and psychosocial functioning [2].

The literature categorizes feeding and eating disorders into eight subcategories. These are: Pica Syndrome, Rumination Disorder, Avoidant/Restrictive Eating Disorder, Anorexia Nervosa, Bulimia Nervosa, Binge Eating Disorder, Other Specified Feeding and Eating Disorder, and Other Unspecified Feeding and Eating Disorder. The contents of these disorders are detailed in Table 1.

Table 1. Eating disorders encountered in the literature in general [2]

#	Class	Description
1	Pica Syndrome	Eating substances of no nutritional value and weighing less than expected.
2	Rumination Disorder	Regurgitation, also known as rumination, is the act of regurgitating food that has been chewed in the mouth, then putting it back into the mouth and spitting it out or swallowing it
3	Avoidant/Restrictive Eating Disorder	Not consuming enough food and inadequate nutritional behaviours for age are present
4	Anorexia Nervosa	Binge eating and purging behaviours are present. An extreme fear of gaining weight, a distorted body image, and a body mass index below expectations are also observed
5	Bulimia Nervosa	Overeating and then vomiting behaviours are observed
6	Binge Eating Disorder	Binge eating of large amounts of food in a short period of time, eating in secret, and feeling shame and guilt afterwards are observed
7	Other Specified Feeding and Eating Disorder	This includes other eating disorders that are quite common in the literature
8	Other Unspecified Feeding and Eating Disorder	Feeding and eating disorders that have not been fully classified in the literature

The most common of these in daily life are anorexia nervosa and bulimia nervosa. The primary reason for this was the perception held by young European women in the 1960s that starving themselves would make them lose weight and thus become more beautiful. This perception persists today and has claimed the lives of many. Bulimia nervosa, an eating disorder characterized by binge eating and subsequent vomiting rather than starving, is known as the disorder that develops approximately ten years after the progression of anorexia nervosa [3]. People commonly engage in eating disorder behaviors such as anorexia nervosa and bulimia nervosa to appear thinner and consume fewer calories. Eating disorders can cause a range of psychological distress, from low self-esteem to anxiety, social phobia, body image distortion, and depression [4], [5], [6], [7]. Additionally, eating disorders are seen in individuals who have weak family ties, who have difficulty meeting their emotional needs, and who have difficulty expressing themselves confidently. Conversely, eating disorders are less common in individuals who develop good, healthy, and fulfilling relationships with family members, due to the lower prevalence of psychological distress [8]. It is claimed that eating disorders are more common in those who have problems with family bonding at an early age and in women between the ages of 15-24 [9].

Classification of eating disorders is a complex process that requires a multidisciplinary approach, with contributions from many disciplines such as psychiatry, psychology, endocrinology, genetics, neuroscience and public health [10]. With the publication of the DSM-5, the diagnostic criteria for these disorders were defined in greater detail, and the recognition of binge eating disorder as a separate diagnostic category marked a significant turning point in the classification system. Subcategories such as anorexia nervosa, bulimia nervosa, and binge eating disorder, as well as atypical anorexia nervosa and other specified eating or eating disorders, are included in the DSM-5. It has been noted that careful examination of objective abnormalities in patients' eating behaviors and psychopathological features played a significant role in the formation of these eating disorder subcategories [11]. In classifying eating disorders, understanding the boundaries and transitions between these categories is as important as identifying diagnostic categories. The "eating disorder not otherwise specified" (EDNOS/OSFED) category, in particular, is one of the most frequently encountered diagnostic groups in clinical practice, and its heterogeneous nature highlights the challenges of the classification system [12]. In the classification of eating disorders, the validity and clinical utility of diagnostic categories is a significant topic of debate. The DSM-5 defines severity specifiers (mild, moderate, severe, and extreme) for anorexia nervosa, bulimia nervosa, and binge eating disorder. These specifiers are based on body weight for anorexia nervosa, frequency of inappropriate compensatory behaviours for bulimia nervosa, and frequency of binge eating episodes for binge eating disorder [13]. Information obtained from the literature

reveals that in the classification of eating disorders, not only the diagnostic categories but also the severity of the disease should be taken into account [14].

II. MATERIALS AND METHOD

The dataset used in this article examines neurobehavioral factors related to eating disorders among university students [15]. The dataset used in the study was a survey related to eating disorders among university students distributed via email and social media to students at Daffodil International University in Bangladesh. This dataset, which includes various factors such as demographics, cognitive control, taste processing, reward processing, habit formation, and taste processing, investigates the neurobiological factors of eating disorders. The dataset, created based on the aforementioned factors, reportedly received 550 student responses. The analysis was conducted using machine learning techniques on a recently published and influential dataset. The methods and parameters used in the analysis are discussed in the following sections.

A. Random Forest

In the fields of machine learning and data mining, decision trees and their ensemble methods, particularly the Random Forest algorithm, are powerful tools widely used in both classification and regression problems. The Random Forest algorithm is essentially an ensemble method created by combining multiple decision trees and aims to mitigate the disadvantages of a single decision tree, such as overfitting [16]. This subsection discusses in detail the fundamental principles of the Random Forest algorithm, its mathematical formulations, and the advantages and application areas of the algorithm in light of various approaches in the literature. Decision trees are intuitively understandable and interpretable models that perform classification or regression operations by dividing data into branches. However, a single decision tree can often overfit the data and have poor generalization capabilities. To address this problem, the Random Forest algorithm combines many weak learners to create a strong ensemble model. This approach increases the diversity and accuracy of the ensemble members, improving the performance of the overall model. The basis of the Random Forest algorithm is that each decision tree is trained on a different subset of data and feature sets. This process utilizes bootstrap sampling (bagging), meaning that samples are randomly and repeatedly selected from the training data, and each tree is trained on these samples [17].

$$\hat{p}(x) = \frac{1}{M} \sum_{m=1}^M h_m(x) \quad (1)$$

The symbols shown in Eq. 1, $h_m(x)$ and M , represent the tree output and decision trees, respectively. Parmar summarizes the working steps of the random forest algorithm in 5 steps in study [18]. The first of these is the assignment of the initial value of M , which represents each feature subset.

In the second step, he selected the θ_k feature subsets based on the feature set M . Any cluster in the feature subset $\theta_1 \dots \theta_{k-1}$ is completely independent of the θ_k named feature subsets. Considering that each classifier is expressed as $h(x, \theta_k)$ in the third step, x represents the inputs. In the fourth step, the operations in the second and third steps are repeated for all other sub-feature sets. In the fifth step, the performance results are obtained using the test data, which is the untrained data of the random forest algorithm [19].

B. XGBoost

This subsection will provide a detailed explanation of the XGBoost algorithm, one of the methods used in this study. XGBoost (Extreme Gradient Boosting), one of the most prominent algorithms in machine learning and data mining in recent years, is particularly notable for its high accuracy and efficiency on tabular data. XGBoost is an optimized and extended version of the gradient boosting decision tree (GBDT) algorithm, which is essentially an ensemble learning method. This algorithm is widely used in both academic and industrial applications and has demonstrated superior performance in various fields [20], [21]. The core of the XGBoost algorithm is the sequential training of decision trees as weak learners, with each tree focusing on correcting the errors of previous trees. This process proceeds by

generating new trees according to the gradient of the loss function to minimize the model's prediction errors. By optimizing this process, XGBoost both increases computational speed and reduces the risk of overfitting [22], [23]. The algorithm is an advanced algorithm in terms of speed, efficiency and ease of use, distinguishing it from other decision tree-based algorithms [24]. The equational expression of the XGBoost algorithm, which can be found in the literature, is shared between Eq. 2-5.

$$\Omega(f_t) = \gamma^T + \frac{1}{2} \lambda \sum_{j=1}^T w_j^2 \quad (2)$$

$$\hat{y}_i = \sum_{k=1}^k f_k(x_i), f_k \in F \quad (3)$$

$$obj^{(t)} = l(y_i, \hat{y}_i^{(t)}) + \Omega(f_t) \quad (4)$$

$$\hat{y}_i = 0\hat{y}_i^{(1)} = \hat{y}_i^{(0)} + f_1(x_i)\hat{y}_i^{(2)} = \hat{y}_i^{(1)} + f_2(x_i) \dots \hat{y}_i^{(t)} = \hat{y}_i^{(t-1)} + f_t(x_i) \quad (5)$$

The large F value expressed in the four equations above represents the tree clusters. Furthermore, f represents the regression tree, and t represents the temporal expression. The time-expressed functions $f_t(x_i)$ in Eq. 5 represent the fit, while the l function, used to abbreviate the loss expression in Eq. 4, represents the loss function [24]. The value of $\Omega(f_t)$ is obtained by adding the square of the weight of the w_j value expressed opposite the equality in Eq. 2 with γ^T [24].

C. SVM

SVM are considered one of the most important algorithms in machine learning and statistical learning theory. SVM stands out for its high accuracy and generalization capabilities, particularly in classification and regression problems. The primary goal of this algorithm is to find a hyperplane (or, in more complex cases, a decision surface) that best separates the data. SVM's success is based on the principles of maximizing geometric margin and minimizing structural risk [25]. One of the fundamental principles behind the success of SVM is structural risk minimization. This principle aims to strike a balance between model complexity and the success of fitting the training data [26]. The SVM algorithm prioritizes the fit between the data and the target to minimize the sum of errors and uses kernel functions to facilitate the discriminability of real-world data [26], [27], [28]. The margin value C , which is the balance parameter used to minimize classification errors, is an important parameter [27], [28], [29]. Eq. 7 represents the polynomial kernel, Eq. 9 represents the radial basis function kernel, Eq. 8 represents the linear kernel, and Eq. 6 represents the sigmoid kernel.

$$\tanh(\gamma x_i, x_j + coef) \quad (6)$$

$$K(x_i, x_j) = (\gamma x_i, x_j + coef)^d \quad (7)$$

$$K(x_i, x_j) = (x_i, x_j) \quad (8)$$

$$K(x_i, x_j) = \exp^{-\gamma |x_i - x_j|^2} \quad (9)$$

The choice of kernel functions varies depending on the structure of the dataset and the type of problem. Liu et al.'s study emphasized that the Gaussian radial basis function (RBF) is widely used in SVM, and that the parameter sigma, which is the kernel function, plays a critical role in classification performance [30].

III. RESULTS AND DISCUSSION

In this section, which is one of the most important parts of the study, experimental studies were carried out in the classification of eating disorders with ablation tests using Random Forest, XGBoost and SVM algorithms.

Table 2. Random Forest Algorithm performance results

Estimator	Max Depth	Class	Precision	Recall	F1 score	Test Accuracy
100	3	0	0.79	0.51	0.62	0.75
100	3	1	0.73	0.91	0.81	
500	3	0	0.70	0.58	0.63	0.73
500	3	1	0.74	0.83	0.78	
1000	3	0	0.71	0.56	0.63	0.73
1000	3	1	0.73	0.85	0.79	
100	7	0	0.69	0.64	0.67	0.74
100	7	1	0.76	0.80	0.78	
500	7	0	0.69	0.69	0.69	0.75
500	7	1	0.78	0.78	0.78	
1000	7	0	0.71	0.67	0.69	0.75
1000	7	1	0.78	0.82	0.80	

Table 2 presents the experimental performance results obtained with the random forest algorithm. In ablation tests conducted with the random forest algorithm, the model achieved the best results when the estimator value was 100, 500, and 1000, and the maximum depth value was 3, 7, and 5, respectively. A success rate of 0.73 was achieved when the maximum depth value was 3 at the estimator values of 500 and 100. Analysis of the obtained results suggests that increasing the maximum depth value improves experimental performance.

Table 3. XGBoost Algorithm performance results

Estimator	Learning Rate	Class	Precision	Recall	F1 score	Test Accuracy
100	0.05	0	0.61	0.69	0.65	0.69
100	0.05	1	0.76	0.69	0.73	
500	0.05	0	0.64	0.76	0.69	0.73
500	0.05	1	0.81	0.71	0.75	
1000	0.05	0	0.63	0.73	0.68	0.72
1000	0.05	1	0.79	0.71	0.75	
100	0.1	0	0.64	0.76	0.69	0.73
100	0.1	1	0.81	0.71	0.75	
500	0.1	0	0.67	0.76	0.71	0.75
500	0.1	1	0.81	0.74	0.77	
1000	0.1	0	0.68	0.80	0.73	0.76
1000	0.1	1	0.84	0.74	0.79	

Table 3 shows the performance results of the XGBoost algorithm in classifying eating disorders. The lowest test accuracy was achieved with 100 estimator parameters at a learning rate of 0.05. In other ablation tests, a success rate of 0.76 was achieved with a learning rate of 0.1 and a 1000 estimator setting.

Table 4. Performance results of the SVM algorithm

C	Kernel	Class	Precision	Recall	F1 score	Test Accuracy
1	Linear	0	0.68	0.80	0.73	0.76
1	Linear	1	0.84	0.74	0.79	
100	Linear	0	0.67	0.82	0.74	0.76
100	Linear	1	0.85	0.72	0.78	
10000	Linear	0	0.67	0.82	0.74	0.76
10000	Linear	1	0.85	0.72	0.78	
1	RBF	0	0.66	0.78	0.71	0.75
1	RBF	1	0.82	0.72	0.77	
100	RBF	0	0.67	0.76	0.71	0.75
100	RBF	1	0.81	0.74	0.77	
10000	RBF	0	0.67	0.76	0.71	0.75
10000	RBF	1	0.81	0.74	0.77	
1	Poly	0	0.65	0.71	0.68	0.73
1	Poly	1	0.79	0.74	0.76	
100	Poly	0	0.65	0.71	0.68	0.73
100	Poly	1	0.79	0.74	0.76	
10000	Poly	0	0.65	0.71	0.68	0.73
10000	Poly	1	0.79	0.74	0.76	
1	Sigmoid	0	0.67	0.76	0.71	0.75
1	Sigmoid	1	0.81	0.74	0.77	
100	Sigmoid	0	0.73	0.78	0.75	0.79
100	Sigmoid	1	0.84	0.80	0.82	
10000	Sigmoid	0	0.67	0.76	0.71	0.75
10000	Sigmoid	1	0.81	0.74	0.77	

In Table 4, the highest success rate of 0.79 was achieved with the sigmoid kernel with a marginal value of 100 C. The lowest experimental performance result was achieved with the poly kernel parameter value at a margin value of 1 C.

IV. CONCLUSION

Machine learning is a powerful tool with the potential to revolutionize the classification and understanding of eating disorders. However, it is essential that this technology be used ethically and responsibly, complementing human expertise. In the future, with more advanced algorithms and more comprehensive datasets, it is anticipated that these tools will provide clinicians with more accurate and earlier intervention opportunities in the fight against eating disorders. The sigmoid kernel variant of the SVM algorithm has maintained its position as a leading machine learning algorithm, achieving higher results than other algorithms.

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***Euphorbia myrsinites*'in Biyolojik Aktiviteleri ve Antidiyabetik Potansiyeli Üzerine Bir Yaklaşım**

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Özet – Diabetes mellitus insülin salgılanmasının veya etkisinin bozulması sonucu ortaya çıkan kronik hiperglisemi ile karakterize metabolik bir hastalıktır. İki ana diyabet türü vardır: Tip 1 diyabet, aynı zamanda insüline bağımlı diabetes mellitus olarak da adlandırılır, pankreasın beta hücreleri tarafından insülin salgılanmamasından kaynaklanır. Tip 2 diyabet, hedef dokuların insüline duyarlılığının azalmasından kaynaklanır. *Euphorbia myrsinites* L. Euphorbiaceae familyasına ait bir bitki türüdür. *Euphorbia* cinsi bronşiyal nezle ve astımı tedavi etmek, müshil olarak kullanmak ve diş ağrısını azaltmak gibi amaçlar ile kullanılmaktadır. Bu çalışmada *E. myrsinites* bitkisinin yaprak, gövde ve köklerinden hazırlanan %80'lik etanol ekstresinin α -amilaz, α -glukozidaz, pankreatik lipaz ve pankreatik kolesterol esteraz enzimleri üzerindeki inhibitör etkileri araştırılmıştır. Bu enzimlerin hepsi de bu türde ilk defa çalışılmıştır. Sonuçlara bakıldığında α -glukozidaz enzimi üzerinde bu üç farklı kısımdan hazırlanan ekstrelerden en yüksek inhibitör etkiyi IC_{50} : $119,53 \pm 1,25$ değeri ile bitkinin yapraklarından hazırlanan ekstre göstermiştir. Referans madde olan akarbozda ise bu değer IC_{50} : $0,01 \pm 0,00$ olarak belirlenmiştir. α -Amilaz enzim inhibisyon değerlerine bakıldığında ise en yüksek aktiviteyi IC_{50} : $55,03 \pm 4,64$ değeri ile yaprak ekstresi gösterirken kök ekstresinde de bu oran IC_{50} : $57,80 \pm 0,03$ ile ona çok yakın olmuştur. Referans madde olan akarbozda ise bu değer IC_{50} : $0,02 \pm 0,01$ olmuştur. Buradan da bitkinin bu enzim üzerinde ılımlı bir etkiye sahip olduğu anlaşılmıştır. Pankreatik lipazda ise bitkinin hiçbir kısmı etkili bulunmamıştır. Bu bulgular bitki üzerinde daha fazla *in vitro* ve *in vivo* çalışmalar yapılması gerektiğini göstermektedir ve elde edilen sonuçların ileride yapılacak çalışmalara öncülük edeceği düşünülmektedir.

Anahtar Kelimeler – *Euphorbia Myrsinites* L., Antidiyabetik, *In Vitro*, Enzim İnhibisyonu, α -Amilaz, α -Glukozidaz *Euphorbiaceae*.

I. GİRİŞ

Geleneksel tıpta uzun süredir kullanılan bitkisel kaynaklı ürünler, günümüzde modern tıbbın da ilgisini çeken doğal biyoaktif bileşikler açısından önemli bir potansiyele sahiptir. Bu bileşikler arasında yer alan fenoller, flavonoidler, kumarinler ve tanenler gibi fitokimyasallar; antioksidan, antiinflamatuvar ve antimikrobiyal etkileriyle öne çıkmakta, dolayısıyla pek çok hastalığın önlenmesi ve destekleyici tedavisinde değerlendirilmektedir. Bitkilerden elde edilen ekstraktların biyolojik aktiviteleri, kullanılan bitki kısmı, coğrafi bölge ve özellikle de ekstraksiyon yöntemi gibi birçok faktörden etkilenmektedir. Bu nedenle geleneksel kullanımın ötesine geçilerek, bilimsel yöntemlerle bu bileşiklerin etkinliğinin belirlenmesi büyük önem taşımaktadır [1]. *Euphorbia* cinsi, yapraklı otsu bitkiler ve sulu sütleğenleri de içeren geniş, kozmopolit ve çeşitli bir bitki grubudur. Birçok tür yabancı ot olarak kabul edilir ve dünya çapında bir dağılım kazanmıştır. Çok farklı olmalarına rağmen, bu bitkilerin ortak özellikleri arasında cyathium'un ortaya çıkması, sıra dışı bir çiçek yapısı ve oyulduktan sonra beyaz, sütlü ve zehirli bir lateks salgılanması yer alır. *Euphorbia*lar, geleneksel tıpta bronşiyal nezle ve astımı tedavi etmek, müshil olarak kullanmak,

diş ağrısını azaltmak ve siğilleri yok etmek için Yunan ve Roma dönemlerinden beri kullanılmaktadır [2]. Cinsin üyeleri üzerinde yapılan fitokimyasal ve tıbbi çalışmalar, Euphorbiaların taksonomik bir belirteci olarak kabul edilebilecek sıra dışı diterpenlerin varlığını göstermiştir. Euphorbia L. (Euphorbiaceae), 2150'den fazla türle çiçekli bitkilerin en büyük cinslerinden biridir. Avrasya'daki türlerin çoğu, diğer üç alt cins kardeş grup olan *Euphorbia* subgen. *Esula* Pers.'e aittir [3]. Bu alt cins 480 tür içermekte olup, Eski Dünya'nın ılıman bölgelerindeki cinsin en önemli radyasyonunu temsil etmektedir ve günümüzde 21 seksiyon tanınmaktadır. *E. myrsinites* L. subsp. *myrsinites*, diploid bir türdür ($2n = 20$) [4]. Tüysüz, mumsu tabakalı (glaucous), yatık-yükselen gövdelere sahip, odunsu rizomdan çıkan çok yıllık bir otsu bitkidir. Yarı-sukkulent gövde yaprakları şekil bakımından değişkenlik göstermekle birlikte, bu seksiyona özgü olan elsi (palmatous) damarlanma ile karakterizedir. Siyathiyum bezleri hilal biçiminde, boynuzlu ve uç kısımları hafifçe genişlemiş yapıdadır. Çoğu *Euphorbia* türünde olduğu gibi, *E. myrsinites* de bir karunkül taşımakta olup, bu yapı karıncaları cezbederek tohum yayılımını sağlayan elaiosom işlevi görmektedir. Tür; kayalık ve taşlı yamaçlarda, çam ormanlarında ve dağ çayırlarında, deniz seviyesinden 2200 m'ye kadar olan yükseltilerde yayılış göstermektedir [5]. Diyabet, dünya çapında insanları etkileyen önemli sağlık sorunlarından biridir. Bu hastalığın görülme sıklığı her geçen gün artmaktadır. 2045 yılında yaklaşık 693 milyon kişinin bu hastalığa sahip olacağı öngörülmektedir [6]. Diabetes mellitus, Batı toplumunda yaygın bir sorundur ve dünyanın geri kalanında da giderek yaygınlaşmaktadır. Bir hastalık değil, benzer semptom, belirti ve komplikasyonları gösteren ancak farklı etiyolojilere sahip çeşitli hastalıklardan oluşan bir sendromdur. Bu hastalıklar artık etiyoloji ve patolojilerine göre tip 1 diabetes mellitus (T1DM), tip 2 diabetes mellitus (T2DM), "diğer" ve gebelik diyabeti (GDM) olarak sınıflandırılmaktadır. GDM, hamile kadınların yaklaşık %5 ila %6'sını etkiler ve çoğu durumda T2DM'nin erken bir formudur. T1DM, diyabetli kişilerin %5 ila %10'unu oluşturur ve geri kalanını, yani hastalığı olanların yaklaşık %90'ını T2DM etkiler. Obezite, diyabet için en önemli ve başlıca risk faktörleri arasındadır [7]. Tip 2 diyabetli hastaların yaklaşık %60-90'ının obez olduğu bildirilmektedir. Çeşitli klinik çalışmalarda obezite ile yetişkinlerde insülin direnci arasında bir ilişki olduğu bildirilmiştir. Ayrıca kilo kaybının, çocuklarda, ergenlerde ve yetişkinlerde insülin konsantrasyonunda azalma ve insülin duyarlılığında artış ile ilişkili olduğunu öne süren raporlar da bulunmaktadır. Bu nedenle, yaygın bir metabolik bozukluk olan diabetes mellitus ile mücadelede; kan şekeri düşürebilen, diyabetin neden olduğu oksidatif stresi azaltabilen ve kilo kontrolünde rol oynayabilen doğal veya sentetik kökenli yeni ilaçlara ihtiyaç duyulmaktadır [8]. Bu çalışmada *E. myrsinites* kök, gövde ve yapraklarından 0,01, 1 ve 2 mg/ml konsantrasyonlarda %80'lik etanol ekstraktları hazırlanarak hem diabetes mellitusta (α -glukozidaz ve α -amilaz), hem obezitede (pankreatik lipazı), hem de hiperkolesterolemide (pankreatik kolesterol esterase) rol oynayan enzimlere karşı bitkinin etkinliği incelenmiştir. Burada bitkinin hem bu enzimler üzerindeki inhibitör etkisi hem de bitkinin farklı kısımlarından aynı solvanlarla ve aynı şartlarda hazırlanan ekstraktların kendi içerisinde yine enzim inhibisyon değerlerinin mukayese edilmesi amaçlanmıştır.

II. MATERYAL VE YÖNTEM

Bitki Materyali

Bu çalışmada kullanılan *E. myrsinites* L. subsp. *myrsinites* bitkisi, 2023'te Türkiye, Balıkesir/Havran/Kaz Dağı'ndan toplanmıştır. Toplanan bitki, Prof. Dr. Osman Tugay (Selçuk Üniversitesi Eczacılık Fakültesi, Farmasötik Botanik Anabilim Dalı, Konya, Türkiye) tarafından teşhis edilmiştir. Bitkinin örnekleri Selçuk Üniversitesi KNYA Herbaryumu'nda (Herbaryum Numarası: KNYA30.222) saklanmaktadır. Bitkinin yaprak, kök ve gövde kısmı kullanılacak şekilde ayrılıp, gölgede oda sıcaklığında kurumaya bırakılmıştır. Kuru bitki mekanik öğütücü yardımıyla toz haline getirilmiştir.

Kullanılan Kimyasal Maddeler

Ekstraksiyon, enzim inhibisyonu ve aktivite değerlendirme çalışmaları yöntemlerinde kullanılan tüm solvanlar ve kimyasal maddeler yüksek saflıkta olup Sigma-Aldrich firmasından temin edilmiştir.

Ekstraksiyon

Kimyasal analizler ve aktivite çalışmalarında kullanmak üzere toplanan bitki materyalleri gölgede kurutulmuştur. Daha sonra bitki örneklerinin yaprak, gövde ve kök (kökle birlikte toplanan türler için) kısımları ayrılmış ve parçalanmıştır. Bu kısımlardan %80'lik etanol ile %10'luk (a/h) ekstreler hazırlanmıştır. Bitki kısımları erlenlere alınarak üzerlerine oda ısısında %80'lik etanol eklenmiş ve 24 saat maserasyona bırakılmıştır. Süre bitiminde ekstreler pilili süzgeç kağıdından süzülmuş, drogun üzerine tekrar %80 etanol ilave edilmiş ve bu işlem toplamda iki sefer tekrar edilmiştir. Elde edilen süzüntüler birleştirilerek alçak basınç altında 45°C'de rotavaporda kuruluğa kadar yoğunlaştırılmıştır. Kuru ekstreler tartılarak verimleri (g ekstre/g bitki) hesaplanmıştır.

Enzim İnhibitör Aktivite Testleri

α -Glukozidaz Enzim İnhibisyon Aktivitesi

Deneyde kullanılmak üzere 0,5 M, pH 6,5 fosfat tamponu hazırlanmıştır. α -Glukozidaz tip IV enzimi bu tampon çözeltisinin içerisinde çözölmüştür. Substrat olarak *p*-nitrofenil α -D-glukopiranozit (PNG) kullanılmıştır. Substrat fosfat tamponunda çözölmüş ve 20 mM konsantrasyonda hazırlanmıştır. 0,01, 1 ve 2 mg/ml konsantrasyonlarda *E. myrsinites* kök, gövde ve yapraklarından %80'lik etanol ekstreleri hazırlanmıştır. Enzim çözeltisi ve ekstreler, 96 kuyucuklu mikrolakta 37°C'de 15 dakika süreyle ön inkübasyon işlemine tabi tutulmuştur. Ardından kuyucuklara hazırlanan 20 mM PNG substratı eklenmiş ve 37 °C'de 35 dakika ikinci bir inkübasyon gerçekleştirilmiştir. ELISA mikrolak okuyucusunda 405 nm'de absorbanslar ölçölmüştür. Bu çalışmada referans akarboz (Bayer, Türkiye) olacak şekilde tercih edilmiştir. Çalışma üç tekrar olarak gerçekleştirilmiştir [9].

α -Amilaz Enzim İnhibisyon Aktivitesi

α -amilaz tip I-A (EC 3.2.1.1, Sigma) enzimi sodyum fosfat tamponu (pH 6.9)'nda çözölmüştür. Substrat, fosfat tampon çözeltisinde hazırlanmış patates nişastasası (%2.5, a/h) olarak belirlenmiştir. *E. myrsinites* kök, gövde ve yapraklarından 0,01, 1 ve 2 mg/ml konsantrasyonlarda %80'lik etanol ekstreleri hazırlanmıştır. Renk reajanı olarak 3,5-dinitrosalisilik asit (DNS) çözeltisi kullanılmıştır. 96 mM DNS, 2M NaOH içinde 5,31 M sodyum potasyum tartarat ile hazırlanmıştır. Örnekler üzerine sodyum fosfat tamponu (pH 6,9) ve α -amilaz enzimi ilave edilmiştir. Ardından oda sıcaklığında 5 dakika inkübasyona bırakılmıştır. İşlem tamamlandıktan sonra üzerlerine substrat eklenen karışımlara 37°C'de 15 dakika ikinci bir inkübasyon işlemi uygulanmıştır. Sonrasında DNS ilave edilerek etüvde 80°C'de 40 dakika inkübasyona bırakılmıştır. 540 nm'de ELISA mikrolak okuyucusunda absorbans değerleri ölçölmüştür. Sonrasında standart maltoz kalibrasyon grafiğı ($y = 0,7618x - 0,1243$ ve $r^2 = 0,9949$) hazırlanmıştır. Bu çalışmada referans olarak akarboz (Bayer, Türkiye) kullanılmıştır. Deneyler 3 tekrar şeklinde yapılmıştır [10].

Pankreatik Lipaz Enzim İnhibisyon Aktivitesi

Bu çalışmada pankreatik lipaz enzimi tip II kullanılmıştır. Enzim çözeltisi 10 mM 4-morfolinpropanesülfonik asit ve 1 mM EDTA tampon çözeltisi (pH 6,8)'nde hazırlanmıştır. Çalışmada *E. myrsinites* kök, gövde ve yaprak ekstrelerinin üç farklı konsantrasyonu (0,01, 1 ve 2 mg/ml) kullanılmıştır. Ekstreler ve referans madde orlistat üzerine Tris tamponu (100 mM Tris-HCl ve 5 mM CaCl₂, pH 7,0) ilave edilmiştir ve ardından da 15 dakika süreyle 37°C sıcaklıkta ön inkübasyon işlemine tabi tutulmuştur. Sonrasında kuyucuklara 5 mM 4-nitrofenil butirat eklenmiştir ve 37°C'de yarım saat inkübasyon işlemine tabi tutulmuştur. Absorbanslar 405 nm'de ELISA mikrolak okuyucusu ile ölçölmüştür. Deneyler 3 tekrar şeklinde yapılmıştır [11].

Pankreatik Kolesterol Esteraz Enzim İnhibisyon Aktivitesi

100 mM NaCl içeren 100 mM tampon çözeltisi ile domuz pankreatik kolesterol enzimi hazırlanmıştır (pH 7). 0,01, 1 ve 2 mg/ml konsantrasyonlarda hazırlanan kök, gövde ve yaprak ekstrelerine 50 μ L fosfat tamponu ilave edilmiştir. Ardından taurokolik asit (12 mM) ve 5 mM *p*-NPB substratı ekstreler üzerine ilave edilmiştir. Oda sıcaklığında 5 dakika inkübasyona bırakılmıştır. Süre sonunda bu karışıma domuz

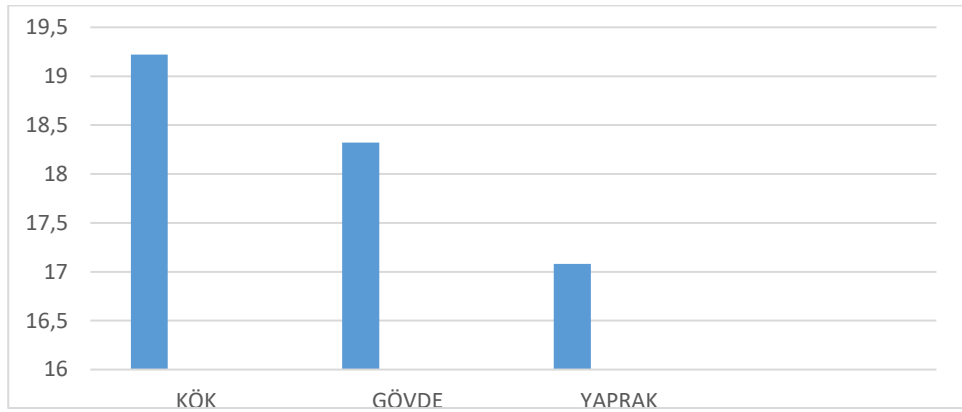
pankreatik kolesterol esteraz enzimi (0,1 µg/ml) eklenmiştir. 405 nm’de 15 dakika ELISA mikropalak okuyucu ile kinetik ölçüm yapılmıştır. Referans olarak da simvastatin kullanılmıştır. Deneyler 3 tekrar şeklinde yapılmıştır [12].

İstatistiksel Analiz

Tüm analizler üç tekrar olacak şekilde yapılmıştır. Bütün değerler ortalama $\pm$ standart sapma (S.S.) olarak hesaplanmıştır ve makalede verilmiştir. Doğrusal regresyon analizleri ve hesaplamalar Microsoft Excel; IC₅₀ istatistiksel olarak anlamlılık GraphPad ANOVA kullanılarak yapılmıştır. (*p<0,05, **p<0,01, ***p<0,001)

III. BULGULAR

Bu çalışmada *E. myrsinites* kök, gövde ve yaprak ekstralarının farklı konsantrasyonlarda antidiyabetik, antiobezite ve antihiperkolesterolemi üzerindeki etkileri in vitro olarak incelenmiştir. Aşağıda şekil 1’de kök gövde ve yaprak ekstralarının yüzde (%) verimleri verilmiştir.



Şekil 1. *E. myrsinites* kök, gövde ve yaprak ekstralarının % verimleri

Sonuçlara bakıldığında α -gukozidaz enzimi üzerinde bu üç farklı kısımdan hazırlanan ekstralardan en yüksek inhibitör etkiyi IC₅₀: 119,53 $\pm$ 1,25 değeri ile bitkinin yapraklarından hazırlanan ekstre göstermiştir. Referans madde olan akarbozda ise bu değer IC₅₀: 0,01 $\pm$ 0,00 olarak belirlenmiştir. Burada bitkinin yapraklarından hazırlanan ekstre bu enzim üzerinde ılımlı bir etki gösterdiği belirlenmiştir.

α -Amilaz enzim inhibisyon değerlerine bakıldığında ise en yüksek aktiviteyi IC₅₀: 55,03 $\pm$ 4,64 değeri ile yaprak ekstresi gösterirken kök ekstresinde de bu oran IC₅₀: 57,80 $\pm$ 0,03 ile ona çok yakın olmuştur. Referans madde olan akarbozda ise bu değer IC₅₀: 0,02 $\pm$ 0,01 olmuştur. Buradan da bitkinin bu enzim üzerinde ılımlı bir etkiye sahip olduğu anlaşılmıştır.

Pankreatik lipaz enzimi üzerine yapılan inhibisyon çalışmalarında ise bitkinin üç kısmından da hazırlanan ekstraların hiçbirisi aktif bulunmazken referans madde orlistatta IC₅₀: 189,90 $\pm$ 0,03’lik bir inhibisyon değeri saptanmıştır.

Pankreatik kolesterol esteraz enzimi üzerinde gerçekleştirilen inhibisyon çalışmalarında en yüksek aktiviteyi IC₅₀: 57,36 $\pm$ 2,40 değeri ile kök ekstresi gösterirken referans madde olan simvastatinde bu değer IC₅₀: 3,88 $\pm$ 0,69 olarak saptanmış olup bitkinin bu enzim üzerinde de ılımlı bir etkiye sahip olduğu anlaşılmıştır.

Tablo 1. *E. myrsinites* kök, gövde ve yaprak ekstralarının α -glukozidaz ve α -amilaz enzimi üzerindeki etkileri

Ekstreler ve referanslar	200 μ g/mL % İnhibisyon $\pm$ S.S. (IC ₅₀ : μ g/mL $\pm$ S.S.)	
	α -Glukozidaz	α -Amilaz
<i>E. myrsinites</i> Kök ekstresi	20,38 $\pm$ 1,29 ^{*a} (IC ₅₀ > 200)	69,77 $\pm$ 0,06 ^a (IC ₅₀ : 57,80 $\pm$ 0,03)
<i>E. myrsinites</i> Gövde ekstresi	59,52 $\pm$ 2,39 ^{***a} (IC ₅₀ : 123,25 $\pm$ 5,73)	76,77 $\pm$ 1,13 ^{***a} (IC ₅₀ : 121,30 $\pm$ 0,16)
<i>E. myrsinites</i> Yaprak ekstresi	81,84 $\pm$ 2,15 ^{***a} (IC ₅₀ : 119,53 $\pm$ 1,25)	66,09 $\pm$ 0,46 ^{***a} (IC ₅₀ : 55,03 $\pm$ 4,64)
Referanslar	100 $\pm$ 0,66 ^{***a} (IC ₅₀ : 0,01 $\pm$ 0,00)	92,93 $\pm$ 1,02 ^{***a} (IC ₅₀ : 0,02 $\pm$ 0,01)

-. Aktivite yok, SS: Standart Sapma, *p<0,05, **p<0,01, ***p<0,001 ^a: Akarboz

Tablo 2. *E. myrsinites* kök, gövde ve yaprak ekstralarının Pankreatik lipaz ve Pankreatik kolesterol esteraz enzimi üzerindeki etkileri

Ekstreler ve referanslar	200 μ g/mL % İnhibisyon $\pm$ S.S. (IC ₅₀ : μ g/mL $\pm$ S.S.)	
	Pankreatik Lipaz	Pankreatik Kolesterol Esteraz
<i>E. myrsinites</i> Kök ekstresi	-	73,32 $\pm$ 2,20 ^{***c} (IC ₅₀ : 57,36 $\pm$ 2,40)
<i>E. myrsinites</i> Gövde ekstresi	-	58,04 $\pm$ 2,55 ^{***c} (IC ₅₀ : 169,03 $\pm$ 5,60)
<i>E. myrsinites</i> Yaprak ekstresi	-	14,91 $\pm$ 1,13 ^{ns} (IC ₅₀ > 200)
Referanslar	55,29 $\pm$ 0,02 ^{**b} (IC ₅₀ : 189,90 $\pm$ 0,03)	81,35 $\pm$ 0,67 ^{***c} (IC ₅₀ : 3,88 $\pm$ 0,69)

-. Aktivite yok, SS: Standart Sapma, *p<0,05, **p<0,01, ***p<0,001, ^b: Orlistat, ^c: Simvastatin

IV. TARTIŞMA

Kang ve arkadaşları tarafından 2012 yılında *E. humifusa*'nın *in vitro* ve *in vivo* α -glukozidaz enzimi üzerindeki inhibitör aktivitesini değerlendirmek amacı ile bir çalışma gerçekleştirilmiştir. Burada bitkiden hazırlanan çeşitli ekstraların ve izole edilen bileşiklerin *in vitro* ve *in vivo* olarak α -glukozidaz enzimi üzerindeki etkileri araştırılmıştır. Yapılan çalışma sonucu metanol ekstresinde IC₅₀: 19,40 μ g/mL, petrol eteri ekstresinde IC₅₀: 279,40 μ g/mL, Etil asetat (EtOAc) ekstresinde IC₅₀: 32,30 μ g/mL, *n*-bütanol (*n*-BuOH) ekstresinde IC₅₀: 130,70 μ g/mL, kersetinde IC₅₀: 8,86 μ g/mL, kemferolde IC₅₀: 73,69 μ g/mL ve referans madde olan akarbozda IC₅₀: 1081,2 μ g/mL olurken *in vivo* da 8 μ L numune konsantrasyonlarında metanol ekstresinde IC₅₀: 638,76 μ g/mL, EtOAc ekstresinde IC₅₀: 696,98 μ g/mL, kersetinde IC₅₀: 131,78 μ g/mL ve kemferolde IC₅₀: 59,54 μ g/mL olurken referans madde akarbozda da etki bulunamamıştır. Metanol ekstresinde, pozitif kontrol olarak akarboza kıyasla α -glukozidaz (IC₅₀: 19,4 μ g/mL) ve sıçan bağırsak α -glukozidazına (IC₅₀: 638,76 μ g/mL) karşı daha güçlü bir inhibitör etki göstermiştir. EtOAc ekstresinde aktivitesi, üç ekstre arasında en güçlü olanı olarak belirlenmiştir. Sonuç olarak da izole edilen kersetin ve kemferolün α -glukozidaz inhibitör aktivitesi, *in vitro* ve *in vivo* olarak akarbozunkinden daha yüksek bulunmuştur [13].

Sheliya ve arkadaşları 2015 yılında yaptıkları bir çalışma ile *E. hirta* L. bitkisinden elde edilen yeni prenile flavonoidlerin α -glukozidaz inhibisyonunu incelemeyi amaçlamışlardır. Yapılan çalışma sonucu bu bitkiden izole edilen 7- *O*-(*p*-kumaroil)-5, 7, 4'-trihidroksi-6-(3, 3-dimetil alil)-flavonol-3- *O* - β -d -glukopiranosil-(2'' $\rightarrow$ 1''')- *O* - α -1-ramnopiranozid bileşiğinin (hirtakumaroflavonozid) 0,2 mM konsantrasyonda IC₅₀: 0,022 (mM) değeri ile referans madde olan akarbozun IC₅₀: 0,092 (mM) değerinden

çok daha iyi bir değerde olduğu ve enzimi akarbozdan bile daha fazla inhibe ettiği gösterilmiştir. Ayrıca izole edilen diğer bileşiklerden kersetin IC₅₀: 0,151(mM), dimetoksi kersetin IC₅₀: 0,182 (mM) ve hirtaflavonozid-B IC₅₀: 0,071 (mM) değerleri ile yine ekili bulunmuştur. Buradan da sonuç olarak *E. hirta* bitkisinin içerisinde bu bileşiklerin kombinasyonu sayesinde α -glukozidaz enzimi üzerinde *in vitro* olarak etkili olduğu bulunmuştur. Fraksiyonlama sırasında metanolik ekstrenin etil asetat fraksiyonu, kersetin ve dimetoksi kersetin olmak üzere iki bilinen flavonol glikozidi ile hirtakumaroflavonozid ve hirtaflavonozid-B olarak adlandırılan iki yeni prenile flavonozid sağlamıştır. Bu çalışma ile *E. hirta* bitkisinde bulunan prenile flavonoidler tarafından gösterilen α -glukozidaz inhibitör aktivitesi ve sukroz toleransı, halk hekimliğinde diyabetin yönetiminde bitkinin etnomedikal kullanımına güvenilirlik kazandırmıştır [14].

Fais ve arkadaşları tarafından 2018'de *E. characias*'ın yaprak ve çiçeklerden elde edilen su ve etanol ekstrelerinin, α -amilaz ve α -glukozidaza karşı *in vitro* inhibe edici aktiviteleri incelenmiştir. Yapraklarından hazırlanan sulu ekstre α -glukozidaz enzimi üzerinde IC₅₀ değeri $1,4 \pm 0,11$ μ g/mL iken etanollü ekstrede $0,8 \pm 0,03$ μ g/mL olmuştur. Bunun yanı sıra çiçeklerden elde edilen sulu ekstrede IC₅₀ değeri $1,1 \pm 0,07$ μ g/mL olurken etanollü ekstrede $0,9 \pm 0,04$ μ g/mL olmuştur. α -Amilaz üzerinde ise yapraklarından hazırlanan sulu ekstre enzimi üzerinde IC₅₀ değeri $74,02 \pm 3,06$ μ g/mL iken etanollü ekstrede $25,41 \pm 1,42$ μ g/mL olmuştur. Çiçeklerden elde edilen sulu ekstrede IC₅₀ değeri $109,12 \pm 10,36$ μ g/mL olurken etanollü ekstre de $29,39 \pm 1,41$ μ g/mL olmuştur. Referans madde olan akarbozda ise IC₅₀ değeri α -amilaz ve α -glukozidazda sırasıyla $90 \pm 7,3$ μ g/mL ve $8,04 \pm 0,65$ μ g/mL olmuştur. Sonuç olarak etanollü ekstrelerin en iyi etkiyi gösterdiği bulunmuştur. Özellikle α -glukozidaz aktivitesi için ekstrelerin standart inhibitörden 100 kat daha aktif olduğu ortaya çıkmıştır [15].

Altamimi ve arkadaşlarının 2019 yılında *E. tirucalli* L.'nin antioksidan, antienzimatik, antimikrobiyal ve sitotoksik özelliklerinin incelenmesi amacı ile yaptıkları çalışmada *E. tirucalli*'nin tıbbi özellikleri *in vitro* olarak araştırılmıştır. Bitki lateksinden elde edilen su ekstre dondurularak kurutulmuş ve 3 sindirim enzimine (Pankreatik lipaz, α -glukozidaz ve α -amilaz) karşı test edilmiştir. Pankreatik lipaz, α -glukozidaz ve α -amilaz için sırasıyla $39,8 \pm 0,22$, $79,43 \pm 0,38$ ve $316,22 \pm 0,3$ IC₅₀ değerleri göstermiştir. Bu sonuçların akarboz, α -glukozidaz ve α -amilaz için sırasıyla $37,01 \pm 0,33$ ve $28,84 \pm 0,15$ iken, orlistatta pankreatik lipaz için $12,56 \pm 0,35$ olarak bulunmuştur. Buradan da bitkinin özellikle pankreatik lipazda etkili olduğu kanısına ulaşılmıştır [16].

Alonazi ve arkadaşları (2020) *E. cyparissias*'ın sulu ve etanolik ekstrelerinin lipaz, α -amilaz ve β -glukozidaz üzerindeki inhibitör etkilerini incelemiştir. Burada ortalama IC₅₀ (μ g/mL) değerleri etanol ekstresinin lipaz üzerinde $4,4 \pm 0,3$ olurken, sulu ekstrenin $23,7 \pm 1,3$ olmuştur. α -amilaz enziminde de etanol ekstresinin $98,8 \pm 8,6$ olurken, sulu ekstrenin $168,9 \pm 5,5$ olmuştur. Etanol ekstresinin β -glukozidaz üzerinde ortalama IC₅₀ (μ g/mL) değeri $8,1 \pm 0,3$ iken sulu ekstrenin $23,5 \pm 0,5$ olmuştur. Buradan da anlaşılmaktadır ki kullanılan tüm sindirim enzimleri üzerinde etanolik ve sulu ekstrelerin IC₅₀ ortalama değerlerinin çoğu, %50 hücre ölümüne yol açan sitotoksik konsantrasyonun altındadır (etanolik ekstre için 30 μ g/mL ve sulu ekstre için >100 μ g/mL) [17].

Mustafa ve arkadaşları (2021) *E. helioscopia*'nın farklı ekstrelerinin antioksidan ve antidiyabetik aktiviteler arasındaki olası etkileri *in vitro* olarak incelemiştir. Çalışmada sulu metanollü ve etanollü ekstreler hazırlanmıştır. Sonuçlara bakıldığında konsantrasyona bağlı bir şekilde gözle görülür amilaz inhibisyon aktivitesi bulunmuştur. Üç ekstre arasında, metanol ekstresi 5 mg/ml konsantrasyonda, $0,4 \pm 0,01$ mg/ml'lik en düşük IC₅₀ değerine sahip olması bakımından maksimum α -amilaz inhibitör aktivitesini gösterirken bu değer referans madde akarbozdan ($0,32 \pm 0,008$ mg/ml) biraz daha yüksek ve sulu ekstrede ($0,57 \pm 0,02$ mg/ml) ve etanol ekstresinden ($0,43 \pm 0,01$ mg/ml) daha düşük bulunmuştur. Ekstrelerin ve akarbozun α -glukozidaz enzim aktivitesini inhibe etme potansiyeli de konsantrasyona bağlı olarak artış göstermiştir. α -Glukozidaz aktivitesinin inhibisyon potansiyeli açısından antidiyabetik aktivite, en düşük IC₅₀ değerine ($0,45 \pm 0,01$ mg/ml) sahip metanol ekstresinde maksimum, sulu ekstrede ise minimum ($0,76 \pm 0,1$ mg/ml) gözlenmiştir [18].

Tran ve arkadaşları (2021) Vietnam'da yetişen *E. antiquorum*'dan elde edilen diterpenlerin α -glukozidaz enzim inhibisyon sonuçlarını incelemişlerdir. Burada ent -1 α , 3 α , 16 β , 17-tetrahidroksiatizan (1), etil ent -3,4- seko -4,16 β , 17-trihidroksiatizan-3-karboksilat (2), ent -atizan-3-okso-16 β , 17-asetonid (3), ent -3 α -asetoksi-16 β , 17-dihidroksiatizan (4), ent -16 β , 17-dihidroksiatizan-3-on (5), kalliterpenon (6) ve ingol 12-asetat (7) bileşikleri izole edilmiştir. Çalışma sonucu elde edilen aktivite sonuçlarına bakıldığında ise IC₅₀ değerleri sırayla bileşik 1 için 125,20 μ M, bileşik 2 için 130,80 μ M, bileşik 3 için 69,62 μ M, bileşik 4 için 102,18 μ M, bileşik 6 için 156,14 μ M, bileşik 7 için 115,23 μ M ve referans madde akarboz için 332,5 μ M olarak hesaplanmıştır. Bileşik 3, 69,62 μ M'lik bir IC₅₀ değeriyle α -glukozidaza karşı en önemli inhibe edici aktiviteyi göstermiştir. α -glukozidaz inhibisyonunun altında yatan mekanizma üzerine yapılan daha ileri çalışmalar, 3'ün enzim fonksiyonunu rekabetçi olmayan bir şekilde geciktirebileceğini göstermiştir [19].

Benrahou ve arkadaşları tarafından 2022 yılında yapılan bir çalışmada *E. resinifera* ekstrelerinin *in vitro* antioksidan, hipoglisemik ve antiobezite etkilerini değerlendirmek ve bu ekstraktların fenolik bileşenlerini ve toksisitesini araştırmak amaçlanmıştır. Bitkinin sulu ve metanollü ekstreleri hazırlanmıştır. Her iki ekstre de α -amilaz ve α -glukozidaza karşı inhibitör aktiviteye sahip bulunmuştur ve referans bileşik olarak kullanılan akarbozdan daha yüksek aktivite göstermiştir. Referans madde olan akarboz, α -amilaz ve α -glukozidaza karşı sırasıyla IC₅₀: 44,75 $\pm$ 0,54 μ g/mL ve IC₅₀: 18,01 $\pm$ 2,00 μ g/mL inhibitör değerleri göstermiştir. Etanolik ekstre α -amilaza karşı 102 $\pm$ 3,63 μ g/mL'lik ve α -glukozidaza karşı 56,6 $\pm$ 1,12 μ g/mL'lik bir IC₅₀ göstermiştir. Sulu ekstrenin, α -amilaza karşı 119,7 $\pm$ 2,15 μ g/mL'lik bir IC₅₀ ve α -glukozidaza karşı 121,4 $\pm$ 1,88 μ g/mL'lik bir IC₅₀ ile daha düşük inhibitör aktiviteye sahip olduğu bulunmuştur. Ayrıca, etanollü ekstrenin lipaza karşı IC₅₀ değeri 13,7 $\pm$ 3,03 μ g/mL olarak belirlenmiş ve bu değer sulu ekstreninkinden daha yüksek olduğu saptanmıştır. *E. resinifera* ekstrelerinin normal sıçanlarda yapılan oral nişasta tolerans testindeki etkilerinin sonuçları 150 mg/kg konsantrasyonda incelenmiştir. Referans madde olan akarboz ve sulu ekstre, 30 dakika sonra kan şekerini düşürmüştür ancak etanol ekstresi, kan şekerini ancak 60 dakika sonra 1,07 g/L'ye düşürebilmiştir. Bununla birlikte, 30. dakikada akarboz ve sulu ekstre (p > 0,05), kan şekerini sırasıyla 0,93 ve 0,81 g/L'ye düşürürken, etanol ekstresi (p > 0,05) kan şekerini yalnızca 120 dakika sonra 0,88 g/L'ye düşürmüştür [20].

Zhang ve arkadaşları 2022 yılında yaptığı bir çalışmada *Euphorbia fischeriana* steud köklerinden elde edilen α -glukozidaz ve α -amilaz inhibitör aktivitesine sahip çeşitli gallotaninleri incelemeyi amaçlamışlardır. Çalışmada fishertannin A'nın, asetofenon, galloil grubu, arabinofuranosil ve glukopiranosil kısımlarından oluşan alışılmadık bir iskelete sahip olduğu belirlenmiştir. Fishertannin B, fishertannin H, fishertannin K, 1,2,3-tri-O-galloyl- β -D-glukopiranoz, 3,4,6-tri-O-galloyl-D-glukopiranoz ve 1,6-di-O-galloyl- β -D-glukopiranoz, 15,48–177,13 μ M'lik IC₅₀ değerleriyle güçlü α -glukozidaz inhibitör aktiviteleri göstermişlerdir. Referans madde olan akarboz ise α -glukozidaz üzerinde 286,23 $\pm$ 0,86 μ M IC₅₀ değeri gösterirken α -amilaz üzerinde 16,99 $\pm$ 0,08 μ M IC₅₀ değerine sahip olmuştur. Yapı-aktivite ilişkilerinin (SAR) incelenmesi, galloil ve glukopiranosil kısımlarının hem α -glukozidaz hem de α -amilaz inhibitör aktivitesi için inhibitör aktivitede önemli bir rol oynadığını göstermiştir. Tüm isolatlar arasında 1,2,3-tri-O-galloil- β -D-glukopiranoz, 15,48 $\pm$ 0,60 μ M'lik bir IC₅₀ değeriyle α -glukozidaza karşı en güçlü ve oldukça spesifik inhibitör aktiviteye sahip olmuştur. 1,2,3-tri-O-galloil- β -D-glukopiranozun kinetik analizi, α -glukozidaz üzerinde karışık inhibisyon tipini ortaya koymuş ve moleküler yerleştirme, α -glukozidazın katalitik cebine (pdb 3A4A) kararlı bağlanmayı görselleştirmiştir. Bu bulgular, *E. fischeriana*'dan elde edilen gallotaninlerin mükemmel antidiyabetik potansiyelini gösterirken, 1,2,3-tri-O-galloil- β -D-glukopiranoz'un daha az yan etkiyle Tip 2 diabetes mellitus'un tedavisi için umut verici bir aday olarak geliştirilebileceği araştırmacılar tarafından ifade edilmiştir [21].

V. SONUÇLAR

Sonuç olarak bakıldığı zaman *E. myrsinites* kök, gövde ve yaprak ekstraktlarının farklı konsantrasyonlarda antidiyabtik, antiobezite ve antihiperkolesterolemi üzerindeki etkileri incelenmiştir. α -Amilaz, α -glukozidaz, pankreatik lipaz ve pankreatik kolesterol esteraz enzimleri üzerindeki inhibitör etkileri bu türde yapılan bu çalışma ile ilk defa çalışılmıştır. Yapılan çalışma sonucunda bitkinin α -amilaz, α -glukozidaz ve pankreatik kolesterol esteraz enzimi üzerinde orta-ılımlı etkilere sahip olduğu belirlenmiştir. Pankreatik lipaz enzimi üzerinde ise hiçbir ekstre etkili bulunmamıştır. Bu çalışmanın bu türde ilk defa yapılması sebebi ile oldukça önem arz etmektedir. İleride bu tür üzerinde hem daha fazla in vitro çalışma yapılması hem izolasyon yapılması hem de in vivo çalışmalar yapılması gerekmektedir.

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Çamlıköy - Işıkdere Yöresi Kayaç ve Topraklarının Yerel Element Ortalama ve Zenginleşme Düzeyleri

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Özet – Bu çalışma, Türkiye'nin önemli metalojenik kuşaklarından biri olan Doğu Pontidler içerisinde yer alan Gümüşhane bölgesinde, kayaç ve topraklardaki bazı temel elementlerin yerel ortalama değerlerinin belirlenmesi amacıyla gerçekleştirilmiştir. Bölge, Tethyan metalojenik kuşağının önemli bir kesimini temsil etmekte olup porfiri (Cu–Mo, Cu–Au), epitermal (Au, Au–Ag) ve volkanik masif sülfür (Cu–Pb–Zn) tipi cevherleşmelere ev sahipliği yapmaktadır. Çalışma sahası Gümüşhane ili güney ve güneydoğusunda yer alan Çamlıköy ve Işıkdere bölgelerini kapsamaktadır. Sahada yüzeyleyen birim Erken–Geç Karbonifer yaşlı Gümüşhane Granitoyidi olup, üzerinde iyi gelişmiş bir toprak örtüsü bulunmaktadır.

Analizlerde 16 adet granitoyid kayaç örneği ve 34 adet toprak örneği kullanılmıştır. Örneklerin analitik işlemleri kısmen Gümüşhane Üniversitesi laboratuvarlarında gerçekleştirilmiş ve element analizleri ICP–AES yöntemiyle yapılmıştır. Kayaç ve toprak örneklerinin tanımlayıcı istatistikleri hesaplanmış; ayrıca element zenginleşme derecelerini belirlemek amacıyla her bir element için üst kabuk değerlerine göre normalize edilmiş PI (Parametric Index) katsayıları kullanılmıştır.

Elde edilen sonuçlara göre, Gümüşhane granitoyidi K₂O, MnO, Sc, Co, Cs, U, W, Pb ve Ni elementlerince üst kabuğa göre daha fakir, diğer elementler açısından ise genel olarak benzer zenginliktedir. Topraklarda ise P, Mn, As, Y, Cd, Sn, Sb, La, Ce, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Pb, Th ve U elementlerinin üst kabuğa göre en az 1,5 kat daha yüksek olduğu belirlenmiştir. Bu sonuçlar, bölgedeki prospeksiyon çalışmalarında bu elementlerin yerel eşik değerlerinin küresel ortalamalara göre daha yüksek tutulması gerektiğini göstermektedir.

Anahtar Kelimeler – Gümüşhane Granitoyidi, Toprak Jeokimyası, Element Zenginleşmesi, Jeokimyasal Prospeksiyon, Yerel Eşik Değer.

I. GİRİŞ

Bu çalışma ile Türkiye'nin önemli metalojenik kuşaklarından biri içinde yer alan Gümüşhane için belli başlı elementlerin kayaç ve topraklardaki yerel ortalama değerlerin belirlenmesine yönelik gerçekleştirilmiştir. Bilindiği üzere Gümüşhane ve civarı önemli maden yataklarına ev sahipliği yapmaktadır [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18]. Bu bölge, Tethyan metalojenik kuşağı içinde önemli bir kaynak alanı olup, porfiri (Cu–Mo, Cu–Au vb.), epitermal (Au, Au–Ag) ve volkanik masif sülfür (Cu–Pb–Zn) cevherleşmeleri dahil olmak üzere çeşitli magmatik-hidrotermal yatak tiplerine ev sahipliği yapmaktadır [12], [19], [20], [21]. Bu yüzden bölgede pek çok maden arama amaçlı çalışma gerçekleştirilmiştir [22], [23], [24], [25], [26], [27], [28], [29], [30].

Maden aramacılığının en önemli bileşeni genel jeokimyasal prospeksiyon (ön arama) çalışmalarıdır [15], [31], [32], [33], [34], [35], [36]. Bu çalışmalarla pek çok maden yatağı tespit edilmiş olup [1], [11], [34], [37], [38], [39], [40], prospeksiyon çalışmalarının temel bileşenleri dere sedimanı, toprak jeokimyası ve bitki jeokimyası iken, detaylı aramalar kayaç jeokimyası çalışmalarını içerir .

Prospeksiyon çalışmalarının başarısındaki en önemli faktörlerden biri element temel değerlerinin ve anomali değerlerinin doğru şekilde tespitidir [13], [41], [42], [43], [44], [45], [46].

Bu çalışmanın amacı, Gümüşhane ili sınırları içinde olan Gümüşhane Granitoyidi ve üzerinde gelişmiş toprakların belli başlı elementler için ortalama değerlerinin belirlenerek yerel anomali/eşik değer hesaplamalarına katkı vermektir.

II. MATERYAL VE YÖNTEM

A. Bölgesel jeoloji

Doğu Pontid’lerde Tersiyer öncesi kayaçlar, Erken Karbonifer yaşlı metamorfik kayaçlardan [47], Erken-Geç Karbonifer yaşlı plütonik kayaçlardan [48], [49], [50], [51], [52], [53], [54], [55], [56], Erken-Orta Jura yaşlı volkan-tortul kayaçlardan [57], [58], Orta-Geç Jura yaşlı plütonik kayaçlardan [20], [56], [59], [60], [61], [62], Geç Jura-Erken Kretase yaşlı karbonat kayaçlardan [63] ve Geç Kretase yaşlı volkanik, plütonik ve tortul kayaçlardan [64], [65], [66], [67], [68], [69] oluşurlar. Tersiyer yaşlı kayaçlar ise Geç Paleosen-Erken Eosen yaşlı adakitik kayaçlar [70], [71], [72], [73], Erken-Orta Eosen yaşlı volkanik-subvolkanik kayaçlar [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], Orta Eosen yaşlı plütonik kayaçlar [2], [5], [12], [73], [84], [85], [86], [87], [88], [89], [90], [91], Geç Eosen ve Oligosen yaşlı volkanik kayaçlar [92], [93] ve Miyosen-Pliyosen yaşlı adakitik-adakitik olmayan volkanik-subvolkanik kayaçlar [94], [95]’den oluşurlar. Bölgenin en genç birimleri ise Kuvaterner alüvyon, yamaç molozu ve travertenlerdir [96], [97], [98], [99], [100]. Çalışmaya konu saha Gümüşhane güney ve güneydoğusunda yer alan Çamlıköy ve Işıkdere bölgeleri olup, sahada yaygın olarak Erken-Geç Karbonifer yaşlı Gümüşhane Granitoyidi yüzeylenmektedir. Sahada, Gümüşhane granitoyidi üzerinde, toprak jeokimyası için uygun kalınlıkta gelişmiş toprak örtüsü mevcuttur.

B. Analitik Süreçler

Çalışmaya konu toprak örneklerinin ve kısmen kayaç örneklerinin analize hazırlanması Gümüşhane Üniversitesi imkanları ile üniversite jeoloji mühendisliği bölümü örnek hazırlama laboratuvarında gerçekleştirilmiştir. Toprak ve kayaç örneklerin önemli bir çoğunluğunun analizi de Gümüşhane Üniversitesi Merkezi Laboratuvarında ICP-AES ile gerçekleştirilmiştir. Örnek hazırlama ve analiz detayları Vural [101], [102], Vural vd. [103], Vural ve Erdoğan [104], Vural ve Şahin [105] ve Bulut vd. [106]’de mevcuttur.

III. BULGULAR

Çamlıköy ve Işıkdere (Gümüşhane Merkez) sahasını için alan bölgenin kayaç ve topraklar için yerel element ortalama değerlerinin tespiti amacıyla Gümüşhane granitoyidine ait 16 adet kayaç örneği ([23] (6 adet), [107] (9 adet), [108] (7 adet)) ve 34 adet toprak örneği dikkate alınmıştır (Tablo 1 ve Tablo 2). Toprak ve kayaç örneklerinin tanımlayıcı istatistikleri hesap edilmiş, ayrıca kayaç ve topraktaki elementlerin ortalama üst kabuk değerlerine göre oranlamasından (PI) yararlanarak bahse konu elementler için zenginleşme katsayıları ve element katsayı ortalamaları tespit edilmiştir (Tablo 1 ve Tablo 2). PI değerleri her bir örnek için hesap edildikten sonra bahse konu element için ortalama PI değeri tespit edilmiştir. Kayaçların element içeriklerinin ortalama, medyan ve geometrik ortalama değerleri birbirine yakın olmakla birlikte (Şekil 1), uç değerlerinin etkisini en aza indirmek için medyan değerleri dikkate alınmıştır. Kayaçların element PI katsayıları Rudnick ve Gao [109]’den alınan üst kabuk değerlerine oranlanarak hesap edilmiştir. Kayaçların element PI değerleri dikkate alındığında Gümüşhane granitoyidinin K₂O, MnO, Sc, Co, Cs, U, W, Pb ve Ni elementlerince daha fakir olduğu, V dışındaki

diğer elementlerce ise üst kabuk değerlerine göre yakın konsantrasyonlarda olduğu görülmüştür. V konsantrasyonunun ise üst kabuğun % 6'sı oranında bulunduğu görülmüştür (Tablo 1).

Topraktaki element konsantrasyonlarının uç değerlere sahip olduğu dikkate alınarak bölge topraklarının element içerikleri için ortalama olarak medyan değerlerinin alınmasının daha uygun olduğu kanaatine varılmıştır (Tablo 2, standart sapma (s.s), çarpıklık (Çar.), basıklık (Bas.) değerlerine bakınız).

Topraklardaki elementlerin PI değerleri dikkate alındığı bölge topraklarının P, Mn, As, Y, Cd, Sn, Sb, La, Ce, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Pb, Th ve U elementlerince üst kabuk değerlerine göre en az 1.5 kat daha yüksek olduğu tespit edilmiştir (Tablo 2, Şekil 2). Dolayısıyla bölge ve yakın çevresinde yapılacak prospeksiyon çalışmalarında bahse konu elementlerin yerel eşik değerlerinin üst kabuğa göre bir miktar daha yüksek olduğu gerçeğinin dikkate alınarak prospeksiyon çalışmalarının yapılmasının daha uygun olacağı anlaşılmaktadır.

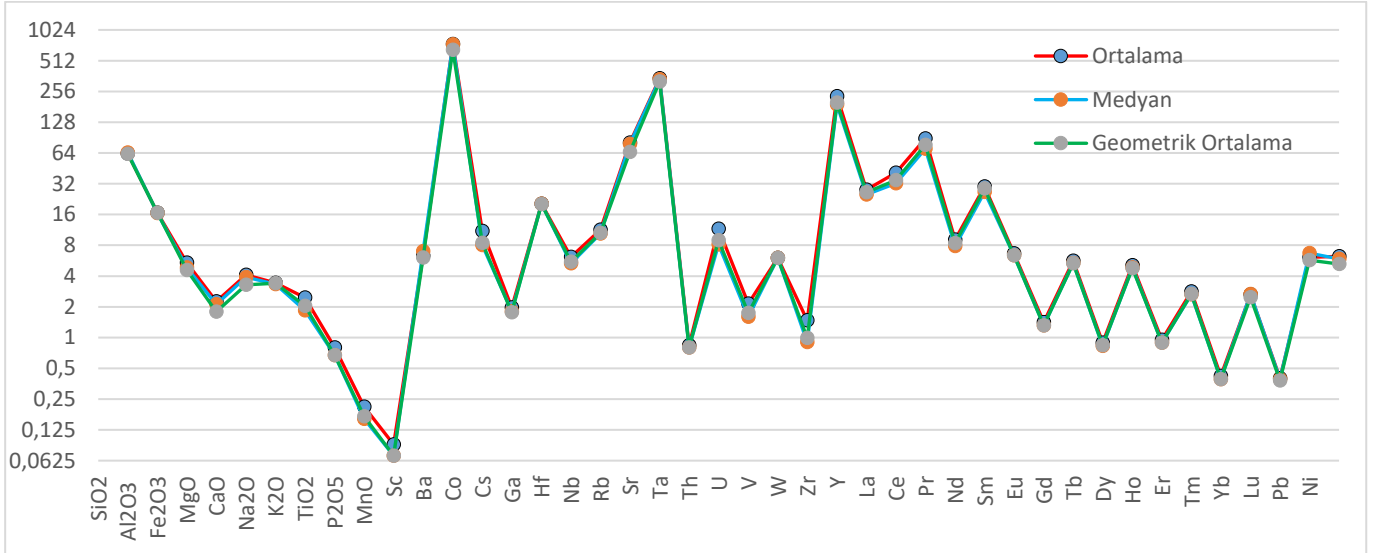
Tablo 1. Bölgede yüzeyleyen Gümüşhane Granitoidine ait anaoksid ve iz element ortalama değerleri ve hesaplanmış PI ve I_{geo} değerleri (Ana oksitler %, diğerleri ise ppm olarak verilmiştir.)

	Ortalama	Medyan	Geo.Ort.	PI
SiO ₂	62,98	64,46	62,56	0,97
Al ₂ O ₃	16,65	16,45	16,58	1,07
Fe ₂ O ₃	5,38	4,84	4,57	0,96
MgO	2,26	2,11	1,79	0,85
CaO	4,10	3,89	3,29	1,08
Na ₂ O	3,43	3,34	3,40	1,02
K ₂ O	2,45	1,84	2,04	0,66
TiO ₂	0,80	0,67	0,67	1,05
P ₂ O ₅	0,21	0,16	0,17	1,07
MnO	0,09	0,07	0,07	0,70
Sc	6,33	7,00	6,07	0,49
Ba	745,05	739,05	652,37	1,18
Co	10,99	8,00	8,43	0,46
Cs	1,96	1,80	1,76	0,37
Ga	20,35	20,40	20,12	1,17
Hf	6,14	5,30	5,52	1,00
Nb	11,35	10,40	10,54	0,87
Rb	80,33	78,05	65,60	0,93
Sr	343,10	335,95	320,44	1,05
Ta	0,84	0,80	0,80	0,89
Th	11,56	8,15	8,91	0,78
U	2,15	1,60	1,74	0,59
V	6,00	6,00	6,00	0,06
W	1,47	0,90	0,99	0,47
Zr	229,98	190,50	197,86	0,99
Y	27,93	25,10	26,38	1,20
La	41,07	32,20	34,69	1,04
Ce	88,57	70,50	76,41	1,12
Pr	9,09	7,85	8,35	1,11
Nd	29,97	26,60	28,76	0,99
Sm	6,66	6,35	6,35	1,35
Eu	1,41	1,31	1,31	1,31
Gd	5,65	5,34	5,32	1,34
Tb	0,89	0,83	0,84	1,19
Dy	5,08	4,85	4,79	1,24
Ho	0,95	0,89	0,89	1,07
Er	2,82	2,65	2,66	1,15
Tm	0,42	0,39	0,39	1,30
Yb	2,65	2,66	2,47	1,33
Lu	0,40	0,39	0,38	1,26
Pb	6,12	6,70	5,73	0,39
Ni	6,25	5,90	5,24	0,13

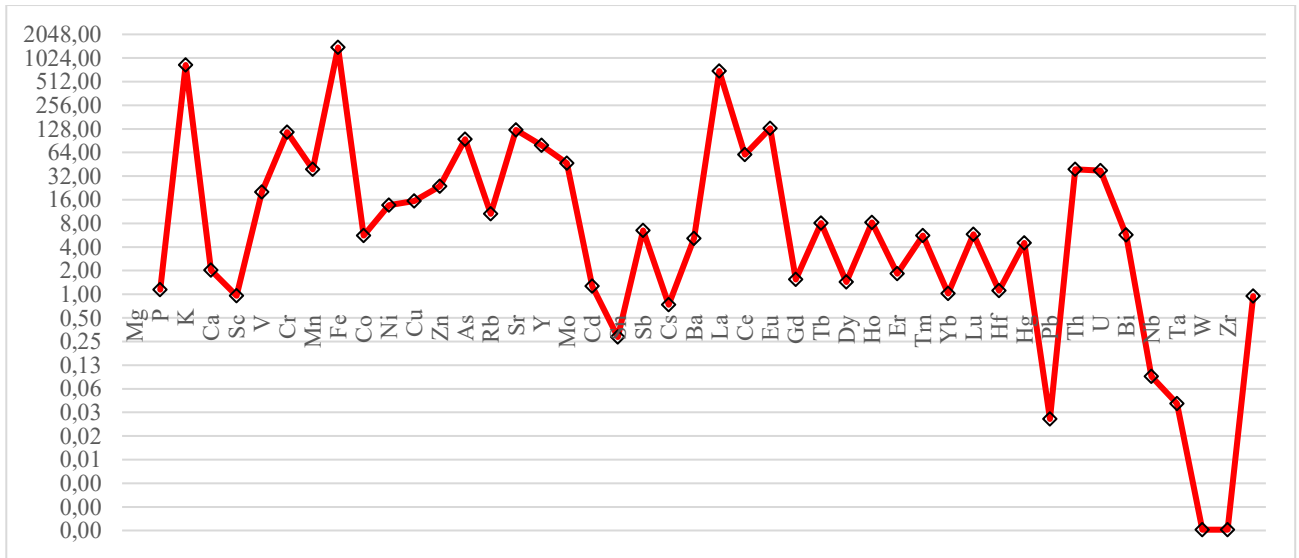
Tablo 2. Çamlıköyü ve Işıkdere bölgelerindeki toprakların element içeriklerine ait tanımlayıcı istatistikler (ppm olarak) 1.5 >PI değerleri koyu renkli gösterilmiştir.

	Ort.	Med.	S.S.	Bas	Çar	#	Mak.	Min		Ort.	Med.	S.S.	Bas	Çar	#	Mak.	Min
<i>Mg</i>	1,14	1,14	0,42	1,20	-0,14	34	2,25	0,19	<i>PI Mg</i>	0,76	0,76	0,28	0,08	1,20	34	1,50	0,13
<i>P</i>	986,90	837,59	474,01	0,68	1,08	34	2246,90	209,04	<i>PI P</i>	15,18	12,89	7,29	53,18	0,68	34	34,57	3,22
<i>K</i>	2,40	2,02	1,71	-0,10	0,55	34	6,78	0,14	<i>PI K</i>	1,04	0,87	0,74	0,55	-0,10	34	2,92	0,06
<i>Ca</i>	1,68	0,96	1,69	1,09	1,52	34	6,21	0,20	<i>PI Ca</i>	0,65	0,37	0,66	0,43	1,09	34	2,42	0,08
<i>Sc</i>	18,92	19,96	8,34	-0,56	-0,14	34	35,41	5,10	<i>PI Sc</i>	1,35	1,43	0,60	0,35	-0,56	34	2,53	0,36
<i>V</i>	109,97	116,21	46,99	-0,22	0,03	34	219,89	19,00	<i>PI V</i>	1,13	1,20	0,48	0,23	-0,22	34	2,27	0,20
<i>Cr</i>	44,66	39,05	31,45	3,92	1,70	34	157,37	11,70	<i>PI C</i>	0,49	0,42	0,34	0,12	3,92	34	1,71	0,13
<i>Mn</i>	1463,76	1394,37	594,16	6,21	2,11	34	3772,90	732,00	<i>PI Mn</i>	1,89	1,80	0,77	0,59	6,21	34	4,87	0,95
<i>Fe</i>	5,81	5,57	2,16	-0,97	0,29	34	9,75	2,60	<i>PI Fe</i>	1,49	1,42	0,55	0,31	-0,97	34	2,49	0,66
<i>Co</i>	15,12	13,69	5,54	6,17	2,09	34	36,60	8,50	<i>PI Co</i>	0,87	0,79	0,32	0,10	6,17	34	2,12	0,49
<i>Ni</i>	17,57	15,45	11,07	6,53	2,26	34	60,40	4,54	<i>PI Ni</i>	0,37	0,33	0,24	0,06	6,53	34	1,29	0,10
<i>Cu</i>	29,99	23,84	25,62	6,32	2,40	34	126,23	5,48	<i>PI Cu</i>	1,07	0,85	0,91	0,84	6,32	34	4,51	0,20
<i>Zn</i>	152,33	94,38	186,55	11,36	3,39	34	905,17	51,32	<i>PI Zn</i>	2,27	1,41	2,78	7,75	11,36	34	13,51	0,77
<i>As</i>	15,41	10,62	13,36	4,68	2,17	34	59,44	4,00	<i>PI As</i>	3,21	2,21	2,78	7,75	4,68	34	12,38	0,83
<i>Rb</i>	121,63	123,90	85,47	0,42	0,63	34	360,78	7,00	<i>PI Rb</i>	1,45	1,48	1,02	1,04	0,42	34	4,30	0,08
<i>Sr</i>	94,97	78,80	81,57	14,82	3,49	34	475,01	10,00	<i>PI Sr</i>	0,30	0,25	0,25	0,06	14,82	34	1,48	0,03
<i>Y</i>	42,16	46,80	17,44	-1,03	-0,41	34	70,70	11,37	<i>PI Y</i>	2,01	2,23	0,83	0,69	-1,03	34	3,37	0,54
<i>Mo</i>	2,06	1,27	2,07	6,27	2,55	34	9,50	0,40	<i>PI Mo</i>	1,87	1,15	1,88	3,55	6,27	34	8,64	0,36
<i>Cd</i>	0,64	0,29	1,30	23,81	4,70	34	7,40	0,10	<i>PI Cd</i>	7,16	3,17	14,41	207,72	23,81	34	82,22	1,11
<i>Sn</i>	6,50	6,50	4,09	-1,12	0,05	34	14,53	0,60	<i>PI Sn</i>	3,09	3,10	1,95	3,80	-1,12	34	6,92	0,29
<i>Sb</i>	1,25	0,73	1,11	-0,46	0,94	34	3,70	0,10	<i>PI Sb</i>	3,12	1,84	2,78	7,72	-0,46	34	9,25	0,25
<i>Cs</i>	6,24	5,14	4,78	0,38	1,13	34	18,03	0,88	<i>PI Cs</i>	1,27	1,05	0,97	0,95	0,38	34	3,68	0,18
<i>Ba</i>	711,69	695,28	346,71	-0,52	0,16	34	1439,27	117,30	<i>PI Ba</i>	1,14	1,11	0,56	0,31	-0,52	34	2,31	0,19
<i>La</i>	59,29	60,12	23,41	-0,47	-0,34	34	105,23	14,20	<i>PI La</i>	1,91	1,94	0,76	0,57	-0,47	34	3,39	0,46
<i>Ce</i>	134,74	129,85	67,60	-0,77	0,27	34	256,52	29,60	<i>PI Ce</i>	2,14	2,06	1,07	1,15	-0,77	34	4,07	0,47
<i>Eu</i>	1,85	1,55	1,02	2,95	1,55	34	5,00	0,58	<i>PI Pr</i>	1,29	1,32	0,55	0,30	-0,47	34	2,59	0,51
<i>Gd</i>	7,95	8,09	2,80	0,11	-0,18	34	13,74	2,57	<i>PI Nd</i>	0,97	1,07	0,74	0,55	-1,15	34	2,47	0,00
<i>Tb</i>	1,38	1,43	0,55	-0,19	-0,18	34	2,47	0,40	<i>PI Sm</i>	1,83	1,87	0,62	0,39	-0,58	34	2,82	0,66
<i>Dy</i>	7,89	8,23	3,25	0,38	0,15	34	15,50	2,32	<i>PI Eu</i>	1,85	1,55	1,02	1,04	2,95	34	5,00	0,58
<i>Ho</i>	1,74	1,83	0,74	0,34	-0,02	34	3,47	0,44	<i>PI Gd</i>	1,99	2,02	0,70	0,49	0,11	34	3,44	0,64
<i>Er</i>	5,35	5,61	2,39	0,31	-0,02	34	10,90	1,21	<i>PI Tb</i>	1,98	2,04	0,78	0,61	-0,19	34	3,53	0,57
<i>Tm</i>	1,15	1,02	0,69	-1,13	0,18	34	2,43	0,16	<i>PI Dy</i>	2,02	2,11	0,83	0,70	0,38	34	3,98	0,59
<i>Yb</i>	5,60	5,78	2,75	-0,70	-0,14	34	10,37	1,00	<i>PI Ho</i>	2,10	2,20	0,90	0,80	0,34	34	4,18	0,53
<i>Lu</i>	1,22	1,11	0,75	-1,02	0,16	34	2,66	0,14	<i>PI Er</i>	2,33	2,44	1,04	1,08	0,31	34	4,74	0,53
<i>Hf</i>	6,39	4,49	6,61	0,23	1,14	34	22,30	0,04	<i>PI Tm</i>	3,83	3,41	2,31	5,33	-1,13	34	8,09	0,53
<i>Hg</i>	0,04	0,03	0,04	3,05	1,97	34	0,15	0,01	<i>PI Yb</i>	2,80	2,89	1,37	1,89	-0,70	34	5,19	0,50
<i>Pb</i>	53,63	39,00	40,65	2,55	1,68	34	181,10	11,93	<i>PI Lu</i>	3,93	3,59	2,41	5,80	-1,02	34	8,57	0,45
<i>Th</i>	41,10	37,61	29,98	0,31	0,87	34	116,09	3,50	<i>PI Hf</i>	1,20	0,85	1,25	1,55	0,23	34	4,21	0,01
<i>U</i>	6,04	5,70	4,30	1,04	1,09	34	17,63	0,60	<i>PI Hg</i>	0,77	0,51	0,72	0,53	3,05	34	3,00	0,14
<i>Bi</i>	0,23	0,09	0,28	0,26	1,10	34	0,99	0,01	<i>PI Pb</i>	3,15	2,29	2,39	5,72	2,55	34	10,65	0,70
<i>Nb</i>	4,05	0,04	6,41	-0,74	1,08	34	16,80	0,00	<i>PI Th</i>	3,91	3,58	2,86	8,15	0,31	34	11,06	0,33
<i>Ta</i>	0,42	0,00	0,70	-0,14	1,25	34	2,10	0,00	<i>PI U</i>	2,24	2,11	1,59	2,53	1,04	34	6,53	0,22
<i>W</i>	1,02	0,00	1,67	1,26	1,53	34	5,30	0,00	<i>PI Bi</i>	1,45	0,56	1,76	3,09	0,26	34	6,19	0,06
<i>Zr</i>	145,31	0,95	252,51	0,88	1,51	34	797,20	0,00	<i>PI Nb</i>	0,34	0,00	0,53	0,29	-0,74	34	1,40	0,00

<i>PI Ta</i>	0,47	0,00	0,78	0,61	-0,14	34	2,33	0,00
<i>PI W</i>	0,54	0,00	0,88	0,77	1,26	34	2,79	0,00
<i>PI Zr</i>	0,75	0,00	1,31	1,71	0,88	34	4,13	0,00



Şekil 1. Gümüşhane granitoidine ait elementlerin ortalama, medyan ve geometrik ortalama değerlerinin kıyaslandığı saçılım-eğri diyagramı (ana oksitler %, diğerleri ppm olarak verilmiş olup, y eksen 2 tabanlı logaritmik ölçektedir)



Şekil 2. Çamlıköyü ve Işıkdere bölgelerindeki toprakların element içeriklerinin medyan değerlerinin saçılım-eğri diyagramında gösterimi (Ana elementler %, diğerleri ppm olarak)

IV. SONUÇLAR

Bu çalışmada, Türkiye'nin önemli metalojenik kuşaklarından biri içerisinde yer alan Gümüşhane Granitoyidi ve bu birim üzerinde gelişmiş topraklarda seçilmiş bazı elementlerin yerel arka plan ve ortalama değerleri belirlenmiştir. Bulgular, granitoyidin element içeriklerinin genel olarak Üst Kıtasal Kabuk (UCC) ortalamalarına yakın değerlere sahip olmakla birlikte, özellikle K₂O, MnO, Sc, Co, Cs, U, W, Pb ve Ni bakımından görece fakirleşmiş olduğunu, vanadyumun ise granitoyitte oldukça düşük bir seviyede (UCC değerinin yaklaşık %6'sı) bulunduğunu ortaya koymuştur.

Granitoyid üzerinde gelişmiş topraklar ise, geniş bir element grubunda belirgin zenginleşme göstermektedir. Özellikle P, Mn, As, Y, Cd, Sn, Sb, nadir toprak elementleri (La–Lu), Pb, Th ve U

elementlerine ait medyan değerlerinin ilgili elementleri için ortalama değer olarak kabul edilmesinin daha uygun olacağı sonucuna varılmış olup, bu element grupları için hesap edilen zenginleşme oranlarının (PI) UCC'ye göre 1,5 katın üzerinde olduğu saptanmıştır.

Elde edilen sonuçlar, çalışma alanındaki bazı elementlerin yerel jeokimyasal arka plan ve eşik değerlerinin küresel ortalamalardan daha yüksek olduğunu göstermektedir. Bu nedenle Gümüşhane ve çevresinde yürütülecek prospeksiyon çalışmalarında, jeokimyasal anomalilerin daha sağlıklı tanımlanabilmesi için bu yükseltilmiş yerel eşik değerlerinin dikkate alınması gerekmektedir. Bu yaklaşım, anomali belirlemede güvenilirliği artıracak ve bölgedeki maden arama çalışmalarının etkinliğine önemli katkı sağlayacaktır.

TEŞEKKÜR

Bu çalışma verilerin bir kısmı TÜBİTAK tarafından desteklenen 115Y146 numaralı proje verilerinden üretilmiş olup, sağlanan destek için TÜBİTAK'a teşekkür edilir.

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Genelleştirilmiş Berezin Sayısı Eşitsizliklerine Yeni Bakış Açıları

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Özet – Bu makaledeki amacımız, pozitif bir $\mathfrak{A}$ operatörü tarafından indirgenen bir yarı-iç çarpım ile donatılmış bir tekrarlayan çekirdekli Hilbert uzayındaki operatörlerin toplamları için birkaç yeni $\mathfrak{A}$ -Berezin normu ve $\mathfrak{A}$ -Berezin sayısı eşitsizliği oluşturmaktır. Bu eşitsizlikler, daha önceki bazı ilgili sonuçları iyileştirmektedir. Özellikle, üçgen eşitsizliğinin bazı iyileştirmeleri elde edilmiş ve çoklu operatörlerin toplamları için $\mathfrak{A}$ -Berezin normu ve $\mathfrak{A}$ -Berezin sayısı için sınırlar türetilmiştir.

Anahtar Kelimeler – Pozitif Operatör; Yarı-İç Çarpım; Tekrarlayan Çekirdek; Berezin Sayısı; $\mathfrak{A}$ -Berezin Sayısı.

I. GİRİŞ

Hilbert uzayları üzerindeki sınırlı lineer operatörler için eşitsizliklerin incelenmesi, operatör teorisinin merkezi bir teması olup bu operatörlerin geometrik ve yapısal özellikleri hakkında derinlemesine bilgiler sağlar. Operatör normu ve nümerik yarıçap gibi klasik kavramlar kapsamlı bir şekilde araştırılmış ve operatör teorisini matematiğin çeşitli dalları ve uygulamalarıyla birleştiren zengin bir sonuçlar bütününe yol açmıştır.

Bu klasik çerçevenin önemli ve doğal bir uzantısı, yarı-Hilbert uzayları üzerindeki operatörler teorisidir. Bir yarı-Hilbert uzayı, sıfırdan farklı bir pozitif $\mathfrak{A} \in \mathfrak{B}(\mathcal{H})$ operatörü tarafından indirgenen bir yarı-iç çarpım ile donatılmış bir vektör uzayıdır. $\langle \eta, \zeta \rangle_{\mathfrak{A}} := \langle \mathfrak{A}\eta, \zeta \rangle$ sesquilinear formu ile tanımlanan bu yapı, standart Hilbert uzayı ortamını ($\mathfrak{A} = I$ durumuna karşılık gelir) genelleştirir ve özellikle dejenere veya kısıtlı sistemleri içeren daha geniş bir problem sınıfını analiz etmek için güçlü bir araç sağlar. $\mathfrak{A}$ -operatör yarı-normu ve $\mathfrak{A}$ -nümerik yarıçapı gibi kavramlar, bu genelleştirilmiş bağlamda temel araçlar olarak ortaya çıkmış ve son yıllarda önemli bir araştırma ilgisi çekmiştir bakınız [2,3,5-7,12-15,22-25]. Ayrıca, nümerik yarıçap ile ilgili son gelişmeler ve eşitsizlikler için bakınız [1,4,8-11,16,20,21].

Bu gelişmeye paralel olarak, tekrarlayan çekirdekli Hilbert uzayları (TÇHU) teorisi, operatör analizi için farklı bir bakış açısı sunar. Bu alandaki kilit bir kavram, bir operatörü TÇHU'nun temel tanım kümesi üzerindeki bir fonksiyona dönüştüren Berezin sembolüdür. Bu fonksiyonun supremum normu olan Berezin sayısı, operatör hakkında temel bilgileri yakalayan güçlü bir ölçüt olarak hizmet eder. Berezin sayısı, klasik operatör normu veya nümerik yarıçaptan daha keskin sınırlar ve daha rafine geometrik yorumlar sunduğu için özellikle değerlidir.

Bu makale, bu iki güçlü genellenmenin birleştiği noktada yer almaktadır. Operatör eşitsizliklerini, aynı anda bir tekrarlayan çekirdekli Hilbert uzayı olan bir yarı Hilbert uzay yapısı çerçevesinde inceliyoruz. Bu durum doğal olarak, $\mathfrak{A}$ -Berezin sembolünün modülünün supremumu olarak tanımlanan ve $\mathfrak{A}\text{-ber}(\mathfrak{T})$ ile gösterilen $\mathfrak{A}$ -Berezin sayısı kavramına yol açar:

$$\mathfrak{A}\text{-ber}(\mathfrak{T}) := \sup_{\lambda \in \Delta} |\langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{A}}|$$

burada $\hat{k}_\lambda$ normalize edilmiş tekrarlayan çekirdektir. $\mathfrak{A}$ -Berezin sayısı, $\mathfrak{A}$ operatörünün dayattığı cebirsel yapıyı, tekrarlayan çekirdekler tarafından kapsanan geometrik bilgiyle zarif bir şekilde birleştirir. Klasik Berezin sayısının ($\mathfrak{A} = I$ olduğunda) doğal bir genellemesi olarak hizmet eder ve $\mathfrak{A}$ -nümerik yarıçapı ile yakından ilişkilidir, ancak TÇHU'ların özel yapısına göre uyarlanmıştır.

Bu çalışmanın birincil amacı, özellikle operatörlerin toplamalarına odaklanarak $\mathfrak{A}$ Berezin sayısı için yeni eşitsizlikler oluşturmaktır. $\mathfrak{A}$ -nümerik yarıçapı için eşitsizlikler iyi çalışılmış olsa da, $\mathfrak{A}$ -Berezin sayısı için olan karşılıkları daha az araştırılmıştır. Katkımız, $\mathfrak{A}\text{-}ber_{\mathfrak{A}}(\mathfrak{T})$ için yeni sınırlar türetmek üzere $\mathfrak{A}$ -nümerik yarıçapı teorisinden gelen son güçlü teknikleri uyarlamak ve rafine etmektir. İki veya daha fazla operatörün toplamaları için $\mathfrak{A}$ -Berezin sayısı ve ilişkili $\mathfrak{A}$ -Berezin normu için birkaç eşitsizlik kuruyoruz. Bu sonuçlar, sadece yarı-Hilbert TÇHU'ları üzerindeki operatörlerin yapısına dair yeni bilgiler sağlamakla kalmaz, aynı zamanda bu ortamdaki temel üçgen eşitsizliğinin iyileştirmelerini de sunar. $\mathcal{H}, \langle \cdot, \cdot \rangle$ iç çarpımına sahip bir karmaşık Hilbert uzayı olsun. $\mathfrak{B}(\mathcal{H}), \mathcal{H}$ üzerindeki tüm sınırlı lineer operatörlerin cebirini gösterebilir. Bu makale boyunca $\mathfrak{A}, \mathfrak{B}(\mathcal{H})$ içinde sıfırdan farklı bir pozitif operatörü belirtecektir. Böyle bir operatör,

$$\langle \eta, \zeta \rangle_{\mathfrak{A}} := \langle \mathfrak{A}\eta, \zeta \rangle, \eta, \zeta \in \mathcal{H}$$

pozitif yarı-tanımlı bir sesquilinear form indirger. Bu yarı-iç çarpım,

$$\|\eta\|_{\mathfrak{A}} := \langle \mathfrak{A}\eta, \eta \rangle^{1/2} = \|\mathfrak{A}^{1/2}\eta\|, \eta \in \mathcal{H}$$

ile tanımlanan bir $\|\cdot\|_{\mathfrak{A}}$ yarı-normu indirger. $\mathcal{H} = \mathcal{H}(\Delta), \Delta$ kümesi üzerinde $\lambda \in \Delta$ için k_λ tekrarlayan çekirdeğine sahip bir tekrarlayan çekirdekli Hilbert uzayı olsun. Normalize edilmiş tekrarlayan çekirdek $\hat{k}_\lambda = k_\lambda / \|k_\lambda\|$ ile gösterilir.

Bir $T \in \mathfrak{B}(\mathcal{H})$ operatörü için, $\mathfrak{T}$ nin $\mathfrak{A}$ -Berezin sembolü $\tilde{\mathfrak{T}}_{\mathfrak{A}}(\lambda) = \langle \mathfrak{T}\hat{k}_\lambda, \hat{k}_\lambda \rangle_{\mathfrak{A}}$ fonksiyonu ile tanımlanır. $\mathfrak{T}$ nin $\mathfrak{A}$ -Berezin sayısı [17]

$$\mathfrak{A}\text{-}ber_{\mathfrak{A}}(\mathfrak{T}) := \sup_{\lambda \in \Delta} \left| \langle \mathfrak{T}\hat{k}_\lambda, \hat{k}_\lambda \rangle_{\mathfrak{A}} \right|$$

ile tanımlanır. $\mathfrak{T}$ nin $\mathfrak{A}$ -Berezin normu [17-19]

$$\|\mathfrak{T}\|_{\mathfrak{A}\text{-}Ber} := \sup_{\lambda \in \Delta} \|\mathfrak{T}\hat{k}_\lambda\|_{\mathfrak{A}}$$

olarak tanımlanır. Bir $\mathfrak{T}$ operatörünün ayırt edilmiş $\mathfrak{A}$ -eşleniği $\mathfrak{A}\mathfrak{T} = \mathfrak{T}^*\mathfrak{A}$ denkleminin indirgenmiş çözümü olan $\mathfrak{T}^{\sharp_{\mathfrak{A}}}$ ile gösteriyoruz. Bir $\mathfrak{T}$ operatörüne, eğer $\mathfrak{A}\mathfrak{T} = \mathfrak{T}^*\mathfrak{A}$ ise $\mathfrak{A}$ -özeşlenik denir. $\mathfrak{A}$ -eşleniği kabul eden operatörler kümesi için $\mathfrak{B}_{\mathfrak{A}}(\mathcal{H})$ gösterimini kullanıyoruz. $\mathfrak{T} \in \mathfrak{B}_{\mathfrak{A}}(\mathcal{H})$ için temel ilişkilere sahibiz:

$$\frac{1}{2} \|\mathfrak{T}\|_{\mathfrak{A}\text{-}Ber} \leq \mathfrak{A}\text{-}ber_{\mathfrak{A}}(\mathfrak{T}) \leq \|\mathfrak{T}\|_{\mathfrak{A}\text{-}Ber} \quad (1.1)$$

Ayrıca, eğer $\mathfrak{T}$, $\mathfrak{A}$ -öz-eşlenik ise, o zaman $\mathfrak{A}\text{-}ber_{\mathfrak{A}}(\mathfrak{T}) = \|\mathfrak{T}\|_{\mathfrak{A}\text{-}Ber}$ olur. Bu makale, $\mathfrak{A}$ -nümerik yarıçapı için son zamanlarda elde edilen eşitsizlikleri $\mathfrak{A}$ -Berezin sayısı bağlamına uyarlamaktadır.

II. ANA SONUÇLAR

Sonuçlarımız için temel olan bir yarı-Hilbert Buzano-tipi eşitsizlikle başlıyoruz.

Lemma 1 (Buzano tipli). Eğer $\eta, \beta, e \in \mathcal{H}$ ve $\|e\|_{\mathfrak{H}} = 1$ ise o zaman

$$|\langle \eta, e \rangle_{\mathfrak{H}} \langle e, \beta \rangle_{\mathfrak{H}}| \leq \frac{1}{2} (\|\eta\|_{\mathfrak{H}} \|\beta\|_{\mathfrak{H}} + |\langle \eta, \beta \rangle_{\mathfrak{H}}|)$$

İlk ana sonucumuz, iki operatörün toplamının $\mathfrak{H}$ -Berezin sayısı için bir üst sınır sunmaktadır.

Teorem 1. $\mathfrak{T}, \mathcal{S} \in \mathcal{B}_{\mathfrak{H}}(\mathcal{H})$ olsun. Bu durumda

$$\begin{aligned} & \text{ber}_{\mathfrak{H}}^2(\mathfrak{T} + \mathcal{S}) \\ & \leq \min \left\{ \frac{1}{2} \|\mathfrak{T}^{\sharp_{\mathfrak{H}}} \mathfrak{T} + \mathcal{S} \mathcal{S}^{\sharp_{\mathfrak{H}}} \|_{\mathfrak{H}-Ber} + \text{ber}_{\mathfrak{H}}(\mathcal{S} \mathfrak{T}), \frac{1}{2} \|\mathfrak{T} \mathfrak{T}^{\sharp_{\mathfrak{H}}} + \mathcal{S}^{\sharp_{\mathfrak{H}}} \mathcal{S} \|_{\mathfrak{H}-Ber} + \text{ber}_{\mathfrak{H}}(\mathfrak{T} \mathcal{S}) \right\} \\ & + \text{ber}_{\mathfrak{H}}^2(\mathfrak{T}) + \text{ber}_{\mathfrak{H}}^2(\mathcal{S}) \end{aligned}$$

sağlanır.

İspat. $\lambda \in \Delta$ keyfi olsun, böylece $\hat{k}_{\lambda}, \|\hat{k}_{\lambda}\|_{\mathfrak{H}-Ber} = \|\mathfrak{H}^{1/2} \hat{k}_{\lambda}\|$ özelliğine sahip bir vektördür. Bu kanıtın basitliği için, $\|\hat{k}_{\lambda}\|_{\mathfrak{H}} = 1$ olduğunu varsayalım. O zaman

$$\begin{aligned} & \left| \langle (\mathfrak{T} + \mathcal{S}) \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|^2 \\ & \leq \left(\left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right| + \left| \langle \mathcal{S} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right| \right)^2 \\ & = \left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|^2 + \left| \langle \mathcal{S} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|^2 + 2 \left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right| \left| \langle \mathcal{S} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right| \\ & = \left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|^2 + \left| \langle \mathcal{S} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|^2 + 2 \left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right| \left| \langle \hat{k}_{\lambda}, \mathcal{S}^* \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right| \\ & \leq \left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|^2 + \left| \langle \mathcal{S} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|^2 + \|\mathfrak{T} \hat{k}_{\lambda}\|_{\mathcal{A}} \|\mathcal{S}^{\sharp_{\mathfrak{H}}} \hat{k}_{\lambda}\|_{\mathfrak{H}} + \left| \langle \mathfrak{T} \hat{k}_{\lambda}, \mathcal{S}^{\sharp_{\mathfrak{H}}} \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right| \end{aligned}$$

Lemma 1 gereği, Aritmetik-geometrik ortalama eşitsizliğini kullanarak,

$$\begin{aligned} & \|\mathfrak{T} \hat{k}_{\lambda}\|_{\mathfrak{H}} \|\mathcal{S}^{\sharp_{\mathfrak{H}}} \hat{k}_{\lambda}\|_{\mathfrak{H}} \\ & \leq \frac{1}{2} \left(\|\mathfrak{T} \hat{k}_{\lambda}\|_{\mathfrak{H}}^2 + \|\mathcal{S}^{\sharp_{\mathfrak{H}}} \hat{k}_{\lambda}\|_{\mathfrak{H}}^2 \right) = \frac{1}{2} \langle (\mathfrak{T}^{\sharp_{\mathfrak{H}}} \mathfrak{T} + \mathcal{S} \mathcal{S}^{\sharp_{\mathfrak{H}}}) \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \end{aligned}$$

olur. Ayrıca, $\left| \langle \mathfrak{T} \hat{k}_{\lambda}, \mathcal{S}^{\sharp_{\mathfrak{H}}} \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right| = \left| \langle \mathcal{S} \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|$ dir. Bu nedenle

$$\begin{aligned} & \left| \langle (\mathfrak{T} + \mathcal{S}) \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|^2 \\ & \leq \left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|^2 + \left| \langle \mathcal{S} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right|^2 + \frac{1}{2} \langle (\mathfrak{T}^{\sharp_{\mathfrak{H}}} \mathfrak{T} + \mathcal{S} \mathcal{S}^{\sharp_{\mathfrak{H}}}) \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} + \left| \langle \mathcal{S} \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{H}} \right| \end{aligned}$$

Tüm $\lambda \in \Delta$ üzerinden supremum almak

$$\text{ber}_{\mathfrak{H}}^2(\mathfrak{T} + \mathcal{S}) \leq \text{ber}_{\mathfrak{H}}^2(\mathfrak{T}) + \text{ber}_{\mathfrak{H}}^2(\mathcal{S}) + \frac{1}{2} \|\mathfrak{T}^{\sharp_{\mathfrak{H}}} \mathfrak{T} + \mathcal{S} \mathcal{S}^{\sharp_{\mathfrak{H}}} \|_{\mathfrak{H}-Ber} + \text{ber}_{\mathfrak{H}}(\mathcal{S} \mathfrak{T}).$$

ifadesini verir. Diğer eşitsizlik simetrik bir argümanla elde edilir, bu da kanıtı tamamlar.

Sonuç 1. Herhangi bir $\mathfrak{T} \in \mathcal{B}_{\mathfrak{A}}(\mathcal{H})$ için

$$\mathfrak{ber}_{\mathfrak{A}}^2(\mathfrak{T}) \leq \frac{1}{4} \|\mathfrak{T}^{\dagger} \mathfrak{T} + \mathfrak{T} \mathfrak{T}^{\dagger}\|_{\mathfrak{A}-Ber} + \frac{1}{2} \mathfrak{ber}_{\mathfrak{A}}(\mathfrak{T}^2)$$

sağlanır.

Lemma 2. $\mathfrak{T} \in \mathcal{B}_{\mathfrak{A}}(\mathcal{H})$ olsun. Bu durumda

$$\left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\mu} \rangle_{\mathfrak{A}} \right|^2 \leq \langle \mathfrak{T}^{\dagger} \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{A}}^{1/2} \langle \mathfrak{T} \mathfrak{T}^{\dagger} \hat{k}_{\mu}, \hat{k}_{\mu} \rangle_{\mathfrak{A}}^{1/2}$$

olur.

İspat. Cauchy-Schwarz eşitsizliği ile:

$$\begin{aligned} \left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\mu} \rangle_{\mathfrak{A}} \right|^2 &= \left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\mu} \rangle_{\mathfrak{A}} \right| \left| \langle \hat{k}_{\lambda}, \mathfrak{T}^{\dagger} \hat{k}_{\mu} \rangle_{\mathfrak{A}} \right| \\ &\leq \|\mathfrak{T} \hat{k}_{\lambda}\|_{\mathfrak{A}} \|\mathfrak{T}^{\dagger} \hat{k}_{\mu}\|_{\mathfrak{A}} = \langle \mathfrak{T}^{\dagger} \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{A}}^{1/2} \langle \mathfrak{T} \mathfrak{T}^{\dagger} \hat{k}_{\mu}, \hat{k}_{\mu} \rangle_{\mathfrak{A}}^{1/2} \end{aligned}$$

Teorem 2. $\mathfrak{T}, \mathcal{S} \in \mathcal{B}_{\mathfrak{A}}(\mathcal{H})$ olsun. Bu durumda

$$\begin{aligned} \|\mathfrak{T} + \mathcal{S}\|_{\mathfrak{A}-Ber}^2 &\leq \frac{1}{2} \left(\|\mathfrak{T}^{\dagger} \mathfrak{T} + \mathcal{S}^{\dagger} \mathcal{S}\|_{\mathfrak{A}-Ber} + \|\mathfrak{T} \mathfrak{T}^{\dagger} + \mathcal{S} \mathcal{S}^{\dagger}\|_{\mathfrak{A}-Ber} \right) \\ &\quad + \|\mathfrak{T}\|_{\mathfrak{A}-Ber} \|\mathcal{S}\|_{\mathfrak{A}-Ber} + \mathfrak{ber}_{\mathfrak{A}}(\mathcal{S}^{\dagger} \mathfrak{T}) \end{aligned}$$

ve özel olarak

$$\|\mathfrak{T} + \mathcal{S}\|_{\mathfrak{A}-Ber} \leq \|\mathfrak{T}\|_{\mathfrak{A}-Ber} + \|\mathcal{S}\|_{\mathfrak{A}-Ber}$$

sağlanır.

İspat. Herhangi $\lambda, \mu \in \Delta$ için

$$\left| \langle (\mathfrak{T} + \mathcal{S}) \hat{k}_{\lambda}, \hat{k}_{\mu} \rangle_{\mathfrak{A}} \right|^2 \leq \left(\left| \langle \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\mu} \rangle_{\mathfrak{A}} \right| + \left| \langle \mathcal{S} \hat{k}_{\lambda}, \hat{k}_{\mu} \rangle_{\mathfrak{A}} \right| \right)^2$$

olur. Genişletilip Lemma 2 ve Lemma 1 uygulandığında,

$$\begin{aligned} \left| \langle (\mathfrak{T} + \mathcal{S}) \hat{k}_{\lambda}, \hat{k}_{\mu} \rangle_{\mathfrak{A}} \right|^2 &\leq \langle \mathfrak{T}^{\dagger} \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{A}}^{1/2} \langle \mathfrak{T} \mathfrak{T}^{\dagger} \hat{k}_{\mu}, \hat{k}_{\mu} \rangle_{\mathfrak{A}}^{1/2} \\ &\quad + \langle \mathcal{S}^{\dagger} \mathcal{S} \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{A}}^{1/2} \langle \mathcal{S} \mathcal{S}^{\dagger} \hat{k}_{\mu}, \hat{k}_{\mu} \rangle_{\mathfrak{A}}^{1/2} \\ &\quad + \|\mathfrak{T} \hat{k}_{\lambda}\|_{\mathfrak{A}} \|\mathcal{S} \hat{k}_{\lambda}\|_{\mathfrak{A}} + \left| \langle \mathcal{S}^{\dagger} \mathfrak{T} \hat{k}_{\lambda}, \hat{k}_{\mu} \rangle_{\mathfrak{A}} \right| \end{aligned}$$

elde edilir. $\lambda = \mu \in \Delta$ üzerinden supremum alınıp $\|\mathfrak{T} \mathcal{S}\|_{\mathfrak{A}-Ber} \leq \|\mathfrak{T}\|_{\mathfrak{A}-Ber} \|\mathcal{S}\|_{\mathfrak{A}-Ber}$ ve $\mathfrak{ber}_{\mathfrak{A}}(\mathfrak{T}) = \|\mathfrak{T}\|_{\mathfrak{A}-Ber}$ ile basitleştirildiğinde istenen eşitsizlikler elde edilir.

Sonuç 2. $\mathfrak{T}, \mathcal{S} \in \mathcal{B}_{\mathfrak{A}}(\mathcal{H})$ olsun. O zaman

$$\begin{aligned} &\max\{\|\mathfrak{T} + \mathcal{S}\|_{\mathfrak{A}-Ber}^2, \|\mathfrak{T} - \mathcal{S}\|_{\mathfrak{A}-Ber}^2\} \\ &\leq \frac{1}{2} \left(\|\mathfrak{T}^{\dagger} \mathfrak{T} + \mathcal{S}^{\dagger} \mathcal{S}\|_{\mathfrak{A}-Ber} + \|\mathfrak{T} \mathfrak{T}^{\dagger} + \mathcal{S} \mathcal{S}^{\dagger}\|_{\mathfrak{A}-Ber} \right) \\ &\quad + \|\mathfrak{T}\|_{\mathfrak{A}-Ber} \|\mathcal{S}\|_{\mathfrak{A}-Ber} + \mathfrak{ber}_{\mathfrak{A}}(\mathcal{S}^{\dagger} \mathfrak{T}) \end{aligned}$$

Lemma 3 ([24]). $\eta, \mathfrak{z} \in \mathcal{H}$ ve $\varpi \geq 2$ olsun. O zaman

$$\|\eta\|_{\mathfrak{U}}^{\varpi} + \|\mathfrak{z}\|_{\mathfrak{U}}^{\varpi} \leq \frac{1}{2} (\|\eta + \mathfrak{z}\|_{\mathfrak{U}}^{\varpi} + \|\eta - \mathfrak{z}\|_{\mathfrak{U}}^{\varpi})$$

sağlanır.

Lemma 4 ([1]). $r = 1, \dots, s$ için $\sigma_r > 0$ olsun. O zaman, tüm $q \geq 1$ için

$$\left(\sum_{r=1}^s \sigma_r \right)^q \leq s^{q-1} \sum_{r=1}^s \sigma_r^q$$

Özel olarak, $s = 2$ için $\left(\frac{\sigma+\beta}{2} \right)^q \leq \frac{\sigma^q + \beta^q}{2}$.

Teorem 3. $\mathfrak{T}, \mathcal{S} \in \mathcal{B}_{\mathfrak{U}}(\mathcal{H})$ ve $\varpi \geq 2$ olsun. O zaman

$$\left\| \frac{\mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathfrak{T} + \mathcal{S}^{\sharp_{\mathfrak{U}}} \mathcal{S}}{2} \right\|_{\mathfrak{U}-Ber}^{\varpi/2} \leq \frac{1}{4} (\|\mathfrak{T} - \mathcal{S}\|_{\mathfrak{U}-Ber}^{\varpi} + \|\mathfrak{T} + \mathcal{S}\|_{\mathfrak{U}-Ber}^{\varpi})$$

İspat. Herhangi bir $\lambda \in \Delta$ için

$$2 \left(\|\mathfrak{T} \hat{k}_{\lambda}\|_{\mathfrak{U}}^{\varpi} + \|\mathcal{S} \hat{k}_{\lambda}\|_{\mathfrak{U}}^{\varpi} \right) \leq \|\mathfrak{T} \hat{k}_{\lambda} + \mathcal{S} \hat{k}_{\lambda}\|_{\mathfrak{U}}^{\varpi} + \|\mathfrak{T} \hat{k}_{\lambda} - \mathcal{S} \hat{k}_{\lambda}\|_{\mathfrak{U}}^{\varpi}$$

Öte yandan, Lemma 4 ile,

$$\|\mathfrak{T} \hat{k}_{\lambda}\|_{\mathfrak{U}}^{\varpi} + \|\mathcal{S} \hat{k}_{\lambda}\|_{\mathfrak{U}}^{\varpi} \geq 2^{1-\varpi/2} \left(\langle (\mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathfrak{T} + \mathcal{S}^{\sharp_{\mathfrak{U}}} \mathcal{S}) \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{U}} \right)^{\varpi/2}$$

olur. $\lambda \in \Delta$ üzerinden supremum almak kanıtı tamamlar.

Sonuç 3. $\mathfrak{T} \in \mathcal{B}_{\mathfrak{U}}(\mathcal{H})$ ve $\varpi \geq 2$ olsun. Bu durumda

$$\left\| \frac{\mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathfrak{T} + \mathfrak{T} \mathfrak{T}^{\sharp_{\mathfrak{U}}}}{2} \right\|_{\mathfrak{U}-Ber}^{\varpi/2} \leq \frac{1}{4} (\|\mathfrak{T} + \mathfrak{T}^{\sharp_{\mathfrak{U}}}\|_{\mathfrak{U}-Ber}^{\varpi} + \|\mathfrak{T} - \mathfrak{T}^{\sharp_{\mathfrak{U}}}\|_{\mathfrak{U}-Ber}^{\varpi})$$

olur.

Teorem 4. $\mathfrak{T}, \mathcal{S} \in \mathcal{B}_{\mathfrak{U}}(\mathcal{H})$ olsun. O zaman

$$\|\mathfrak{T} + \mathcal{S}\|_{\mathfrak{U}-Ber}^2 \leq \|\mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathfrak{T} + \mathcal{S}^{\sharp_{\mathfrak{U}}} \mathcal{S}\|_{\mathfrak{U}-Ber}^2 + \frac{1}{2} \|\mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathcal{S} + \mathcal{S}^{\sharp_{\mathfrak{U}}} \mathfrak{T}\|_{\mathfrak{U}-Ber}^2 + \frac{1}{2}$$

İspat. $\|\hat{k}_{\lambda}\|_{\mathfrak{U}} = 1$ ile herhangi bir $\lambda \in \Delta$ için,

$$\begin{aligned} \|(\mathfrak{T} + \mathcal{S}) \hat{k}_{\lambda}\|_{\mathfrak{U}}^2 &= \|\mathfrak{T} \hat{k}_{\lambda}\|_{\mathfrak{U}}^2 + \|\mathcal{S} \hat{k}_{\lambda}\|_{\mathfrak{U}}^2 + 2\Re \langle \mathfrak{T} \hat{k}_{\lambda}, \mathcal{S} \hat{k}_{\lambda} \rangle_{\mathfrak{U}} \\ &= \left\langle (\mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathfrak{T} + \mathcal{S}^{\sharp_{\mathfrak{U}}} \mathcal{S}) \hat{k}_{\lambda}, \hat{k}_{\lambda} \right\rangle_{\mathfrak{U}} + \left\langle (\mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathcal{S} + \mathcal{S}^{\sharp_{\mathfrak{U}}} \mathfrak{T}) \hat{k}_{\lambda}, \hat{k}_{\lambda} \right\rangle_{\mathfrak{U}} \end{aligned}$$

dır. $|\langle x, y \rangle_{\mathfrak{U}}| \leq \frac{1}{2} (\|x\|_{\mathfrak{U}}^2 + \|y\|_{\mathfrak{U}}^2)$, eşitsizliğini kullanarak,

$$\left| \langle (\mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathfrak{T} + \mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathcal{S}) \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{U}} \right| \leq \frac{1}{2} (\|(\mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathfrak{T} + \mathfrak{T}^{\sharp_{\mathfrak{U}}} \mathcal{S}) \hat{k}_{\lambda}\|_{\mathfrak{U}}^2 + 1)$$

$\lambda \in \Delta$ üzerinden supremum almak iddiayı kanıtlar.

Sonuç 4. $\mathfrak{T} \in \mathcal{B}_{\mathfrak{U}}(\mathcal{H})$ olsun. O zaman

$$\left\| \frac{\mathfrak{T} + \mathfrak{T}^{\sharp\mathfrak{U}}}{2} \right\|_{\mathfrak{U}-Ber}^2 \leq \|\mathfrak{T}^{\sharp\mathfrak{U}}\mathfrak{T} + \mathfrak{T}\mathfrak{T}^{\sharp\mathfrak{U}}\|_{\mathfrak{U}-Ber} + \frac{1}{2} \left\| \frac{\mathfrak{T}^2 + (\mathfrak{T}^{\sharp\mathfrak{U}})^2}{2} \right\|_{\mathfrak{U}-Ber} + \frac{1}{2}$$

Uyarı 1. $\mathfrak{U} = I$ için Sonuç 4

$$\left\| \frac{\mathfrak{T} + \mathfrak{T}^*}{2} \right\|^2 \leq \|\mathfrak{T}^*\mathfrak{T} + \mathfrak{T}\mathfrak{T}^*\| + \frac{1}{2} \left\| \frac{\mathfrak{T}^2 + (\mathfrak{T}^*)^2}{2} \right\| + \frac{1}{2}$$

ifadesine indirgenir, bu da Hilbert uzayı operatör teorisindeki bilinen sonuçlarla örtüşmektedir.

Eşitsizlikleri şimdi çoklu operatörlerin toplamalarına genişletiyoruz.

Teorem 5. $\mathfrak{T}_1, \dots, \mathfrak{T}_s \in \mathcal{B}_{\mathfrak{U}}(\mathcal{H})$ olsun. O zaman

$$\left\| \sum_{j=1}^s \mathfrak{T}_j \right\|_{\mathfrak{U}-Ber}^2 \leq \left\| \sum_{j=1}^s \mathfrak{T}_j^{\sharp\mathfrak{U}} \mathfrak{T}_j \right\|_{\mathfrak{U}-Ber} + \sum_{1 \leq j \neq k \leq s} \text{ber}_{\mathfrak{U}}(\mathfrak{T}_k^{\sharp\mathfrak{U}} \mathfrak{T}_j).$$

İspat. Herhangi bir $\lambda \in \Delta$ için

$$\left\| \sum_{j=1}^s \mathfrak{T}_j \hat{k}_{\lambda} \right\|_{\mathfrak{U}-Ber}^2 = \sum_{j=1}^s \|\mathfrak{T}_j \hat{k}_{\lambda}\|_{\mathfrak{U}}^2 + \sum_{1 \leq j \neq k \leq s} \Re \langle \mathfrak{T}_j \hat{k}_{\lambda}, \mathfrak{T}_k \hat{k}_{\lambda} \rangle_{\mathfrak{U}}$$

Bu şu şekilde yeniden yazılabilir

$$\left\| \sum_{j=1}^s \mathfrak{T}_j \hat{k}_{\lambda} \right\|_{\mathfrak{U}-Ber}^2 = \left\langle \sum_{j=1}^s \mathfrak{T}_j^{\sharp\mathfrak{U}} \mathfrak{T}_j \hat{k}_{\lambda}, \hat{k}_{\lambda} \right\rangle_{\mathfrak{U}} + \sum_{1 \leq j \neq k \leq s} \Re \langle \mathfrak{T}_k^{\sharp\mathfrak{U}} \mathfrak{T}_j \hat{k}_{\lambda}, \hat{k}_{\lambda} \rangle_{\mathfrak{U}}$$

$\lambda \in \Delta$ üzerinden supremum alıp $\Re(z) \leq |z|$ gerçeğini kullanmak sonucu verir.

Sonuç 5. $\mathfrak{T}, \mathcal{S} \in \mathcal{B}_{\mathfrak{U}}(\mathcal{H})$ olsun. O zaman

$$\begin{aligned} \|\mathfrak{T} + \mathcal{S}\|_{\mathfrak{U}-Ber}^2 &\leq \|\mathfrak{T}^{\sharp\mathfrak{U}}\mathfrak{T} + \mathcal{S}^{\sharp\mathfrak{U}}\mathcal{S}\|_{\mathfrak{U}-Ber} + 2\text{ber}_{\mathfrak{U}}(\mathcal{S}^{\sharp\mathfrak{U}}\mathfrak{T}) \\ &\leq (\|\mathfrak{T}\|_{\mathfrak{U}-Ber} + \|\mathcal{S}\|_{\mathfrak{U}-Ber})^2 \end{aligned}$$

Lemma 5. $\mathfrak{T}, \mathcal{S} \in \mathcal{B}_{\mathfrak{U}}(\mathcal{H})$ olsun. O zaman

$$\text{ber}_{\mathfrak{U}}(\mathfrak{T}\mathcal{S}) \leq 4\text{ber}_{\mathfrak{U}}(\mathfrak{T})\text{ber}_{\mathfrak{U}}(\mathcal{S})$$

Önerme 1. $\mathfrak{T}_1, \dots, \mathfrak{T}_s \in \mathcal{B}_{\mathfrak{U}}(\mathcal{H})$ olsun. O zaman

$$\left\| \sum_{j=1}^s \mathfrak{T}_j \right\|_{\mathfrak{U}-Ber}^2 + 4 \sum_{j=1}^s \text{ber}_{\mathfrak{U}}(\mathfrak{T}_j)^2 \leq \left\| \sum_{j=1}^s \mathfrak{T}_j^{\sharp\mathfrak{U}} \mathfrak{T}_j \right\|_{\mathfrak{U}-Ber} + 4 \left(\sum_{j=1}^s \text{ber}_{\mathfrak{U}}(\mathfrak{T}_j) \right)^2$$

İspat. Teorem 5 den

$$\begin{aligned}
 & \left\| \sum_{j=1}^s \mathfrak{T}_j \right\|_{\mathfrak{A}-Ber}^2 \\
 & \leq \left\| \sum_{j=1}^s \mathfrak{T}_j^{\sharp \mathfrak{A}} \mathfrak{T}_j \right\|_{\mathfrak{A}-Ber} + \sum_{1 \leq j \neq k \leq s} \text{ber}_{\mathfrak{A}}(\mathfrak{T}_k^{\sharp \mathfrak{A}} \mathfrak{T}_j) \\
 & \leq \left\| \sum_{j=1}^s \mathfrak{T}_j^{\sharp \mathfrak{A}} \mathfrak{T}_j \right\|_{\mathfrak{A}-Ber} + \sum_{1 \leq j \neq k \leq s} \|\mathfrak{T}_k^{\sharp \mathfrak{A}}\|_{\mathfrak{A}-Ber} \|\mathfrak{T}_j\|_{\mathfrak{A}-Ber} \\
 & \leq \left\| \sum_{j=1}^s \mathfrak{T}_j^{\sharp \mathfrak{A}} \mathfrak{T}_j \right\|_{\mathfrak{A}-Ber} + 4 \sum_{1 \leq j \neq k \leq s} \text{ber}_{\mathfrak{A}}(\mathfrak{T}_k) \text{ber}_{\mathfrak{A}}(\mathfrak{T}_j) \\
 & = \left\| \sum_{j=1}^s \mathfrak{T}_j^{\sharp \mathfrak{A}} \mathfrak{T}_j \right\|_{\mathfrak{A}-Ber} + 4 \left[\left(\sum_{j=1}^s \text{ber}_{\mathfrak{A}}(\mathfrak{T}_j) \right)^2 - \sum_{j=1}^s \text{ber}_{\mathfrak{A}}(\mathfrak{T}_j)^2 \right].
 \end{aligned}$$

Terimleri yeniden düzenlemek istenen eşitsizliği verir.

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Validating and modeling of metrics of micro turbojet engine by experimental and machine learning methods

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Abstract –Micro turbojet engines are increasingly preferred in aviation studies due to their suitability (such as cost and setup) for experimental work. In this study, experimental work is conducted on the JetCat-P80 micro turbojet engine. Within this scope, 660 lines of data are obtained from the engine, ranging from idle speed (35,000 RPM) to maximum speed (125,000 RPM). Throughout the engine operation, several parameters such as turbine RPM, exhaust gas temperature, fuel flow, thrust, and air mass flow are measured. These mentioned performance parameters are verified for twenty different points using gas turbine engine software (Gasturb). Subsequently, parameters such as fuel flow and thermal efficiency were predicted by utilizing Random Forest (RF), algorithm thanks to the experimentally obtained dataset. According to the analysis results, the fuel flow is calculated with a MAPE value of 2.1069%, while the air mass flow rate is verified with 2.947%. Based on the prediction results obtained through random forest, the R^2 values for fuel flow and thermal efficiency were calculated as 0.9997 and 0.9999 respectively.

Keywords – Micro Turbojet, Random Forest, Modeling, Fuel Flow, Thermal Efficiency.

I. INTRODUCTION

In recent years, technological advancements and particularly the rapidly increasing use of unmanned aerial vehicles (UAVs) have significantly increased interest in micro-scale versions of gas turbines. Micro gas turbine engines are frequently preferred in both academic research and applied engineering projects due to their low costs, integrated structures, and controllable operating characteristics [1, 2]. In this regard, the experimental studies conducted with aviation engines allow jet engines to be examined from different aspects. When considering the literature review, Kilic et al. [3] obtained 321 data points by testing the SR-30 turbojet engine under various flight conditions. In this regard, , thrust, shaft speed, and EGT parameters were predicted by employing the LSTM network. The model inputs were selected through correlation analysis where turbine inlet pressure was found to be the most important variable for thrust, combustion chamber inlet pressure for shaft speed, and combustion chamber inlet temperature for EGT. According to the validation results, LSTM networks successfully modeled the complex and nonlinear behaviors of the turbojet engine, with R^2 values ranging between 0.9811–0.9891 in the best model, whereas RMSE and SE values were found to be quite low. Anderson et al. [4] tested a micro gas turbine engine with Jet-A, hydrogen, ammonia, and microalgal biodiesel blends. Microalgal biodiesel was mixed with Jet-A at 10% and 30% ratios, and additionally, 10 lpm hydrogen was added to both mixtures to obtain B10JH and B30JH fuels. The engine was operated between 30,000-70,000 RPM where thrust, thrust specific fuel consumption (TSFC), turbine inlet temperature (TIT), and emissions were measured. The findings explained that as the biodiesel ratio increased, thrust decreased and TSFC increased. The addition of hydrogen mitigated these negative effects, improving performance. The LSTM model predicted thrust, TSFC, TIT, NO_x, and CO values with an accuracy above 0.9. However, both LSTM and linear regression models failed to accurately

predict CO₂ emissions. Menga et al. [5] applied ANN and ELM methods to predict the compressor and turbine efficiency and mass flow rate of a micro turbojet engine. The digital twin of the engine was validated with experimental data obtained from the test bench and actual flights, and then expanded using the Monte Carlo technique to predict different degradation intensities. In this context, the predictions with a small number of sensors in the actual engine were successful for mass flow rate, however accuracy in component efficiency slightly decreased, with the CoD value being approximately 80%. The average errors remained at acceptable levels, but reached up to 6% in off-design flight conditions. Kim [6] developed a machine learning-based performance adaptation method based on measurement data to enhance the accuracy of aero gas turbine performance models. The method provides real-time adaptation using component adaptation factors with a feed-forward artificial neural network in steady-state, and correction factors in transient state. Mean absolute errors have been reduced to 0.14% for total temperature at the high-pressure turbine exit, 0.38% for fan pressure ratio, 0.15% for low-pressure shaft speed, and 1.11% for engine net thrust. Praveenkumar et al. [7] examined the effects of microalgal biofuel blends (10% and 30%) combined with hydrogen were in a micro gas turbine (MGT). The addition of biogas to the 10% biofuel blend increased static thrust by 1%, however, due to the low calorific value, TSFC increased for all biofuel blends, and the B30 blend yielded the highest TIT and EGT values. The addition of biogas reduced NO_x formation by lowering combustion temperature, with the B30 blend providing the lowest NO_x values compared to Jet-A, and also showing significant reductions in CO and CO₂ emissions. In machine learning modeling, LSTM's RMSE value was found to be higher than CNN, which provides that CNN is a more suitable method for processing MGT data. Rubiales Mena et al. [8] developed an ensemble-based machine learning method has been to continuously monitor combustion in a combined cycle gas turbine by utilizing exhaust gas temperature measurements and operational variables. The temperatures were measured on four gas turbines, each using 21 thermocouples, and artificial neural networks and PCA methods were applied for anomaly detection. The method detects combustion chamber failures and sensor errors early by comparing current performance with past performance under normal operating conditions. According to outcomes, the mentioned strategy is useful in maintenance planning and particularly successful in early diagnosis of combustion chamber failures.

When analyzing the literature studies, it has been observed that machine learning algorithms are utilized in gas turbine engine parameter and component efficiency estimation, fault detection, and model improvements. The originality of this study is expressed as the validation of real jet engine data through simulation and the prediction of critical parameters using random forest.

II. MATERIALS AND METHOD

A. System description

In a jet engine, the centrifugal compressor draws in air, compressing it to increase its temperature and pressure; the diffuser then reduces the air's velocity while increasing its pressure. In the combustion chamber, the continuous burning of air and fuel produces gas at high temperature, pressure, and velocity [9]. Fig. 1 demonstrates the micro turbojet engine used in the experiments, which consists of components including the compressor, combustion chamber, turbine, starter, air intake, and exhaust nozzle. Moreover, Fig.2 presents the sensor and jet engine connections located on the micro turbojet engine.

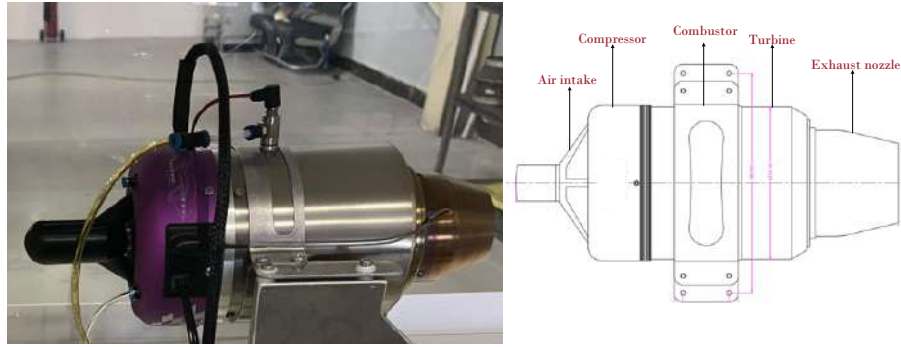


Fig.1 Demonstration of JetCat-P80 micro turbojet engine

Table 1 presents main specifications of gas turbine engine used in this study in detail.

Table 1. Main features of micro turbojet engine

Parameters	Values
Idle – Max. thrust (N)	3 - 87
Pressure ratio	2.3
Idle – Max. speed (RPM)	35000 - 125000
Exhaust gas temperature range (K)	783 - 973
Mass flow (kg/s)	0,24
Max. SFC (kg/Nh)	0,15

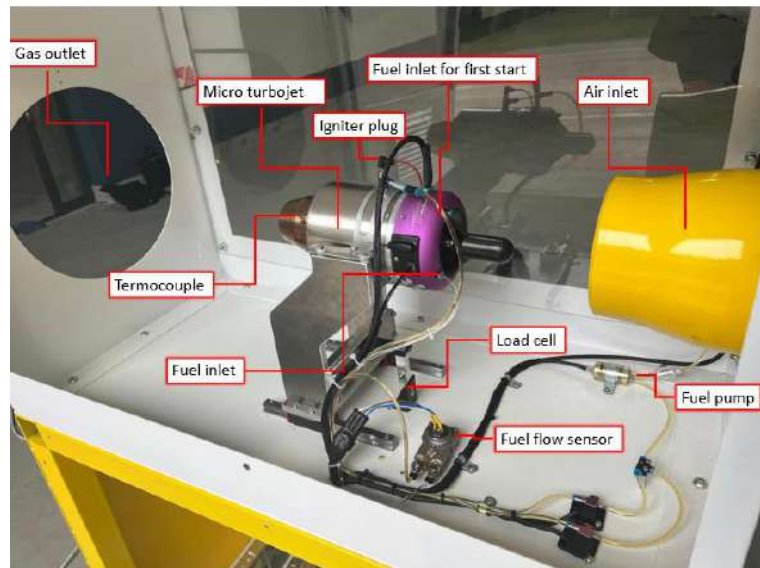


Fig.2 Experimental setup of JetCat P80

B. Random forest

This technique is used as a machine learning-based regression method, which is based on bagging and random subspace approaches. With the bagging technique, multiple learner trees are obtained from the training data, and these trees are combined to obtain an overall prediction. Each tree is trained with independent bootstrap samples obtained by allowing reselection of samples from the original dataset. RFR is an ensemble model that enhances predictive power by combining multiple models and creates the most suitable prediction model using regression trees [10]. Random forest prediction is obtained by taking the average prediction ($h(x)$) of K trees [11].

$$RF = \frac{1}{K} \sum_{k=1}^K h_k(x) \quad (1)$$

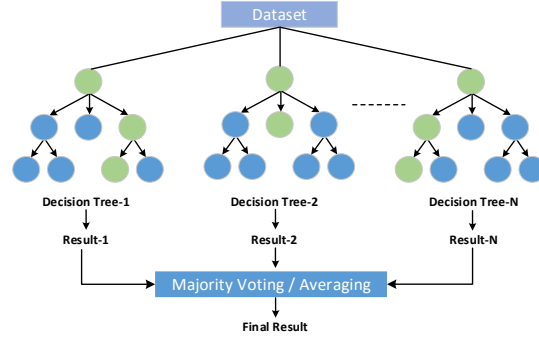


Fig.3 Demonstration of random forest technique

Table 2 presents the hyper-parameters used in modeling micro turbojet engine parameters using random forest technique.

Table 2. Hyper-parameters for RF and GBM algorithms

RF	Max depth	Max features	N estimators	Min samples split
	10	2	500	2

Eqs.2-4 shows error metrcis and coefficient of determination related to the modelled parameters.

$$MAPE = \frac{100\%}{n} \sum_{i=1}^n \left| \frac{y_i - \hat{y}_i}{y_i} \right| \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \quad (3)$$

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y}_i)^2} \quad (4)$$

Fig.4 shows the block diagram for predicting micro turbojet parameters using random forest in detail.

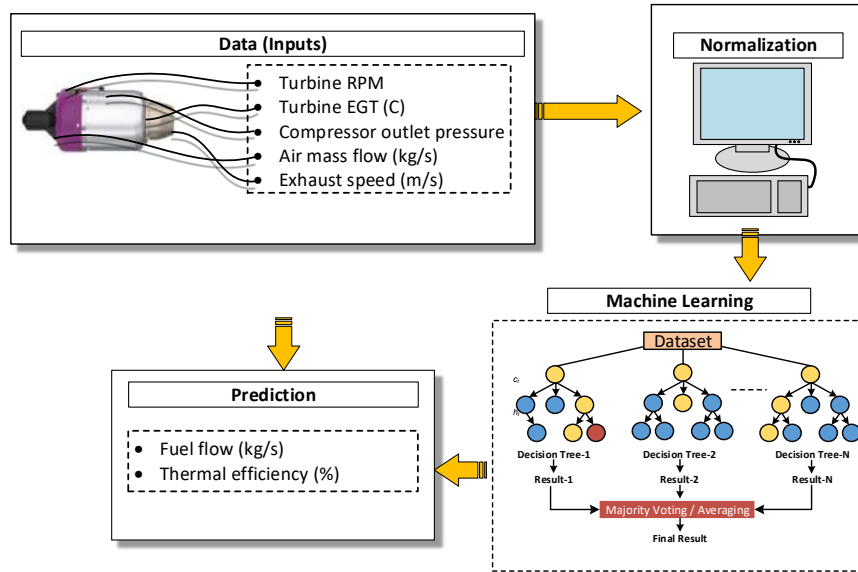


Fig.4 Random forest block diagram for micro turbojet performance prediction

III. RESULTS

In this section, the results of the experimental study and the simulation results obtained from Gasturb are presented comparatively. In this context, net thrust, fuel flow, and air mass flow results are compared in Figures 5 to 7. The differences between the two methods are presented in Tables 4-5. On the other hand, the random forest prediction results for the engine's fuel flow, thermal efficiency, and exergy efficiency are shared in Figures 8-9. The model performance results are provided in Tables 6-8.

As can be seen from fig.5, the thrust force measured by the load cell varies between 9 N and 92 N. Moreover, a graph shows the variation of net thrust obtained from Gasturb with RPM is presented. Moreover, the results obtained through both methods are presented comparatively.

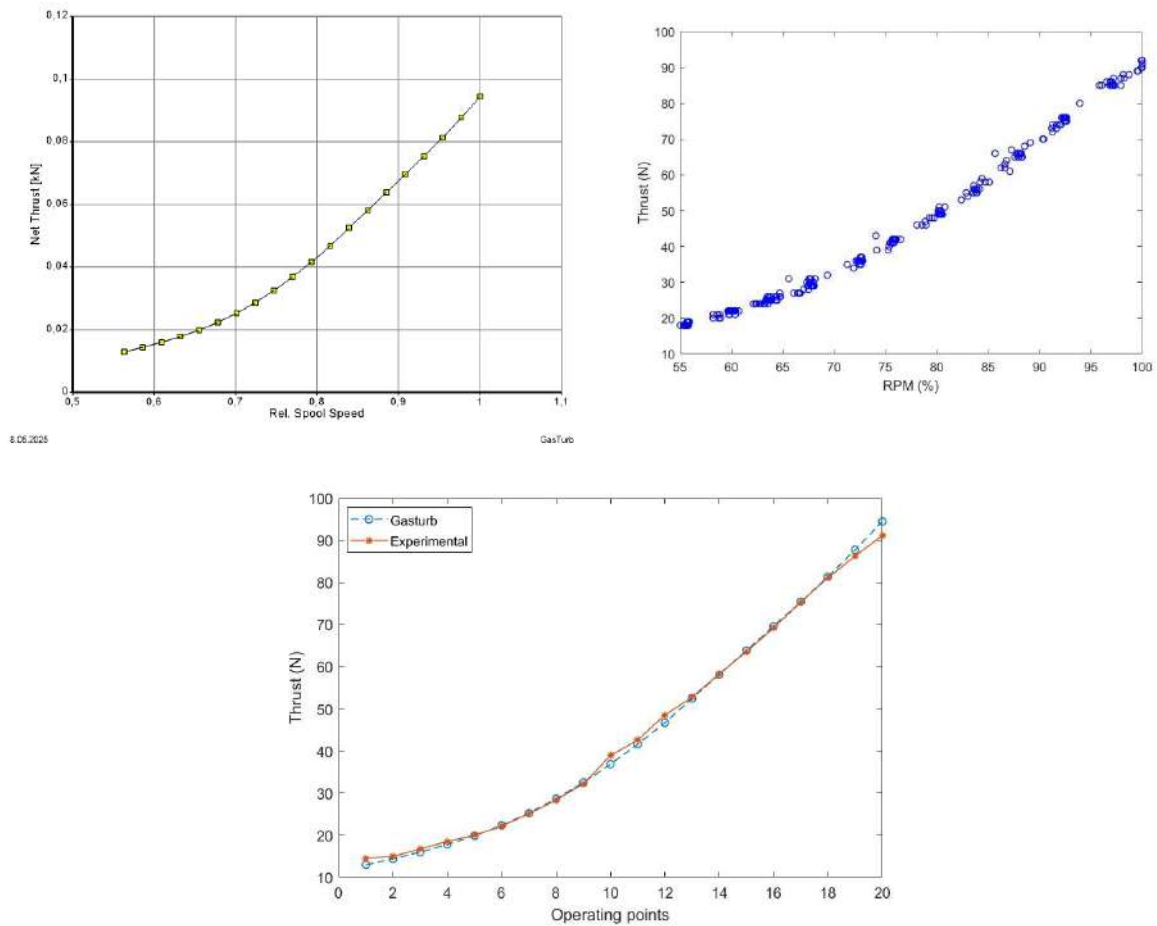


Fig.5 Variation of net thrust obtained by experimental and Gasturb

Table 3 expresses the difference in impulse obtained by both methods using error metrics. As can be seen, the MAPE value was obtained as 4.8332%. Generally, the high MAPE is due to this comparison being made for only twenty points. It should be noted that if the simulation program had provided data for as many points as the experimental data points, it is anticipated that the MAPE values would decrease.

Table 3. The error values regarding net thrust between experimental and Gasturb

Error metrics	Values
MSE	3.3483
RMSE	1.8298
MAE	1.2867
MAPE (%)	4.8332

According to fig.6, the fuel flow measured with the flow meter varies between 0.000969 kg/s and 0.00479 kg/s. Furthermore, a graph shows the variation of fuel flow obtained from Gasturb with RPM is presented and the results obtained through both methods are presented comparatively.

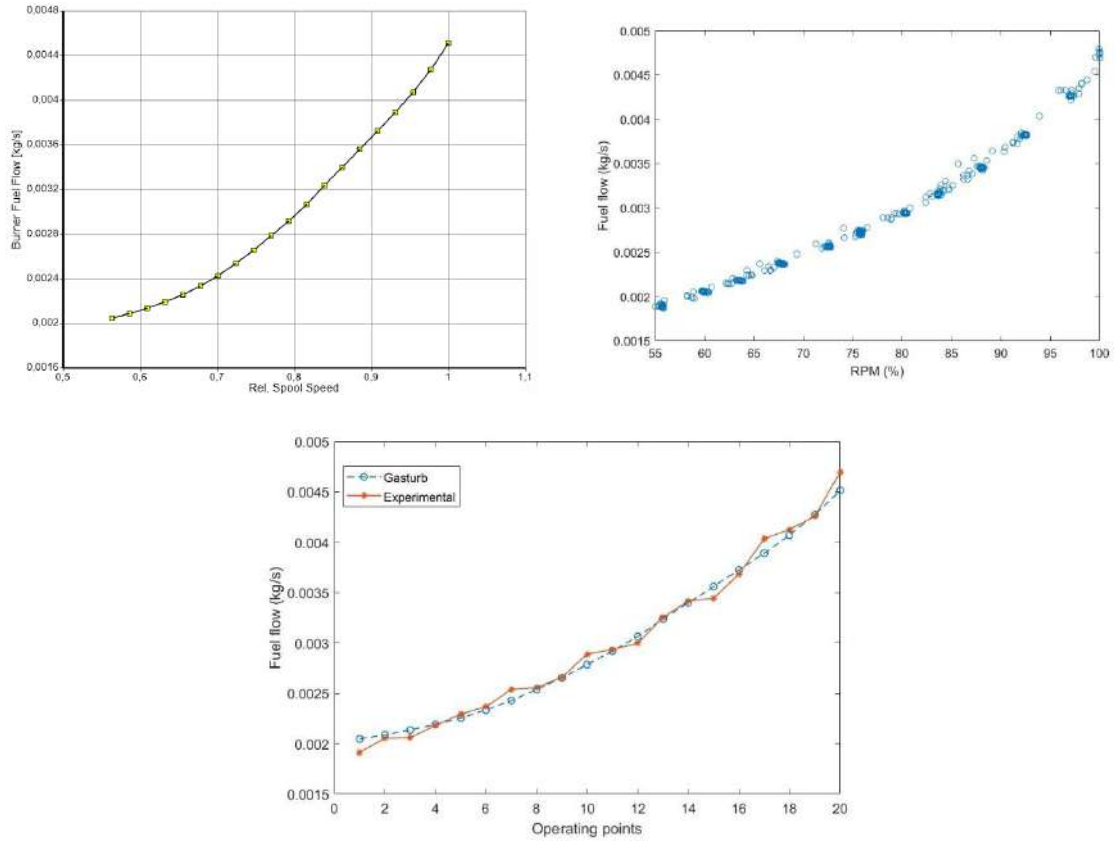


Fig.6 Variation of fuel flow obtained by experimental and Gasturb

Table 4 expresses the difference in fuel flow obtained by both methods using error metrics. As can be seen, the MAPE value was obtained as 2.1069%.

Table 4. The error values regarding fuel flow between experimental and Gasturb

Error metrics	Values
MSE	$6.3682 \cdot 10^{-9}$
RMSE	$7.9801 \cdot 10^{-5}$
MAE	$6.1522 \cdot 10^{-5}$
MAPE (%)	2.1069

According to fig.7, the air mass flow measured with the anemometer varies between 0.077 kg/s and 0.258 kg/s. Furthermore, a graph shows the variation of air mass flow obtained from Gasturb with RPM is presented and the results obtained through both methods are presented comparatively.

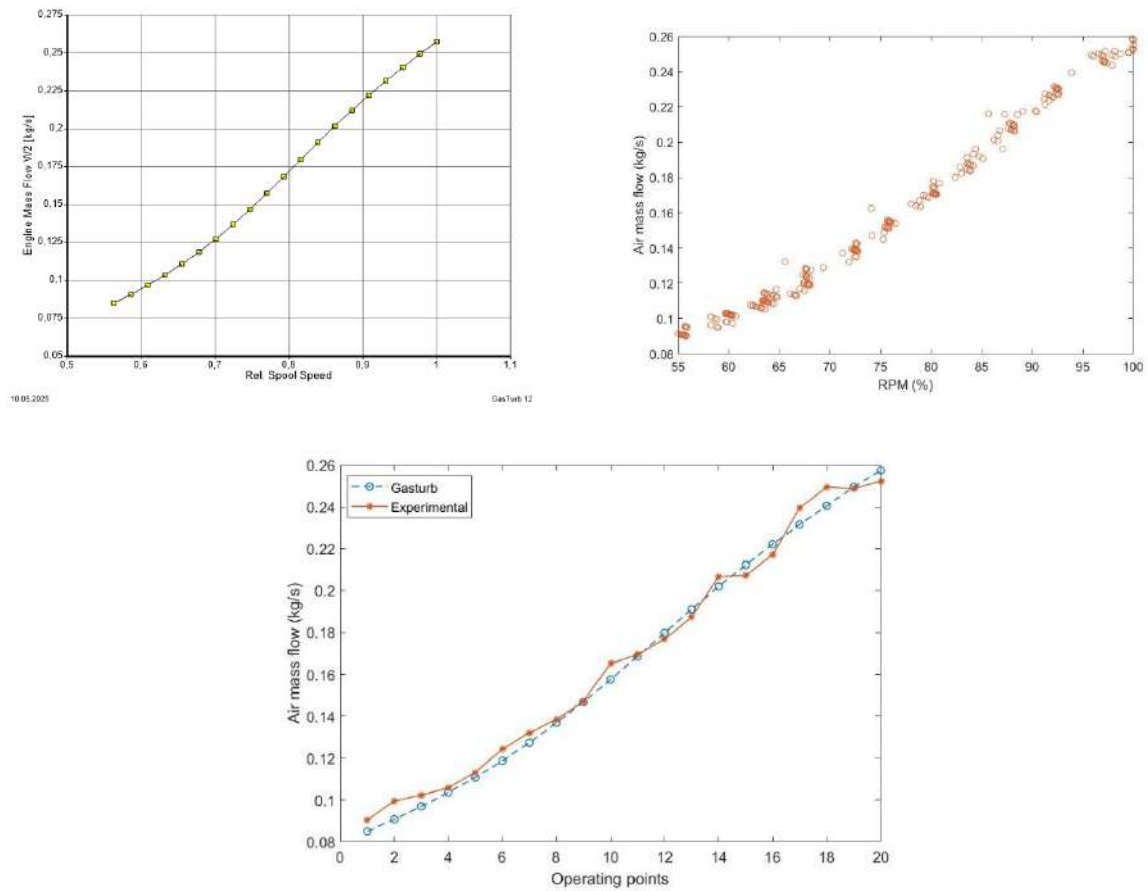


Fig.7 Variation of air mass flow obtained by experimental and Gasturb

Table 5 expresses the difference in air mass flow rate obtained by both methods using error metrics. As can be seen, the MAPE value was obtained as 2.947%.

Table 5. The error values regarding air mass flow between experimental and Gasturb

Error metrics	Values
MSE	2.6449×10^{-5}
RMSE	0.0051
MAE	0.0045
MAPE (%)	2.9470

Figure 8 shows the actual and predicted fuel flow curves obtained using random forest. Moreover, it shows the importance levels of input variables in predicting fuel flow. As can be understood, in fuel prediction, turbine RPM has the relatively highest importance level with a value of over 25%, while turbine EGT has an importance level of less than 5%.

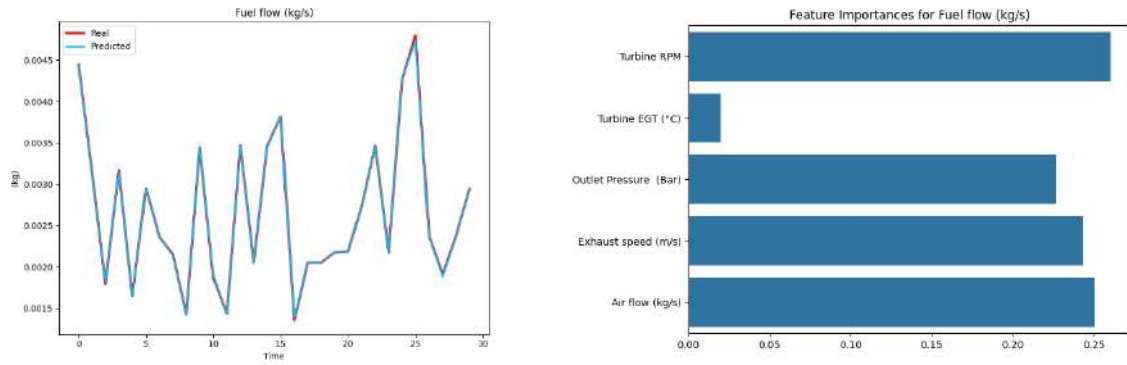


Fig.8 Real and predicted fuel flow with random forest

Table 6 presents a comparative display of the test data (actual) and prediction data for fuel flow obtained through random forest.

Table 6. Random forest results for fuel flow prediction (kg/s)

Index	Real (kg/s)	Predicted (kg/s)
1	0.0044	0.0044
2	0.0031	0.0031
3	0.0018	0.0018
4	0.0032	0.0032
5	0.0016	0.0017
6	0.0029	0.0029
7	0.0024	0.0024
8	0.0021	0.0021
9	0.0014	0.0014
10	0.0034	0.0034

Fig. 9 shows the actual and predicted thermal efficiency curves obtained using random forest. Moreover, it shows the importance levels of input variables in predicting fuel flothermal efficiency. Furthermore it shows the importance levels of input variables in thermal efficiency prediction. As can be understood, while the air mass flow rate has the relatively highest importance level with a value of over 40% in fuel prediction, the turbine EGT has an importance level of less than 5%.

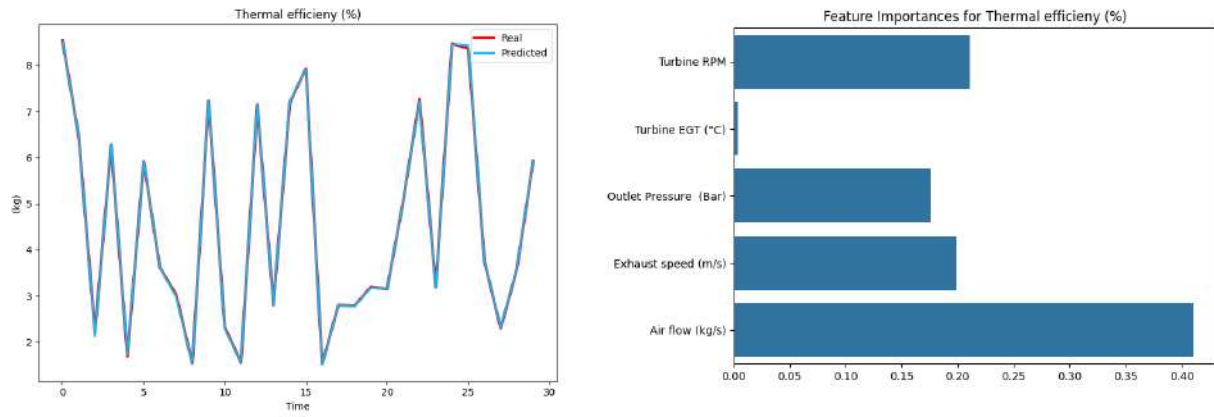


Fig.9 Real and predicted thermal efficiency with random forest

Table 7 presents a comparative display of the test data (actual) and prediction data for thermal efficiency obtained through random forest.

Table 7. Random forest results for thermal efficiency prediction (%)

Index	Real (%)	Predicted (%)
1	8.5287	8.5089
2	6.4696	6.4703
3	2.1842	2.1213
4	6.2757	6.3022
5	1.6868	1.7315
6	5.9134	5.9147
7	3.6173	3.6194
8	3.0238	2.9783
9	1.5367	1.5406
10	7.2230	7.2217

Table 8 presents the error values and coefficient of determination that demonstrate the modeling success of fuel flow and thermal efficiency modeled using the random forest method. According to the results in Table 8, both parameters are modeled with an R^2 value above 0.999.

Table 8. Error metrics and coefficient of determination (random forest)

Index	MAE	RMSE	R^2
Fuel flow (kg/s)	0.0000	0.0000	0.9997
Thermal efficiency (%)	0.0165	0.0246	0.9999

IV. CONCLUSION

Micro turbine engines are fundamental propulsion and power generation systems in aviation, energy, and defense industries due to their high efficiency and power-to-weight ratios. Within the scope of the study, firstly, experimental data (fuel flow, net thrust and air mass flow) are compared with data obtained from the Gasturb simulation program. Secondly, fuel consumption and thermal efficiency are predicted based on engine parameters, RPM, EGT, compressor outlet pressure, exhaust outlet velocity, and air flow rate by using machine learning method (random forest). Namely, the outcomes could be summarized as follows;

- The MAPE value for experimental fuel flow results with Gasturb was obtained as 2.1069%, while it was calculated as 2.947% for air mass flow rate.
- Thanks to Random Forest, the R2 for thermal efficiency was found to be 0.9999, while it was measured as 0.9997 for fuel flow.

ACKNOWLEDGMENT

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A Short Survey on Optimization in Engineering

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Abstract – Optimization plays a key role in solving complex engineering problems by improving efficiency, reducing costs, and enhancing system performance. Over the years, a variety of optimization techniques, ranging from classical mathematical methods to modern heuristic and metaheuristic algorithms, are developed and applied in different engineering fields. This short survey provides an overview of major optimization approaches, including deterministic, stochastic, and hybrid methods. The study highlights their applications in mechanical, civil, and energy engineering, emphasizing their advantages and limitations. Finally, current trends such as the integration of machine learning with optimization are briefly discussed to outline future research directions.

Keywords – Optimization, Engineering, Metaheuristics, Constrained Problems, Uncertainty.

I. INTRODUCTION

Optimization is a core concept in engineering that focuses on identifying the best possible solution for a given problem within defined boundaries. It plays a crucial role in improving system performance, reducing costs, and achieving efficient use of materials and energy. In real-world engineering systems, uncertainties such as variations in material properties, external conditions, or operational parameters often affect performance outcomes. Therefore, modern optimization not only seeks the best design but also ensures that the solution remains robust under uncertainty, making it essential for reliable engineering decision-making.

Optimization techniques can generally be divided into gradient-based and non-gradient-based approaches. Gradient-based algorithms, such as steepest descent and conjugate gradient methods, rely on derivative information to guide the search toward an optimal point [1]. These methods are efficient for smooth, continuous, and well-behaved functions but may struggle with highly nonlinear or discontinuous problems. In contrast, non-gradient-based algorithms, often called metaheuristic or evolutionary methods, such as Genetic Algorithm (GA) [2], Particle Swarm Optimization (PSO) [3], and Ant Colony Optimization (ACO) [4], do not require gradient information and can explore complex, multimodal search spaces more effectively. Their flexibility makes them suitable for solving large-scale and real-world engineering problems.

Optimization problems in engineering can be classified as constrained or unconstrained depending on whether limitations are imposed on the variables or objective function [5, 6]. For example, minimizing the weight of a truss structure while maintaining stress and displacement limits represents a constrained optimization problem, whereas tuning parameters in a control system to achieve minimum error without explicit constraints is an unconstrained one. Both types are widely encountered across mechanical, civil, and energy engineering disciplines, often requiring tailored solution methods.

The aim of this work is to provide a brief overview of commonly used optimization techniques and their applications in engineering. The study outlines the fundamental differences between gradient-based and non-gradient-based methods, discusses their advantages and limitations under uncertain conditions, and highlights their role in solving both constrained and unconstrained problems. By summarizing key concepts

and emerging trends, this survey aims to serve as a concise reference for understanding the evolving landscape of optimization in modern engineering practice.

II. MATERIALS AND METHOD

A. Classification of Optimization Methods

Optimization methods can generally be classified into two main categories: classical (deterministic) and metaheuristic (stochastic) approaches. Classical optimization methods, also known as deterministic methods, rely on mathematical formulations and derivative information to locate the optimum point. These include gradient-based algorithms, such as the steepest descent, conjugate gradient, and Newton's method, which use the slope of the objective function to move iteratively toward an optimal solution. Classical methods are particularly effective when the objective function is smooth, continuous, and well-defined. Additionally, linear and nonlinear programming techniques are widely used in engineering optimization problems involving equality and inequality constraints. However, these methods often struggle with complex, multimodal, or discontinuous problems where gradient information is difficult or impossible to obtain [7].

In contrast, metaheuristic methods are non-gradient-based algorithms inspired by natural or social phenomena, as presented in Fig. 1. They provide greater flexibility in exploring large and complex search spaces. Popular examples include Genetic Algorithm (GA) [2], inspired by biological evolution; Particle Swarm Optimization (PSO) [3], based on the survival behavior of bird flocks; and Teaching and Learning Based Optimization (TLBO) [8], modeled on the social behavior and rules. These algorithms employ randomization and iterative improvement to search for near-optimal solutions. Although they do not guarantee the exact global optimum, metaheuristics are powerful tools for solving real-world engineering problems where traditional methods are inefficient or fail to converge.

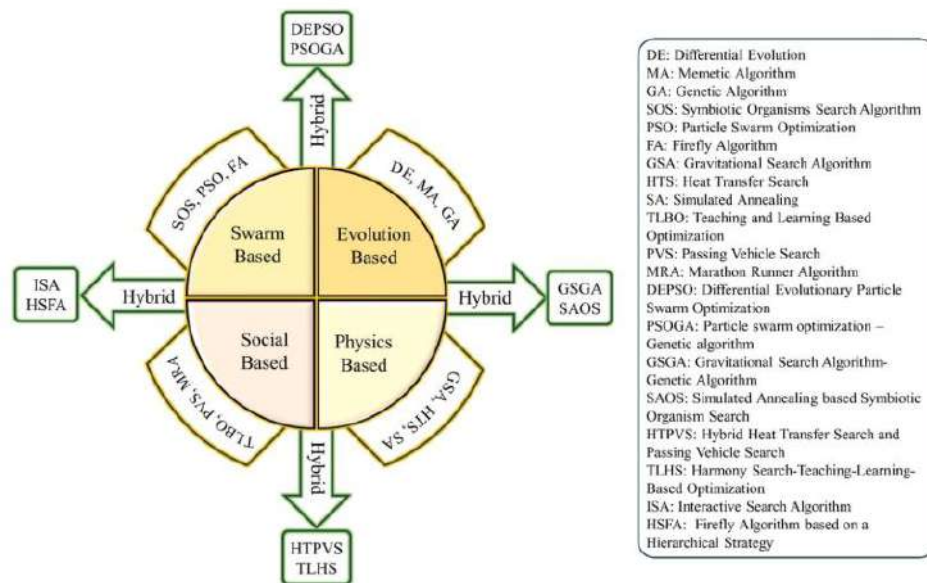


Fig. 1 Classification of Optimization Methods [9]

B. Applications in Engineering

Optimization is successfully applied across a wide range of engineering disciplines to improve performance, minimize cost, and enhance reliability [10-13]. In mechanical engineering, optimization techniques are used for the design of mechanical components and systems, such as determining optimal dimensions, materials, and operating parameters to maximize efficiency or minimize weight [14]. In civil engineering, optimization is applied to structural design, where the objective may be to minimize material usage while maintaining safety and load-bearing capacity. In energy engineering, optimization plays a key

role in improving system performance, such as maximizing energy output from renewable systems or enhancing the thermal efficiency of heat exchangers [15-17]. These applications demonstrate that both classical and metaheuristic methods serve as valuable tools for addressing a variety of constrained and unconstrained optimization problems in modern engineering practice.

III. RECENT TRENDS AND FUTURE OUTLOOK

In recent years, optimization in engineering has evolved beyond traditional algorithmic approaches toward more intelligent and adaptive frameworks. One of the most significant developments is the integration of Artificial Intelligence (AI) and optimization. Machine learning techniques are increasingly used to enhance optimization performance, for example, by predicting promising regions of the search space or automatically tuning algorithm parameters. This combination of AI and optimization enables faster convergence, improved solution accuracy, and greater adaptability to dynamic or uncertain environments.

Another important trend is the growing emphasis on sustainability and multi-objective optimization. Engineering problems today often involve multiple conflicting objectives, such as minimizing cost while maximizing energy efficiency or environmental performance. Multi-objective algorithms, such as NSGA-II and MOEA/D, allow decision-makers to explore trade-offs between different goals and select balanced, sustainable solutions. This approach has become essential in areas like renewable energy systems, resource management, and green manufacturing.

Furthermore, advances in sensing, computation, and data availability have led to the rise of real-time and data-driven optimization. Modern engineering systems increasingly operate under time-dependent conditions and large data flows, requiring algorithms that can make rapid decisions based on continuously updated information. Data-driven optimization methods, often combined with digital twins and Internet of Things (IoT) technologies, allow engineers to monitor performance, predict failures, and dynamically adjust control strategies.

Overall, the future of optimization in engineering lies in hybrid, intelligent, and adaptive methods that merge data analytics, AI, and classical mathematical reasoning. These advancements promise more efficient, resilient, and sustainable engineering systems capable of meeting the complex demands of modern society.

IV. DISCUSSION

The comparative evaluation of optimization methods reveals that no single approach can be considered universally superior for all engineering problems. The choice of an appropriate technique depends largely on the nature of the objective function, the presence of constraints, and the level of uncertainty involved. Classical gradient-based methods remain valuable when the problem is smooth, differentiable, and well-defined, providing high accuracy and fast convergence. However, they are often limited in dealing with discontinuous or highly nonlinear systems, which are common in real-world engineering applications.

On the other hand, metaheuristic algorithms such as GA, PSO, and ACO have shown remarkable success in solving complex, large-scale, and non-convex problems. Their ability to explore the search space globally and avoid local optima makes them attractive alternatives to classical methods. Nevertheless, these algorithms may require longer computation times and careful parameter tuning to achieve consistent performance. This balance between exploration, exploitation, and computational cost continues to be a central discussion point in optimization research.

An emerging consensus in the engineering community is that hybrid and adaptive approaches can offer the best of both worlds. By combining the analytical strength of deterministic methods with the flexibility of stochastic ones, hybrid techniques can provide robust and efficient solutions under uncertainty. Moreover, the integration of data-driven modeling and artificial intelligence has opened new possibilities for developing intelligent optimization frameworks capable of learning and improving over time.

Overall, the discussion highlights that the evolution of optimization in engineering is moving toward adaptive, intelligent, and problem-specific strategies that respond effectively to the increasing complexity of modern systems.

V. CONCLUSION

Optimization has become an indispensable tool in modern engineering, offering systematic approaches to improve performance, minimize costs, and ensure sustainable design solutions. This paper briefly reviewed the main categories of optimization methods, including classical deterministic algorithms and modern metaheuristic techniques, emphasizing their roles in solving both constrained and unconstrained problems. The discussion highlighted that while gradient-based methods are efficient for smooth and well-defined problems, metaheuristic and hybrid approaches provide more flexibility for complex, nonlinear, and uncertain systems.

Recent advances, particularly the integration of artificial intelligence and data-driven modeling, are transforming the way optimization is applied in engineering. These developments are leading to adaptive and intelligent frameworks capable of handling real-time decision-making and multi-objective trade-offs.

In summary, the future of engineering optimization lies in the fusion of classical mathematical rigor, heuristic exploration, and intelligent learning. Such integration will enable the design of more efficient, robust, and sustainable engineering systems that meet the evolving needs of modern technology and society.

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Uncertainty Quantification and Statistical Approaches in Engineering Design

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Abstract – Uncertainty is an inherent aspect of engineering design, arising from variations in material properties, environmental conditions, and modeling assumptions. Effectively managing these uncertainties is crucial for ensuring reliable, efficient, and safe systems. Statistical methods provide a systematic framework to quantify, analyze, and mitigate uncertainty in engineering applications. This short review presents commonly used approaches, including probabilistic modeling, Monte Carlo simulation, and sensitivity analysis, highlighting their roles in addressing both design and operational variability. The study also discusses hybrid strategies that combine statistical techniques with optimization or artificial intelligence to enhance decision-making under uncertainty. By summarizing key methods and applications, this paper aims to provide engineers and researchers with a concise overview of strategies for uncertainty quantification in modern engineering design.

Keywords – Uncertainty, Statistical Methods, Engineering Design, Monte Carlo Simulation, Sensitivity Analysis.

I. INTRODUCTION

Uncertainty is an unavoidable component of engineering design, arising from various sources such as material inconsistencies, environmental variability, measurement errors, and incomplete modeling. These uncertainties can significantly affect system performance, safety, and reliability. In modern engineering practice, understanding and managing uncertainty is essential for making informed design decisions and avoiding unexpected failures [1, 2]. Consequently, engineers increasingly rely on statistical approaches to quantify and mitigate the effects of uncertainty, ensuring that designs remain robust under variable conditions.

Several statistical methods have been developed to address uncertainty in engineering. Probabilistic modeling represents uncertain parameters as probability distributions, allowing designers to predict the likelihood of different outcomes. Monte Carlo simulation employs repeated random sampling to estimate the performance of a system under varying conditions, providing insights into risk and reliability. Additionally, sensitivity analysis identifies the most influential parameters, helping to prioritize design improvements and resource allocation. Together, these methods offer a systematic framework for analyzing and reducing the impact of uncertainty in engineering systems [3, 4].

Engineering problems often involve both constrained and unconstrained designs, where uncertainties can influence not only performance metrics but also the feasibility of solutions [5]. For example, in structural engineering, variations in material strength and load conditions may affect safety margins, while in energy systems, environmental fluctuations can impact efficiency and output. Statistical methods allow engineers to account for these variations during the design process, making solutions more resilient and reliable.

The aim of this paper is to provide a concise overview of statistical approaches used for uncertainty quantification in engineering design. By summarizing key methods, their advantages, and typical

applications across different engineering fields, this study offers a practical reference for researchers and practitioners seeking to incorporate uncertainty analysis into modern engineering workflows.

II. MATERIALS AND METHOD

In engineering design, uncertainty can originate from multiple sources such as material properties, manufacturing tolerances, environmental variability, or model approximations. Statistical approaches provide systematic tools to quantify and manage these uncertainties, enabling engineers to make robust design decisions. This section reviews commonly used methods, their principles, and applications.

A. Probabilistic Approaches

Probabilistic approaches model uncertain parameters as random variables with defined probability distributions. Common distributions include Normal, Log-normal, Weibull, and Uniform distributions. The general form for a random variable X with probability density function $f_X(x)$ is [6]:

$$P(a \leq X \leq b) = \int_a^b f_X(x) dx$$

These methods are particularly useful in applications such as assessing structural reliability under variable loads and accounting for material strength variability in mechanical components. By representing uncertainty quantitatively, probabilistic modeling allows designers to predict the likelihood of failure or the probability of meeting performance targets.

B. Monte Carlo Simulation (MCS)

Monte Carlo Simulation is another widely used statistical technique that employs repeated random sampling to evaluate system performance under uncertain conditions. In practice, uncertain input parameters are sampled from their probability distributions, and the corresponding system outputs are calculated iteratively. If $Y = f(X_1, X_2, \dots, X_n)$ represents the system output, the expected value $E[Y]$ and standard deviation σ_Y could be approximated as [7]:

$$E[Y] \approx \frac{1}{N} \sum_{i=1}^N Y_i, \quad \sigma_Y \approx \sqrt{\frac{1}{N-1} \sum_{i=1}^N (Y_i - E[Y])^2}$$

Monte Carlo simulation has been successfully applied to predict energy output fluctuations in renewable energy systems and to assess tolerances in complex mechanical designs. Its flexibility allows analysis of nonlinear and high-dimensional problems that are difficult to tackle using analytical methods.

C. Sensitivity Analysis

Sensitivity analysis complements these approaches by identifying which input parameters most significantly affect system performance. By calculating local or global sensitivity indices, such as the variance-based Sobol index [8]:

$$S_i = \frac{\text{Var}_{X_i}(E[Y|X_i])}{\text{Var}(Y)}$$

In engineering design fraction of output variability could be determined attributable to each input parameter. This information helps prioritize critical parameters, optimize resource allocation, and reduce overall uncertainty in designs ranging from mechanical components to multi-variable energy systems.

D. Hybrid Methods

Hybrid methods integrate statistical techniques with optimization algorithms or artificial intelligence to enable adaptive and robust design under uncertainty. For example, combining Monte Carlo simulation with Genetic Algorithm allows optimization of complex designs while accounting for stochastic variability. Such hybrid approaches are increasingly used in reliability-based design optimization (RBDO) and data-driven adaptive control systems, offering a balance between robustness and performance.

The statistical methods for uncertainty quantification are comparatively listed in Table 1.

Table 1. Comparison of statistical methods for uncertainty quantification

Method	Key Concept	Typical Applications
Probabilistic Modeling	Parameters as random variables	Structural reliability, material variability
Monte Carlo Simulation	Random sampling	Energy systems, manufacturing tolerances
Sensitivity Analysis	Input-output variance	Mechanical design, multi-variable systems
Hybrid Methods	Combination with optimization/AI	RBDO, real-time adaptive control

III. DISCUSSION

The increasing complexity of modern engineering systems makes uncertainty quantification (UQ) a critical component of design and analysis. As the sources of uncertainty can originate from both intrinsic randomness (aleatory uncertainty) and lack of knowledge (epistemic uncertainty), their joint treatment becomes essential for achieving robust and reliable designs. Classical deterministic approaches often fail to capture this variability, leading to either over-conservative or unsafe designs. Therefore, integrating probabilistic and statistical techniques has become a key direction in engineering optimization and reliability assessment.

Among the discussed approaches, Monte Carlo simulation remains the most widely applied due to its simplicity and generality. However, it is computationally expensive when applied to large-scale or high-dimensional systems. To overcome these limitations, surrogate modeling and response surface methods have been introduced to approximate system behavior with lower computational cost. Similarly, sensitivity analysis provides deeper insight into the relative importance of uncertain parameters, guiding engineers in focusing modeling efforts on critical variables rather than treating all parameters equally.

The applications of uncertainty quantification span across various engineering disciplines. In structural engineering, probabilistic analysis helps assess the likelihood of failure under variable loads and uncertain material properties. In mechanical design, statistical characterization of fatigue and strength variability improves component durability. In energy systems, uncertainty methods are used to predict and optimize the performance of renewable energy sources, such as wind and solar, where environmental fluctuations are inevitable. These applications collectively demonstrate that uncertainty analysis not only enhances safety but also promotes cost-effective and sustainable design practices.

Recent years have witnessed a strong shift toward integrating artificial intelligence (AI) and machine learning (ML) with uncertainty quantification. Data-driven models can learn probabilistic relationships directly from experimental or operational data, bypassing some of the limitations of traditional analytical formulations. For example, Gaussian Process Regression (GPR) and Bayesian Neural Networks (BNN) have been successfully used to capture uncertainty in high-dimensional and nonlinear systems. Such models enable real-time uncertainty estimation, which is particularly valuable in adaptive control and predictive maintenance applications.

Another emerging trend is multi-objective uncertainty optimization, where trade-offs between performance, cost, and reliability are considered simultaneously. This approach aligns with the global shift toward sustainable engineering, as it balances economic, environmental, and social objectives under uncertainty. Additionally, the increasing availability of sensor data and digital twins allows engineers to perform data-driven uncertainty analysis, continuously updating model predictions as new data are collected from real systems.

Future research is expected to focus on hybrid frameworks combining physics-based modeling, AI, and probabilistic reasoning. These approaches will facilitate dynamic and self-learning systems capable of making robust decisions under evolving conditions, particularly in autonomous energy networks, smart materials, and resilient infrastructure systems.

IV. CONCLUSION

Recent years have witnessed a strong shift toward integrating artificial intelligence (AI) and machine learning (ML) with uncertainty quantification. Data-driven models can learn probabilistic relationships directly from experimental or operational data, bypassing some of the limitations of traditional analytical formulations. For example, Gaussian Process Regression (GPR) and Bayesian Neural Networks (BNN)

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Kültivatör Uç Demirlerinin Laboratuvar Şartlarında Aşınma Davranışlarının İncelenmesi

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Özet – Bu çalışma, tarım makinelerinde kritik öneme sahip olan kültivatör uç demirlerinin laboratuvar şartlarında incelenen aşınma davranışları üzerine yapılmış mevcut literatürü derinlemesine analiz etmeyi amaçlamaktadır. Amaç, kontrollü ortam deneylerinin metodolojilerini, elde edilen temel bulguları ve bu alandaki bilgi boşluklarını sistematik olarak sentezlemektir.

Çalışmada, farklı araştırmacıların kullandığı laboratuvar test metotları (örneğin, pin-on-disc, bilye-yüzey ve kuru kum/lastik çark testleri) ve bu metotların tarla koşullarını simüle etme başarısı karşılaştırılmıştır. Odak noktası, özellikle aşındırıcı aşınma türüne tabi tutulan uç demirlerinin farklı malzeme bileşimlerine (örneğin, yüksek karbonlu çelikler, manganlı çelikler ve kompozitler) verdikleri tepkilerdir.

İncelenen çalışmalar, normal yük, kayma mesafesi, aşındırıcı partikül tipi (kuvars kumu, toprak vb.) ve ısıtma işlem parametrelerinin özgül aşınma miktarı (Ws) üzerindeki etkilerini ortaya koyan kantitatif verileri sentezlemektedir. Ayrıca, yüzey analiz tekniklerinin (SEM, EDX, profilometri) aşınma mekanizmalarını (mikro-kesme, oyulma) belirlemedeki rolü ve etkinliği de değerlendirilmiştir.

Sonuç olarak bu çalışma, laboratuvar simülasyonlarının kültivatör uç demirlerinin aşınma direncini tahmin etmedeki gücünü ve sınırlılıklarını açıkça belirlemekte, gelecekteki deneysel çalışmalar için en uygun test protokollerinin geliştirilmesine yönelik bir referans çerçevesi sunmaktadır.

Anahtar Kelimeler – Kültivatör Uç Demiri, Aşınma Davranışı, Özgül Aşınma Miktarı, Triboloji, Laboratuvar Simülasyonu.

I. GİRİŞ

Bu Tarım makinelerinin en kritik çalışma organlarından olan toprak işleme aletleri, toprakla doğrudan temas halinde çalıştıkları için, yüksek oranda aşınmaya maruz kalmaktadır. Kültivatör ve pulluk uç demirleri gibi aktif iş organlarında meydana gelen aşınma, aletlerin geometrik şekillerini ve dolayısıyla işlevsel özelliklerini kaybetmelerine yol açar [1]. Bu durum, makinenin performansında önemli bir düşüşe ve verimlilik kayıplarına neden olur. Örneğin, bir pulluğun kesici kenarının 2 mm incilmesi bile çekiş direncini %15-24 oranında artırabilmektedir [2]. Benzer şekilde, aşınmış uç demirleri, traktörün yakıt tüketimini %15-20 oranında yükselterek hem işletme maliyetlerini artırmakta hem de makinenin genel verimliliğini düşürmektedir [3].

Çalışmanın amacı, kültivatör uç demirlerinin karmaşık aşınma sürecini laboratuvar ortamında güvenilir, tekrarlanabilir ve kontrollü bir şekilde incelemek için gerekli olan deneysel bir düzeneğin tasarımı ile teknik gerekliliklerini ve operasyonel prosedürlerini ortaya koymaktadır. Bu tür bir tasarımlar, saha koşullarının değişkenliğinden kaynaklanan zorlukları ortadan kaldırarak, aşınmaya karşı daha dayanıklı yeni malzeme veya kaplamaların araştırılması ve geliştirilmesi için bilimsel bir temel sağlamayı hedeflemektedir [4].

A. Toprak İşleme Aletlerinde Aşınmanın Önemi

Aşınma, makinelerde hasara neden olan ve genellikle fark edilmeden gelişen genel bir mekanik olaydır [1],[5]. Tarım aletleri ve makineleri çok çeşitli ve zorlu koşullar altında çalışmak zorunda oldukları için, imalatlarında kullanılan malzemenin cinsi ve kalitesi büyük önem taşır [2]. Aşınma, engellenmesi mümkün olmayan ancak sonucunda oluşan kayıpların azaltılması bazı etmenlerin kontrolü ile mümkün olan bir süreçtir [1]. Aşınan uç demirleri, toprağı kesmek yerine sadece ileri doğru itme (öteleme) hareketi yaparak taban taşı oluşumunu hızlandırır, bu da bitki gelişimi ve dolayısıyla verim üzerinde olumsuz etkilere sahiptir [2]. Bu nedenle, toprak işleme aletlerin ömrünü uzatmak hem çiftçiler için maliyetleri düşürmek hem de genel tarımsal verimliliği artırmak için acil bir problem olarak öne çıkmaktadır.

B. Laboratuvar Şartlarında Aşınma Testlerinin Avantajları

Tarla koşullarında yapılan deneyler, toprağın nem içeriği, **bileşimi**, sıcaklığı ve penetrasyon direnci gibi sürekli değişen çevresel faktörler nedeniyle tekrarlanabilirlik ve veri tutarlılığı açısından büyük zorluklar barındırır [6]. Bu durum, farklı malzemelerin veya alet tasarımlarının performansını objektif bir şekilde karşılaştırmayı neredeyse imkânsız hale getirir. Laboratuvar ortamı, bu kontrol edilemeyen değişkenleri minimize ederek, aşınma sürecini oluşturan ana unsurların her birinin izole edilmeden hassas bir şekilde gözlemlenmesini sağlar. Bu sayede, farklı alet geometrileri, malzeme sertlikleri veya yüzey kaplamalarının aşınma direnci üzerindeki etkisi bilimsel olarak kanıtlanabilir sonuçlarla değerlendirilebilir.

C. Aşınma Teorisi ve Toprak-Alet Etkileşimi

Tribolojik Sistem Bileşenleri

Aşınma, tek bir kuvvetin sonucu değildir. Aksine, dört ana bileşenin dinamik etkileşiminden oluşan karmaşık bir "tribolojik sistemin" sonucudur [7]. Bu bileşenler şunlardır:

1. **Jeolojik Malzeme (Aşındırıcı Ortam):** Aşınmaya neden olan kaya veya toprak gibi doğal malzemelerdir. Bu malzemelerin aşındırıcılık düzeyi, tane boyutu, mineralojik bileşimi (özellikle kuvars içeriği) ve şekli gibi özelliklerine bağlıdır [8].
2. **Alet Malzemesi:** Toprakla etkileşimde bulunan ve aşınan aletin kendisidir. Toprak işleme aletlerinde aşınma direncine uygunluğu ve ekonomik ulaşılabilirliği nedeniyle genellikle çeşitli çelikler kullanılır [7].
3. **Çevre Ortamı:** Etkileşimin gerçekleştiği ortamı ifade eder. Toprak işleme aletleri için bu, toprağın nem içeriği, pH değeri ve sıcaklığı gibi çevresel parametrelerdir.
4. **Yük Tipi (Dinamik Etkileşim):** Alet ile jeolojik malzeme arasındaki etkileşim sırasında uygulanan kuvvetlerin doğasıdır. Bu, aletin toprağa uyguladığı basınç ve hareket hızını içerir.

Tribolojik sistemlerde herhangi bir bileşendeki küçük bir değişim bile, aşınma modunu ve oranını önemli ölçüde değiştirebilir. Bu nedenle, laboratuvar düzeneği tasarlanırken bu dört bileşenin her birinin hassas bir şekilde kontrol edilmesi esastır.

D. Aşınma Mekanizmaları ve Aşınmayı Etkileyen Anahtar Faktörler

Tarım aletlerinde en yaygın görülen aşınma türü, düşük stresli abrazyon aşınmasıdır [6]. Bu, topraktaki sert parçacıkların (kuvars, feldspat vb.) alet yüzeyi üzerinde kayması ve mekanik olarak malzeme kaldırmasıyla meydana gelir. Aşınma süreci, toprağın fiziksel ve mekanik özelliklerinin yanı sıra, aletin kendi özellikleri ve çalışma koşullarıyla da yakından ilişkilidir.

- **Toprak Özellikleri:** Toprağın aşındırıcılığı, aşınma hızını belirleyen en önemli unsurdur. Toprağın granülometrik bileşimi (kum, silt ve kil oranları), aşındırıcı partiküllerin sertliği, boyutu ve şekli aşınma derecesini doğrudan etkiler [3]. Örneğin, kum partiküllerinin hızı ile aşınma arasındaki ilişki, aşınmanın partikül hızının 1.5 ila 2.3. kuvvetiyle orantılı olduğunu göstermektedir [8]. Bu, laboratuvar ortamında aletin topraktaki hareket hızının ne kadar hassas bir şekilde simüle edilmesi gerektiğini ortaya koymaktadır. Toprağın nem içeriği ve yoğunluğu da aşınma sürecinde kritik rol oynar [3].
- **Alet Özellikleri:** Aletin aşınma direnci, kullanılan malzemenin sertliğine, kimyasal bileşimine ve aletin geometrisine bağlıdır [3]. Aletin kesici kenarlarının ve burun kısmının özel geometrileri, farklı aşınma hızlarına yol açar. Örneğin, yapılan araştırmalar, uç demirinin burun kısmındaki

aşınma yoğunluğunun kanatlara göre 3-4 kat daha fazla olduğunu göstermektedir [3]. Bu tespit, test numunesi için en temsili bölgenin seçilmesinde ve aşınma ölçümlerinin odaklanacağı alanların belirlenmesinde hayati önem taşır.

- **İşletme Parametreleri:** Aletin çalışma hızı, toprağa uyguladığı basınç (yük) ve çalışma derinliği, aşınma hızını doğrudan etkileyen operasyonel parametrelerdir [3]. Bu parametrelerin kontrolü, laboratuvar testlerinin tekrarlanabilirliği ve gerçek dünya koşullarını simüle etme yeteneği için kritik öneme sahiptir.

Aşınma sürecini ve bu faktörlerin etkileşimini anlamak, etkili bir laboratuvar düzeneği tasarlamının temelini oluşturur. Tablo 1’de, bu faktörleri ve laboratuvar ortamında nasıl kontrol edildiklerini özetlemektedir.

Tablo 1. Laboratuvar Test Prosedürü

Değişken Tipi	Etkileyen Faktör	Açıklama	Laboratuvar Kontrol Yöntemi
Toprak Özellikleri	Aşındırıcılık (Tane Büyüklüğü, Mineral Bileşimi)	Aşınma hızını belirleyen birincil faktör. Özellikle kuvars içeriği kritik öneme sahiptir.	Standartlaştırılmış sentetik toprak karışımı kullanarak.
Toprak Özellikleri	Nem İçeriği ve Yoğunluk	Toprağın sürtünme katsayısını ve alete uyguladığı direnci etkiler.	Nem analizörü ile nem içeriğini hassas bir şekilde ölçülerek ve test ortamını sıkıştırarak.
Alet Özellikleri	Malzeme Bileşimi ve Sertliği	Aletin aşınmaya karşı direncini belirler. Sertlik arttıkça aşınma direnci genellikle artar.	Farklı sertliklerde ve kimyasal bileşimlerde numuneler kullanarak.
Alet Özellikleri	Geometri (Şekil)	Kuvvet dağılımını etkiler ve belirli bölgelerde aşınma yoğunluğunu artırabilir.	Gerçek kültivatör uç demirlerinin kendilerini veya ölçekli modellerini kullanarak.
Operasyonel Parametreler	Normal Yük (Basınç)	Aletin toprağa uyguladığı kuvvet, aşınma oranını doğrudan etkiler.	Ayarlanabilir ağırlıklar veya kuvvet kontrol sensörleri kullanarak.
Operasyonel Parametreler	Sürtünme Hızı	Aşındırıcı partiküllerin alet yüzeyi üzerindeki hızı aşınma oranını büyük ölçüde etkiler.	Tahrik motorunun hızını kontrol ederek.
Operasyonel Parametreler	Aşınma Mesafesi	Kümülatif aşınma miktarını belirler.	Deneyin süresini veya döngü sayısını kontrol ederek.

E. Mevcut Aşınma Testi Standartları ve Düzeneği Tipleri

Genel Malzeme Aşınma Testleri

Malzemelerin aşınma direncini belirlemek için çeşitli uluslararası standartlar ve ticari test cihazları mevcuttur. Bunlar genellikle düzlem yüzeyli numuneler üzerinde kontrollü koşullarda test yapmaya odaklanır [9].

- **ASTM G65 Kuru Kum/Kauçuk Tekerlek Düzeneği:** Bu standart, metalik malzemelerin düşük stresli, üç cisimli (test numunesi, kauçuk tekerlek, kum tanecikleri) abrazif aşınma direncini ölçmek için yaygın olarak kullanılır [10]. Test, sabit bir yük altındaki düz bir numune ile dönen bir kauçuk tekerlek arasına ölçeklendirilmiş kuru kumun beslenmesi prensibine dayanır. Belirli bir devir

sayısından (örn. 6000 devir/dakika) sonra, numunenin kütle veya hacim kaybı belirlenerek aşınma direnci karşılaştırılır [11]. Daha az hacim kaybı, daha yüksek aşınma direncine işaret eder [11].

- **Döner Tambur Testi ve Düşen Kum Testi:** Döner tambur testi, çelik bilyelerin dönen bir tambur içindeki numuneye çarpıp onu öğütmesiyle malzemenin dayanıklılığını değerlendirir [12]. Düşen kum testi ise, ASTM D 968 standardına uygun olarak, belirli bir tane boyutundaki kumun bir rehber tüp aracılığıyla test plakasının üzerine düşmesiyle yüzey kaplamalarının aşınma direncini ölçer [12].
- **Martindale ve Taber Aşınma Testleri:** Martindale aşınma testi, kumaşların aşınma direncini belirlemek için kullanılırken [13], Taber Aşındırıcı (Taber Abraser), organik kaplamaların aşınma direncini ölçmek için dönen aşındırıcı tekerlekler kullanır [14]. Taber'ın Linear Abraser (Model 5770) cihazı ise, doğrusal bir hareketle hem düz hem de konturlu yüzeyleri test edebilme yeteneği sunar [15].

F. Standart Testlerin Kültivatör Uç Demiri İçin Yetersizlikleri

Kültivatör uç demirlerinin aşınması, karmaşık bir geometrik şekle sahip bir aletin, sürekli değişen toprak ortamında dinamik bir yük altında ilerlemesini içeren benzersiz bir tribolojik problemdir. Bu bağlamda, yukarıda belirtilen standart testlerin çoğu, kültivatör aşınmasını simüle etmekte yetersiz kalmaktadır.

Araştırmalar, ASTM G65 gibi standart testlerin ve pin-on-disk testlerinin, toprak işleme aletlerinin karmaşık şekillerinin aşınma karakteristiklerini doğru bir şekilde simüle edemediğini açıkça belirtmektedir [6]. Bu testler, genellikle küçük, düz yüzeyler üzerinde, tek yönlü bir aşındırıcı ortam ile birlikte çalışır. Oysa bir kültivatör uç demiri, toprak içinde hareket ederken farklı bölgeleri (burun, kanatlar, kesici kenar) farklı açılardan ve yük altında aşınmaya maruz kalır [3]. Her ne kadar Taber Linear Abraser gibi cihazlar “serbest yüzer” bir test sistemi ile konturlu yüzeylerin izini sürebilse de [15], bu sistemler, toprağın sıkıştırılabilirlik, kohezyon ve nem gibi özelliklerini tam olarak taklit eden bir ortamda çalışmazlar. Bu durum, standart testlerin prensiplerini kullanarak ancak kültivatör uç demirlerinin gerçek çalışma koşullarını (kompleks geometri, dinamik yük, gerçek toprak özellikleri) taklit edebilen özel bir laboratuvar düzeneği geliştirmenin mutlak bir gereklilik olduğunu göstermektedir. Bu özel düzeneğe, malzemeleri yalnızca aşınma direnci açısından değil, aynı zamanda aletin işlevsel performansı (çekiş direnci, toprak işleme kalitesi) açısından da değerlendirilmesini mümkün kılacaktır. Tablo 2’de standart test yöntemlerinin kültivatör uç demiri aşınmasının belirlenmesinde neden uygun olamayacağını göstermektedir.

Tablo 2. Standart Testlerin Olumsuzlukları

Test Yöntemi	Aşındırıcı Tipi	Numune Geometrisi	Aşınma Mekanizması	Kültivatör Aşınması İçin Uygunluğu
ASTM G65	Standartlaştırılmış kuru kum	Düzlem yüzey	Düşük stresli abrazif (Üç cisimli)	Düşük. Toprak özelliklerini ve aletin karmaşık geometrisini simüle edemez.
Taber Abraser	Standart tekerlekler	Düzlem panel	Döner abrazif	Düşük. Toprak aşınmasını ve karmaşık alet şeklini simüle edemez.
Martindale	Keçe, aşındırıcı bez	Kumaş	Sürtünme ve Lissajours hareketi	Tarım aletleri için uygun değil.
Düşen Kum Testi	Standartlaştırılmış kuvars kum	Düzlem plaka	Darbeli aşınma	Düşük. Toprak-alet sürtünmesini simüle edilemez.

G. Laboratuvar Düzeneği Tasarımı

Tasarım Felsefesi

Laboratuvar düzeneği, kültivatör uç demirlerinin tarla koşullarında maruz kaldığı düşük stresli abrazif aşınmayı güvenilir ve tekrarlanabilir bir şekilde taklit etme felsefesi üzerine inşa edilmiştir [6]. Bu, alet, aşındırıcı ortam, hareket profili ve aşınma ölçüm sistemi gibi tribolojik sistemin tüm bileşenlerinin titizlikle

kontrol edilmesini gerektirir. Düzenegin temel amacı, tek bir deney ortamında farklı malzemelerin aşınma performansını doğrudan karşılaştırmaya olanak sağlamaktır.

H. Düzenegin Ana Bileşenleri

1. Test Ortamı: Sentetik Toprak Havuzu

Gerçek tarla toprağının değişkenliğini (nem, tane büyüklüğü, mineralojik bileşim) ortadan kaldırmak ve deneylerin tekrarlanabilirliğini sağlamak için, özelliklerini hassas bir şekilde kontrol edebileceğimiz sentetik bir toprak karışımı kullanılmalıdır [16]. Araştırma materyallerine göre, standart kuvars kumu genellikle aşındırıcı testlerde kullanılmaktadır [14], [17]. Ancak, gerçek toprak aşınması sadece kuvars kumunun mekanik sürtünmesinden ibaret değildir. Toprağın nem içeriği, kil ve silt fraksiyonları, alet yüzeyinde adezyon ve korozyon gibi diğer aşınma mekanizmalarını etkiler. Bu nedenle, sentetik toprak karışımı, gerçekçi bir simülasyon sağlamak için standart kuvars kumuna (%80-90) ek olarak, kil, silt ve kontrollü miktarda su içermelidir. Bu kompozit karışım, toprağın nem içeriği [18] ve yoğunluğu gibi özelliklerinin izlenmesini ve ayarlanmasını mümkün kılar. Karışımın partikül boyutu dağılımı (granülometrik analiz) ve pH değeri gibi kimyasal özellikleri, her deney döngüsü öncesinde kontrol edilmeli ve gerekirse yenilenmelidir [7].

2. Tahrik ve Hareket Sistemi

Uç demirinin toprak içinde doğrusal bir hareketle ilerlemesini simüle etmek en gerçekçi yöntemdir. Bu, Taber Linear Abraser'ın temel prensibine benzer şekilde, doğrusal bir hareketle ileri geri giden bir yatay kol veya taşıyıcı sistemi içermelidir [15]. Bu sistem, hız ve strok uzunluğu gibi parametrelerin ayarlanabilmesine olanak tanımalıdır [15]. Kaynağında belirtilen 2 ila 75 devir/dakika hız aralığı ve 0.2 ila 4.0 inç strok uzunluğu, bu tür bir sistemin ayarlanabilirlik kabiliyetine iyi bir örnek teşkil etmektedir. Alternatif olarak, büyük bir çembersel toprak havuzu içinde uç demirinin dönerek sürekli olarak aynı toprakla etkileşimini sağlayan bir düzenek de tasarlanabilir. Bu yöntem, deney süresini kısaltabilir ancak aletin hareket profili gerçek tarla koşullarına tam olarak uymayabilir. Her iki durumda da tahrik sistemi, aşınma testlerinin tekrarlanabilirliği için hızı ve mesafeyi hassas bir şekilde kontrol edebilmelidir.

3. Yükleme ve Ölçüm Sistemi

Düzenegin, uç demirine toprağın normal kuvvetini (yük) uygulayan ve bu kuvveti kontrol eden bir mekanizması olmalıdır. Taber Linear Abraser'daki "serbest yüzen" test sistemi prensibi, numunenin toprağın yüzey hatlarını takip etmesini sağladığı için bu düzeneğe adapte edilebilir [15]. Yük, ayarlanabilir ağırlıklar veya hidrolik/pnömatik bir piston ile sağlanabilir. Aletin topraktaki ilerleyişi sırasında maruz kaldığı çekiş direncini (sürtünme kuvveti) sürekli olarak ölçmek için bir yük hücresi sistemine entegre edilmelidir. Bu, aşınmanın artan çekiş direncine etkisini nicel olarak belirlemeye yardımcı olacaktır [3].

4. Numune Tutucu Tasarımı

Test edilecek kültivatör uç demiri, aletin tarla koşullarındaki gerçek çalışma derinliğini ve açısını taklit edecek şekilde özel olarak tasarlanmış bir tutucu ile düzeneğe monte edilmelidir. Taber Linear Abraser için kullanılan "T-slot table" ve "vice mounts" gibi genel tutucular [19] bu karmaşık geometrili aletler için yetersiz kalabilir. Bu nedenle, aletin şekline ve çalışma parametrelerine (derinlik, eğim açısı) uygun, sert ve sağlam bir tutucu sistemi tasarlamak ve üretmek zorunludur. Tablo 3'te önerilen laboratuvar düzeneginin temel bileşenlerini ve teknik özelliklerini verilmiştir.

Tablo 3. Önerilen Düzenegın Teknik Özellikleri

Bileşen	Önerilen Tip	Teknik Özellikler	Ölçüm ve Kontrol
Test Ortamı	Sentetik Toprak Havuzu	Kuvars kumu, kil, silt, su karışımı (ayarlanabilir nem içeriği ve granülometri).	Nem analizörü [18], hidrometre, elek analizi.
Tahrik Sistemi	Lineer Hareketli Kol	Hız ayarı (örneğin 2-75 devir/dakika) [15], strok uzunluğu ayarı (örneğin 0.2-4.0 inç) [15]	Entegre motor ve kontrol ünitesi.
Yükleme Sistemi	Serbest Yüzen Yükleyci	Ayarlanabilir normal kuvvet (örneğin 10-2100 gram) [15].	Ayarlanabilir ağırlıklar veya pnömatik sistem.
Ölçüm Cihazları	Yük Hücresi	Çekiş direncini (sürtünme kuvvetini) anlık olarak ölçme.	Dijital gösterge ve veri toplama sistemi.
Numune Tutucu	Özel Fikstür	Uç demirini doğru çalışma açısı ve derinliğinde sabitleme.	Sert çelik veya alüminyumdan özel üretim.

İ. Aşınma Ölçüm Yöntemleri ve Veri Analizi

Yüksek hassasiyetli bir aşınma analizi için tek bir ölçüm yöntemi yeterli değildir. Kapsamlı ve güvenilir sonuçlar elde etmek için, gravimetrik (kütle kaybı) ve boyutsal (geometrik değişim) yöntemlerin bir arada kullanılması önerilmektedir [20].

Gravimetrik (Kütle Kaybı) Yöntemi

Bu, aşınma kaybını ölçmek için en ekonomik ve en yaygın kullanılan yöntemdir [19]. Prosedür aşağıdaki adımları içerir:

- Ön Hazırlık:** Deneye başlamadan önce, kültivatör uç demiri numunesi yüzey hatalarından arındırılır, temizlenir ve pürüzsüz hale getirilir [21]. Ardından, 10^{-3} veya 10^{-4} hassasiyetli bir terazi kullanılarak numunenin başlangıç kütlesi hassas bir şekilde ölçülür [19].
- Test Sonrası Temizlik:** Belirli bir aşınma döngüsü tamamlandıktan sonra, numune test düzeneğinden çıkarılır. Yüzeyine yapışan toprak ve diğer kalıntılar, numuneye zarar vermeden, aseton gibi uygun bir çözelti ile tamamen temizlenir [20].
- Kütle Ölçümü:** Temizlenmiş ve kurutulmuş numunenin son kütlesi tekrar aynı terazi ile ölçülür. Başlangıç ve son kütle arasındaki fark, aşınma nedeniyle meydana gelen kütle kaybını verir. Bu değer, birim sürtünme mesafesi başına kütle kaybı (gr/km veya mgr/km) olarak ifade edilebilir [19]. Özgül aşınma miktarı ise, aşağıdaki (1) nolu denklem yardımıyla hesaplanabilir.

$$W_s = \frac{\Delta V}{F_n \cdot S} \quad (1)$$

Burada;

W_s : Özgül aşınma miktarı (mm^3/Nm) veya (m^3/Nm),

ΔV : Hacimsel malzeme kaybı (mm^3) veya (m^3),

F_n : Uygulanan normal kuvvet (N),

S : Aşınma mesafesini (m) [19].

J. Boyutsal Ölçüm Yöntemleri

Kültivatör uç demirlerinin işlevsel performansı, sadece kütle kaybıyla değil, aynı zamanda şekil ve boyut değişimleriyle de doğrudan ilişkilidir. Aletin burun kısmındaki ve kanatlarındaki aşınma, çekiş direncini ve toprak işleme kalitesini doğrudan etkiler [3]. Bu nedenle, sadece kütle kaybı ölçümleriyle yetinmek, aletin ne zaman “işlevsel özelliklerini kaybettiğini” anlamak için yeterli değildir [1].

Boyutsal ölçümler için “ızgara (grid) yöntemi” kullanılabilir [20]. Bu yöntemde, numunenin yüzeyi düzenli aralıklarla (örneğin 2 cm'lik bölümler halinde) bölünür. Dijital bir kumpas kullanılarak bu

bölümlerin genişliği ve kalınlığı test öncesi ve sonrası ölçülerek aşınma miktarları belirlenir [20]. Bu sayede, aşınmanın aletin hangi bölgelerinde en yoğun olduğu tespit edilebilir.

K. Yüzey Profilometri ve Gelişmiş Analiz

Daha derinlemesine bir analiz için, aşınma sonrası numunenin yüzey topografyasındaki değişiklikler 3D optik profilometri gibi gelişmiş tekniklerle incelenebilir [21]-[23]. Bu yöntem, yüzeydeki mikron düzeyindeki çiziklerin derinliğini ve genişliğini ölçerek, aşınma profilinin kantitatif bir analizini sunar [10]. Bu veriler, aşınma mekanizmalarını daha iyi anlamak ve farklı malzemelerin yüzey dirençlerini karşılaştırmak için değerli bilgiler sağlar. Tablo 4’de farklı aşınma ölçüm yöntemlerini karşılaştırmalı olarak verilmiştir.

Tablo 4. Farklı aşınma ölçüm yöntemlerini karşılaştırması

Yöntem	Ölçülen Parametre	Gerekli Ekipman	Avantajlar	Dezavantajlar
Gravimetrik	Kütle kaybı (ΔV)	Hassas terazi (10-3 veya 10-4 g)	Ekonomik, yüksek hassasiyetli sonuçlar sağlar [19].	Sadece toplam kütle kaybını gösterir, aşınmanın bölgesel dağılımını belirleyemez.
Boyutsal	Geometrik değişim (genişlik, kalınlık)	Dijital kumpas (mikrometre) [20]	Aletin işlevsel şekil değişimlerini nicel olarak belirler [6].	Ölçüm hataları daha yüksek olabilir, yüzeydeki mikro değişimleri ölçemez.
Yüzey Profilometri	Yüzey topografyası, profil	3D optik profil modülü	Aşınmanın mikro düzeydeki etkilerini inceler, çiziklerin derinliğini ölçer [10].	Yüksek maliyetli ve karmaşık bir ekipman gerektirir.

L. Örnek Bir Test Prosedürü ve İşletim Planı

Aşağıda, önerilen laboratuvar düzeneği ile gerçekleştirilebilecek tipik bir test prosedürü sunulmaktadır:

- Numune Hazırlığı:** Test edilecek kültüratör uç demiri numuneleri seçilir ve yüzeyleri temizlenir. Her numunenin başlangıç kütlesi, hassas bir terazi kullanılarak ölçülür. Numunenin kritik bölgelerindeki (burun, kanatlar) başlangıç boyutları (genişlik, kalınlık) bir dijital kumpas ile ölçülerek kaydedilir.
- Test Ortamının Hazırlığı:** Sentetik toprak havuzu, önceden belirlenmiş nem içeriği, yoğunluk ve granülometrik bileşime göre hazırlanır. Bu parametreler test öncesi bir nem analizörü ve elek analizi ile doğrulanır [18].
- Düzeneğin Kurulumu:** Uç demiri numunesi, numune tutucuya, tarla koşullarını taklit eden bir çalışma açısı ve derinliği ayarlanarak monte edilir. Yükleme sistemi aracılığıyla numuneye uygulanacak normal kuvvet belirlenir ve düzeneğin hareket hızı ayarlanır [15].
- Testin Yürütülmesi:** Düzeneğin tahrik sistemi çalıştırılarak test başlatılır. Test, belirlenen bir döngü sayısı veya mesafe için çalıştırılır. Test sırasında, entegre yük hücresi tarafından ölçülen çekiş direnci verileri sürekli olarak kaydedilir.
- Periyodik Veri Toplama:** Test, belirli aralıklarla (örneğin her 20 saatlik çalışma sonrası) durdurulur [20]. Numune düzeneğinden çıkarılır, temizlenir ve kütle ile boyutsal ölçümleri tekrarlanır. Elde edilen veriler kaydedilerek aşınma dinamikleri izlenir.
- Veri Analizi:** Tüm ölçüm verileri (kütle kaybı, boyut değişimi) ve çekiş direnci, tablo ve grafikler halinde düzenlenir. Farklı malzemeler veya kaplamalar arasındaki aşınma direnci karşılaştırılır. Daha az hacim kaybı, daha yüksek aşınma direncine eşittir [11]. Bu analiz, test edilen malzemelerin aşınma performansı hakkında net bir fikir verir.

II. SONUÇ VE ÖNERİLER

Bu çalışma, k ltivat r u  demirlerinin laboratuvar ortamında aşınma testlerinin nasıl ger ekleřtirileceğine dair kapsamlı bir  er eve sunmaktadır. Analizler, standart laboratuvar testlerinin (ASTM G65, Taber vb.) toprak iřleme aletlerinin karmařık aşınma mekanizmasını tam olarak sim le etmekte yetersiz kaldığını g stermektedir. Bu nedenle, Laboratuvar řartlarında ve tekrarlanabilir bir toprak ortamında aletin doęrusal hareketini taklit eden  zel olarak tasarlanmış bir d zeneęe ihtiya  vardır.

 alıřmada  nerilen d zeneğin, aletin ger ek i tribolojik sistem bileřenlerini (laboratuvar ortamında toprak, dinamik y k,  alıřma hızı) kontrol etme yeteneęi, aletin performansını artırmak i in farklı malzeme ve y zey kaplamalarını bilimsel bir temelde karřılařtırmaya olanak tanıyacaktır. En g venilir ve anlamlı sonu lar i in, sadece k tle kaybı deęil, aynı zamanda boyutsal deęiřim ve y zey topografisi gibi birden fazla  l  m y nteminin bir arada kullanılması  nerilmektedir. Bu  ok y nl  yaklařım, aşınmanın aletin iřlevsel  zelliklerini nasıl etkilediğini derinlemesine anlamayı m mk n kılacaktır.

Gelecekteki arařtırmalar i in, bu d zeneğin kullanımıyla ařaęıdaki  alıřmaların yapılması  nerilmektedir:

- Farklı sertliklerdeki ve kimyasal bileřimlerdeki malzemeler ( rneğin tungsten karb r, krom karb r) ile kaplamasız malzemelerin karřılařtırmalı aşınma testlerinin yapılması [11].
- Sentetik topraęın nem i erięi ve mineral bileřimi gibi parametrelerin aşınma hızı  zerindeki etkilerinin sistematik olarak incelenmesi.
- Laboratuvar ortamında elde edilen aşınma verilerinin, aynı malzemelerin ger ek tarla kořullarındaki performans verileriyle karřılařtırılarak bir korelasyon modelinin geliřtirilmesi olarak sıralanabilir.

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ELEKTROOKSİDASYON YÖNTEMİ İLE REAKTİF BOYALARDAN RENK GİDERİMİNDE pH ve SICAKLIK ETKİSİNİN ARAŞTIRILMASI

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Özet – Çok çeşitli endüstrilerde kullanılmakta olan reaktif boyaların arıtılması ve uzaklaştırılması alıcı ortam konusunda büyük bir önem taşımaktadır. Bu boyar maddelerin sudan uzaklaştırılması oldukça kritik bir konudur. Reaktif boyar maddeler, suda yüksek çözünürlükleri ve biyolojik olarak zor parçalanabilir özellikleri nedeniyle alıcı ortamlarda kalıcı kirliliğe yol açmaktadır. Bu durum, geleneksel arıtma yöntemleriyle renk gideriminin sınırlı kalmasına ve ileri arıtma teknolojilerine duyulan ihtiyacın artmasına neden olmaktadır. Bu çalışmada, elektrooksidasyon prosesi kullanılarak reaktif boyar madde içeren sulu çözeltilerden renk giderimi araştırılmıştır. Deneysel çalışmalarda, farklı sıcaklık (10, 25, 40 ve 55°C) ve pH (3, 5, 7, 9 ve 11) değerleri altında renk giderim verimi incelenmiş; ayrıca sistemin elektrik enerji tüketimi değerlendirilmiştir. Deneyler, 2000 mL hacimli ceketli cam reaktörde, Ti/IrO₂/RuO₂ anot ve paslanmaz çelik katot elektrotlar kullanılarak gerçekleştirilmiştir. Elektrotlar monopolar düzeneğe paralel bağlanmış, akım yoğunluğu 0,325 mA/cm² ve karıştırma hızı 200 rpm sabit tutulmuştur. Renk ölçümleri fotometrik yöntemle 420–470 nm dalga boyu aralığında yapılmıştır. Elde edilen bulgular, sıcaklık ve pH değişimlerinin renk giderim verimi üzerinde belirleyici olduğunu; düşük pH ve yüksek sıcaklık koşullarında daha yüksek verim sağlandığını göstermektedir. Ayrıca enerji tüketimi açısından optimum çalışma koşullarının belirlenmesi, elektrooksidasyon prosesinin sürdürülebilir atıksu arıtımında uygulanabilirliğini ortaya koymaktadır. Gelecekte yapılacak araştırmalarda farklı elektrot malzemelerinin kullanılması, kombine proseslerin denenmesi ve enerji maliyet analizi çalışmalarının yapılmasının prosesin sürdürülebilirliği açısından katkı sağlaması düşünülmektedir.

Anahtar Kelimeler – elektrooksidasyon, atıksu arıtımı, renk giderimi, reaktif boya, Ph, sıcaklık

1. GİRİŞ

Modern endüstrileşme süreci, daha fazla atık su oluşumuna yol açarak çevre üzerinde önemli baskılar oluşturmıştır [1]. Tekstil kaynaklı atıklar içerisinde yer alan reaktif boyar maddeler, aerobik koşullar altında neredeyse hiç giderilememekte ve anaerobik ortam koşullarında ise potansiyel olarak kanserojen aromatik aminlere parçalanabilmektedir [2]. Ayrıca, bu boyar maddelerin suda yüksek çözünürlüğe sahip olmaları, kimyasal koagülasyon yöntemleriyle uzaklaştırılmalarını önemli ölçüde güçleştirmektedir [3]. Boya atıksularının çevreye salımındaki iki kaynak tekstil işleme üniteleri ve boya imalat ünitelerinden kaynaklanmaktadır [4, 5]. Boyalar karmaşık aromatik yapıya sahiptir, bu sebeple parçalanması ve ayrılması zordur. Ek olarak, boyalar oldukça toksik ve kanserojendir [6, 7]. Tekstil endüstrisi, kağıt endüstrisi, gıda işleme ve boya imalatı gibi çeşitli endüstrilerde kullanılan boya çeşitleri bulunmaktadır [8]. Boyalar katyonik, anyonik ve noniyonik boyalar olarak kategorize edilebilir. Bunlar arasında katyonik boyalar, anyonik ve noniyonik boyalara kıyasla daha toksiktir, çünkü katyonik boyalar kolayca parçalanamaz ve tüm besin zincirinden geçebilir [9]. Son zamanlarda gerçekleştirilen çalışmalar, endüstriyel atıksuların arıtımında elektrokimyasal yöntemlerin geleneksel tekniklere kıyasla dikkate değer

bir alternatif oluşturduğunu ortaya koymuştur. Bu bağlamda elektrooksidasyon (EO) prosesi, atıksularda bulunan biyolojik olarak parçalanması güç kirleticilerin giderimine yönelik etkili ve yenilikçi bir yaklaşım olarak değerlendirilmektedir [10]. Arıtılmış atık sularda bulunan boyalar ve fenoller gibi organik ve toksik kirleticiler, genellikle doğrudan anodik oksidasyon süreçleriyle veya hidroksil radikalleri, ozon gibi güçlü oksidanların oluşumunu içeren dolaylı anodik oksidasyon mekanizmaları aracılığıyla giderilmektedir [11]. Elektrokimyasal reaksiyon, bir arayüz üzerinden yük transferini içeren kimyasal bir reaksiyon olarak tanımlanabilir. En yaygın bilinen yük transferi şekli, elektronların katı bir elektrot-sıvı elektrolit arayüzü üzerinden aktarılmasıdır. En basit haliyle, elektronlar elektrottan çözeltideki bir kimyasal maddeye aktarılabilir (redüksiyon) veya kimyasal maddeden oksidasyon yoluyla salınan elektronlar elektrot tarafından alınabilir. Bu genellikle Elektrokimyasal reaksiyon, katı elektrot-sıvı elektrolit ara yüzeyi üzerinden Denklem 1.1 elektronların aktarılmasıdır.



Burada, O ve R sırasıyla oksidan ve indirgeyicidir venarayüz üzerinden aktarılan elektron sayısıdır. Bu denklemden, yük transferinin (bu durumda, elektrot-elektrolit çözeltisi arayüzünden geçen elektronlar) kimyasal dönüşümleri (O'nin R'ye dönüşümü veya tersi) ifade ettiği açıktır [12].

Elektrooksidasyon teknolojisinin temel özellikleri aşağıda tablo olarak verilmiştir.

Tablo 1. Elektrooksidasyon teknolojisinin temel özellikleri [13]

Kullanım yerleri	Aktif oksijen türlerinin (OH radikalleri) üretimi, tuzlardan güçlü oksidanların üretimi, mikroorganizmaların inaktivasyonu, iki boyutludan üç boyutlu elektrotlara evrimin çok yönlülüğü, pH sınırlaması olmaksızın ve atık sudaki çeşitli organik kirleticilerin etkili arıtımı: (1) kimya endüstrisi, kağıt hamuru endüstrisi ve kağıt, petrokimya endüstrileri, ilaç endüstrileri, tekstil endüstrileri, deri endüstrileri, gıda endüstrileri, çöp sahası sızıntı suları; (2) tarım endüstrileri (zeytinyağı ve süt gübreleri) ve (3) belediye ve evsel atık su
Avantajları	Büyük hacimleri arıtmada çok yönlülük, otomasyon kolaylığı, iletkenliği artırmak için toksik olmayan reaktiflerin eklenmesi, biyolojik arıtma, Fenton oksidasyonu, iyon değişimi, membran filtrasyonu, membran biyoreaktörleri ve elektrokimyasal teknolojiler gibi diğer teknolojilerle birlikte atık suyun ön arıtımı veya son arıtımı olarak kullanılması
Dezavantajları/zorlukları	Halojen yan ürünlerinin oluşma potansiyeli, elektrot birikmesi ve korozyon olayları, yüksek enerji tüketimi nedeniyle yüksek işletme maliyetleri, düşük atık su iletkenliği, reaktör hidrodinamik koşullarının optimizasyonu ve pahalı elektrotlar

Elektrooksidasyon prosesi geleneksel arıtım yöntemlerine kıyasla sağladığı avantajlar nedeniyle pek çok endüstriyel atıksu arıtımında tercih edilmektedir. Bu bağlamda, bu çalışmada Reaktif Orange-13 boyar maddesinin elektrooksidasyon yöntemiyle atıksudan uzaklaştırılmasında sıcaklık ve pH değişimlerinin renk giderim verimine etkilerinin yanı sıra, enerji tüketiminin de araştırılması amaçlanmıştır.

II. MATERYAL VE YÖNTEM

Reactive Orange-13 boyasından 50 mg alınıp 500 mL kullanım suyunda çözündürülmüş ve 1000 mL kullanım suyu ile tamamlanarak stok boyar madde çözeltisi olarak kullanılmıştır.

A. Reaktif Boyanın Özellikleri

Reactive Orange-13 boyasının kimyasal formülü $C_{24}H_{15}ClN_7Na_3O_{10}S_3$ ve mol kütlesi 762.034 g/mol'dür. Reaktif Turuncu 13, kimyasal adı CI 15580 olan ve Metil Asetat International 13 olarak da

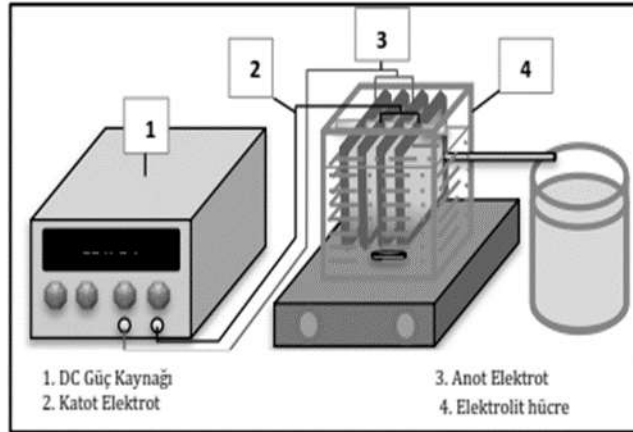
bilinen organik bir bileşiktir. Moleküler yapısı bir metil keton grubu ve bir benzen halkası yapısı içeren koyu turuncu ila kırmızı bir boyadır. Reaktif Orange 13 esas olarak tekstil boyaları ve pigmentleri olarak kullanılır. Tekstildeki hidroksil gruplarıyla birleşerek kovalent bağlar oluşturabilir, bu nedenle boyama sürecinde iyi bir haslığa sahiptir. Ayrıca Reaktif Orange 13, boyama, mürekkep, boya kalemleri ve plastik ürünlerde de yaygın olarak kullanılır.

B. Elektrooksidasyon düzeneği

Bu çalışmada elektrooksidasyon deneyleri, 2000 mL hacimli ceketli cam reaktör kullanılarak gerçekleştirilmiştir. Elektrotlar 70×100 mm boyutlarında olup, toplam yüzey alanı 3080 cm²'dir. Elektrot plakalarının yaklaşık ıslak yüzey alanı 2464 cm² olarak hesaplanmıştır. Anot elektrot olarak Ti/IrO₂/RuO₂ kaplı DSA tipi, katot elektrot olarak ise plaka biçimli paslanmaz çelik tercih edilmiştir. Reaktör içerisinde beş adet anot ve beş adet katot, monopolar bağlantı prensibiyle paralel olarak dizilmiş ve aralarındaki mesafe 5 mm olacak şekilde yerleştirilmiştir. Tüm elektrotlar, reaktör içerisindeki sentetik atıksu çözeltisine tamamen daldırılmıştır.

Voltaj ve akım değerlerinin kontrolü ile ölçümleri, dijital özelliklere sahip Control Unit PE280 marka güç kaynağı aracılığıyla yapılmıştır. Çözelti, deney süresince homojen karışımın sağlanabilmesi amacıyla Yellowline MST marka dijital manyetik karıştırıcı ile sürekli karıştırılmıştır. Reaktörün işletimi doğru akım güç kaynağı altında yürütülmüş olup, deney öncesinde başlangıç koşullarının belirlenmesi için pH, sıcaklık ve iletkenlik değerleri Thermo Orion marka çok parametrelili ölçüm cihazı ile tayin edilmiştir. Reaksiyon süresince sıcaklığın sabit tutulması amacıyla reaktör, harici bir soğutma sistemi ile desteklenmiştir.

Renk giderimi ölçümleri, 420–470 nm dalga boyu aralığında çalışan Lovibond marka fotometre kullanılarak gerçekleştirilmiştir. Bu deneysel düzenek kapsamında, elektrooksidasyon prosesi ile boyar madde içeren sentetik atıksuda pH, sıcaklık, iletkenlik, akım yoğunluğu, uygulanan voltaj ve renk parametrelerindeki değişimler sistematik olarak incelenmiştir.



Şekil 1. Elektrooksidasyon deney düzeneği

C. Deneyin yapılışı

Çalışmada gerçekleştirilen deney, 1 A sabit akım şiddeti, 200 rpm karıştırma hızı, 250 mg/L başlangıç boya konsantrasyonu ve 25 °C sabit sıcaklık koşullarında yürütülmüştür. Deneysel çalışmalar için hazırlanan 1000 mL stok çözeltiden, otomatik pipet yardımıyla 5 mL'lik numuneler alınarak plastik tüplere aktarılmıştır. Toplam deney süresi 60 dakika olarak belirlenmiş, bu süre zarfında başlangıç anı dahil olmak üzere 5., 10., 15., 20., 30., 45. ve 60. dakikalarda olmak üzere toplam sekiz numune alınmıştır.

Her bir numunede sıcaklık, iletkenlik ve pH parametreleri ölçülmüş, ardından renk tayini için numuneler 10 mL'lik cam tüplere aktarılmıştır. Böylece elektrooksidasyon sürecinde zamanla meydana gelen değişimlerin izlenmesi sağlanmıştır.

D. Hesaplama

Deneyler 0.325 mA/cm² akım yoğunluğunda 200 rpm karıştırma hızı, 250 mg/L başlangıç konsantrasyonu ve 25°C sıcaklıkta gerçekleştirilmiştir. 1000 mL stok çözeltiden 5 mL numune otomatik pipet ile alınarak tüplere aktarılmıştır. Toplam deney süresi 60 dakika olarak belirlenmiştir. Numuneler başlangıç (0), 5. dk, 10. dk, 15. dk, 20. dk, 30. dk, 45. dk ve 60. dk olmak üzere 8 adet alınmıştır. Alınan her numunenin sıcaklık, iletkenlik, pH değerlerine bakılıp 10 mL cam numune tüplerine alınarak renk tayini yapılmıştır.

$$\% \text{ Renk Giderim Verimi} = (C_o - C) / C_o * 100$$

Burada;

C_o: Giriş konsantrasyonu, mg/L

C: Çıkış konsantrasyonu, mg/L

% Renk Giderim Verimi

Verim: Kütlesel olarak sistemin verimidir.

Burada;

J: akım yoğunluğu mA/cm²

I: Akım Şiddeti mAmper,

A: Aktif anot yüzey alanı, cm²'dir.

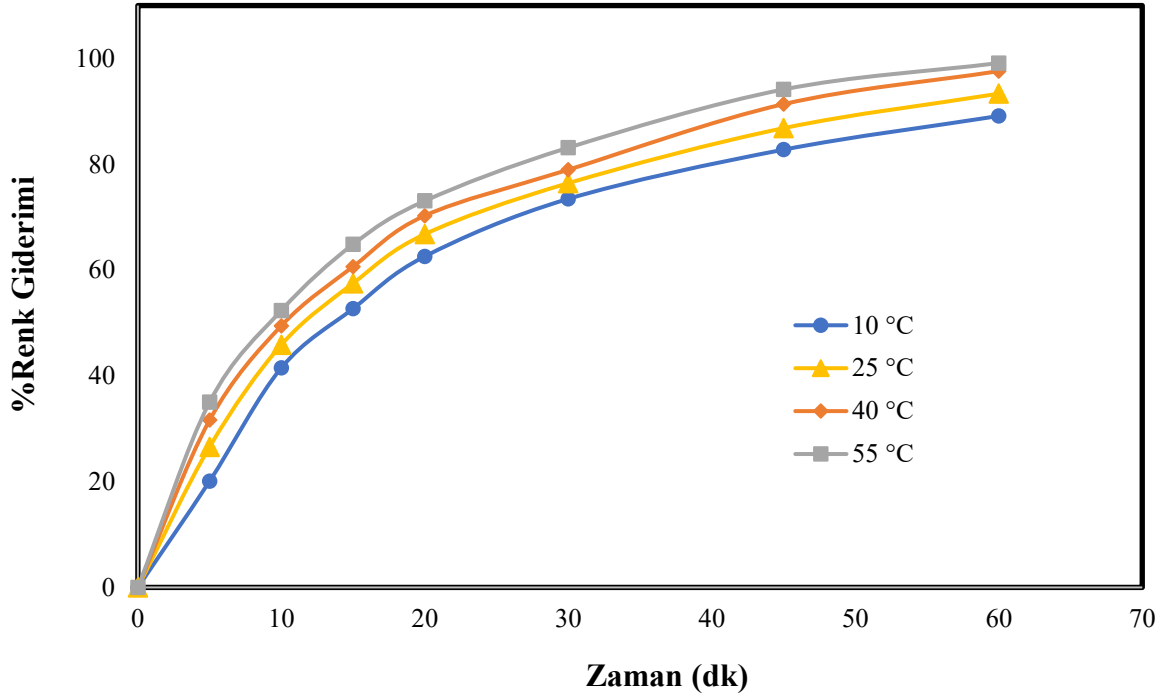
Enerji Tüketimi hesaplanırken;

$$J = I/A$$

III. BULGULAR

A. *Elektrooksidasyon Prosesinde Sıcaklığın Renk Giderimine Etkisi*

Sıcaklık, elektrooksidasyon sürecinde renk giderimini etkileyen önemli bir parametre olarak değerlendirilmektedir. Bu parametre yalnızca tek başına değil, aynı zamanda diğer işletim koşullarıyla da doğrudan ilişkilidir. Atıksu sıcaklığının artması, reaksiyon kinetiğini hızlandırarak arıtma süresinin kısılmasına katkı sağlamaktadır. Deneysel çalışmalarda sıcaklığın etkisini incelemek amacıyla, koşulların standardizasyonuna dikkat edilmiştir. Bu bağlamda pH değeri doğal aralıkta korunmuş, akım yoğunluğu 0,325 mA/cm² olarak sabitlenmiş, karıştırma hızı 200 rpm düzeyinde tutulmuştur. Ayrıca destek elektrolit konsantrasyonu 5 mM olarak belirlenmiş, destek elektrolit türü olarak NaCl tercih edilmiştir. Boyar madde başlangıç konsantrasyonu ise 250 mg/L olacak şekilde ayarlanmıştır.



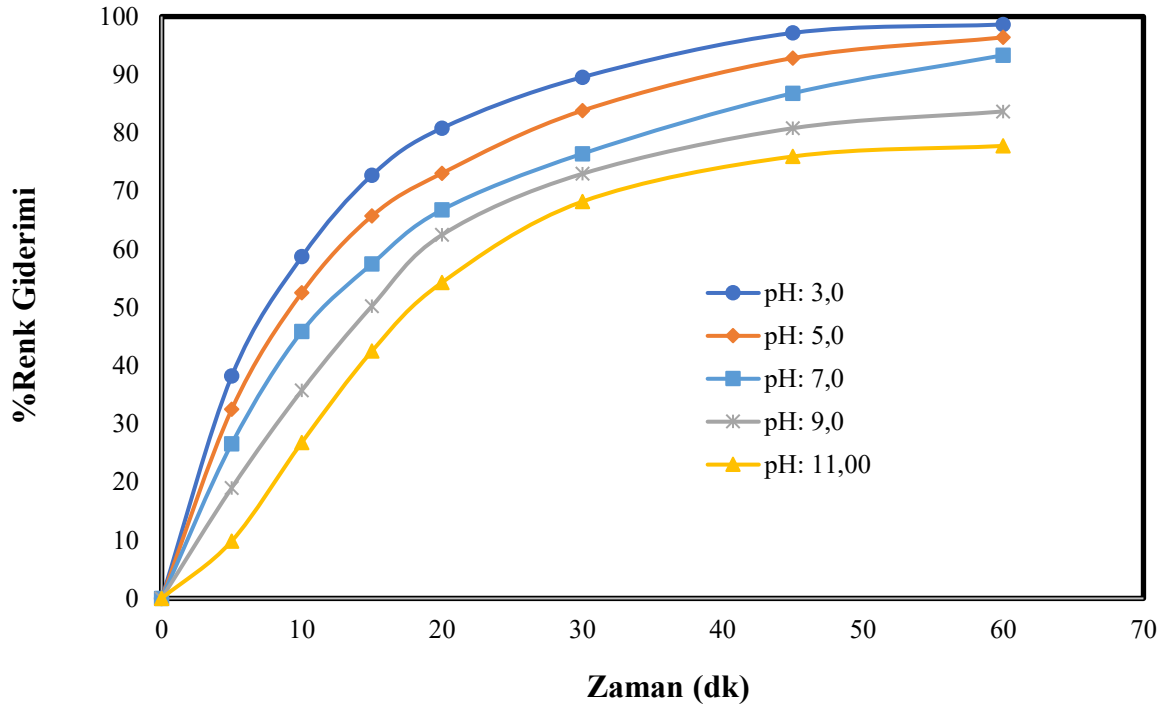
Şekil 2. Sıcaklığa bağlı olarak renk giderim verimi

Sıcaklığın renk giderim verimi üzerindeki etkisi Şekil 2’de sunulmaktadır. Bulgular, sıcaklık artışının renk giderim verimini anlamlı ölçüde artırdığını ortaya koymuştur. Çalışmada sıcaklık değerleri 10 °C, 25 °C, 40 °C ve 55 °C olarak seçilmiştir. Deney sonuçlarına göre, 10 °C’de renk giderim verimi %89,12 olarak belirlenmiştir. Atıksu sıcaklığı 25 °C’ye yükseltildiğinde verim %93,34’e ulaşmıştır. Daha yüksek sıcaklık koşullarında ise verim artışı daha belirgin hale gelmiş; 40 °C’de %97,61 ve 55 °C’de %99,13 oranında renk giderimi elde edilmiştir. Samuel ve diğerleri de yaptıkları çalışmada sıcaklığın elektrooksidasyon prosesi için önemli bir parametre olduğunu ve sıcaklık artışının prosesi olumlu yönde etkilediği sonucuna ulaşmışlardır [14].

Bu bulgular, sıcaklığın elektrooksidasyon sürecinde reaksiyon kinetiğini hızlandırarak arıtma performansını olumlu yönde etkilediğini göstermektedir.

B. Elektrooksidasyon Prosesinde pH Parametresinin Renk Giderimi Üzerine Etkisi

Başlangıç pH değeri (pH_i), atıksu içerisinde bulunan organik maddelerin yapısal özelliklerini doğrudan etkileyen kritik bir parametre olarak elektrooksidasyon (EO) sürecinde önemli bir rol oynamaktadır. Atıksuyun başlangıç pH seviyesindeki değişimler, farklı hidroksit türlerinin kararlılığı üzerinde belirleyici olup, bu durum organik bileşiklerin mineralizasyon sürecine hem olumlu hem de olumsuz yansımalar gösterebilmektedir [15]. pH’ın atıksu arıtımında reaksiyon hızını etkileyen başlıca faktörlerden biri olduğu görülmektedir. Çözelti ortamının asidik, nötr veya bazik özellik göstermesi, elektrokimyasal reaksiyonların seyrini ve dolayısıyla arıtım performansını doğrudan etkilemektedir. pH’ın renk giderim verimi üzerindeki etkisini incelemek amacıyla yapılan deneylerde, işletim koşullarının standardizasyonuna dikkat edilmiştir. Bu kapsamda akım yoğunluğu 0,325 mA/cm² olarak sabitlenmiş, karıştırma hızı 200 rpm olarak belirlenmiştir. Ayrıca destek elektrolit konsantrasyonu 5 mM olacak şekilde ayarlanmış, destek elektrolit türü olarak NaCl seçilmiştir. Boyar madde başlangıç konsantrasyonu 250 mg/L, sıcaklık ise 25 °C olarak sabit tutulmuştur. Elde edilen sonuçlar Şekil 3’te verilmiş olup, zaman içerisinde pH değerinin renk giderim verimi üzerindeki etkisini göstermektedir.

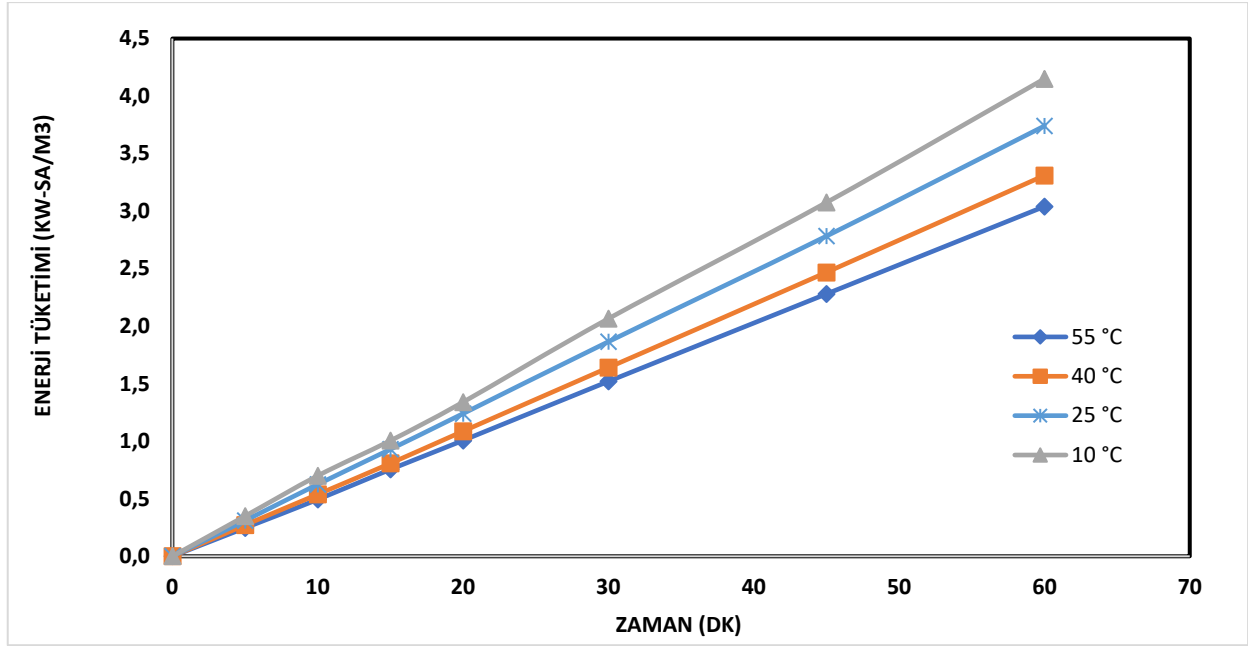


Şekil 3. pH parametresinin renk giderimine etkisi

Yapılan çalışmada farklı pH değerlerinin renk giderim verimi üzerindeki etkisi değerlendirilmiştir. pH = 3 koşullarında renk giderim verimi %98,65 olarak belirlenmiştir. pH = 5 seviyesinde bu oran %96,43'e, pH = 7'de ise %93,35'e düşmüştür. Daha bazik koşullarda ise verimliliğin azaldığı gözlemlenmiştir; nitekim pH = 9'da renk giderim verimi %83,70, pH = 11'de ise %77,78 olarak hesaplanmıştır. Bu sonuçlar, optimum renk giderim veriminin asidik koşullarda elde edildiğini ve pH yükseldikçe verimliliğin kademeli olarak azaldığını ortaya koymaktadır.

C. Elektrokimyasal Prosesinde Sıcaklığın enerji tüketimine etkisi

Sıcaklık elektrokimyasal proseslerde hem verimlilik hem de maliyet açısından önemli parametrelerden biridir. Atıksuyun sıcaklığının enerji tüketimi üzerindeki etkisinin incelendiği deneylerde, çalışma koşullarının standardizasyonu sağlanmıştır. Bu kapsamda, pH değeri doğal aralıkta tutulmuş, akım yoğunluğu 0,325 mA/cm² olarak sabitlenmiş, karıştırma hızı 200 rpm olarak belirlenmiştir. Ayrıca, destek elektrolit konsantrasyonu 5 mM, destek elektrolit türü NaCl ve boyar madde başlangıç konsantrasyonu 250 mg/L olacak şekilde ayarlanmıştır.

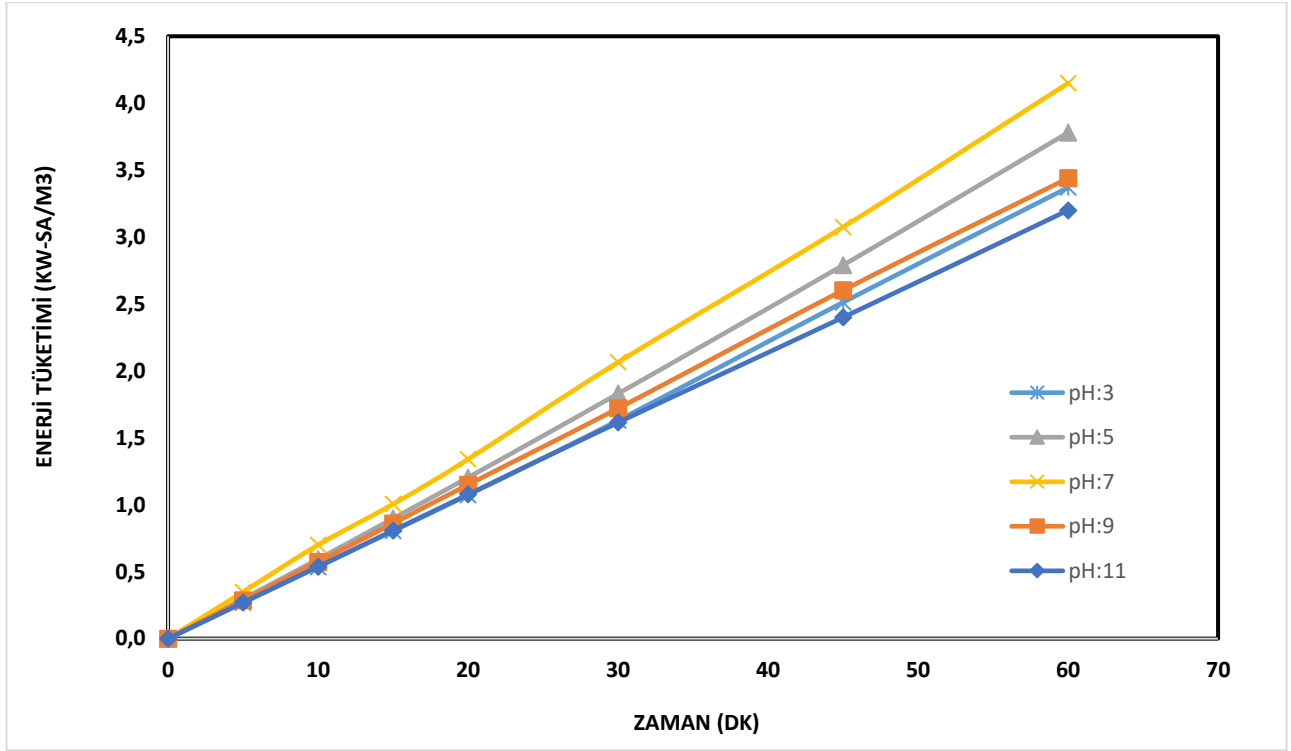


Şekil 4. Sıcaklığın enerji tüketimine etkisi

Yukarıda Şekil 4’te gösterildiği gibi sıcaklık arttıkça tüketilen enerji miktarı azalmaktadır. Sıcaklık değerleri arttıkça reaksiyon hızı artar. Giderimin fazla olduğu sıcaklık değerinde tüketilen enerji miktarı daha azdır. Yapılan çalışmada da araştırıldığı üzere sıcaklık değeri 55°C olduğu zaman aralığında enerji tüketim miktarı 3,16 kW-sa/m³ olarak belirlenmiştir. Atıksuyun sıcaklık değeri 40°C olduğu zaman diliminde tükettiği enerji miktarı 3,38 kWsa/m³ olarak bulunmuştur. Atıksu sıcaklık değeri 25°C olarak incelendiği zamanda enerji tüketim miktarı 3,81 kW-sa/m³ olarak tespit edilmiştir. Atıksu sıcaklık değeri 10°C olarak değerlendirildiği zaman skalasında enerji tüketim miktarı 4,33 kW-sa/m³ olarak hesaplanmıştır.

D. Elektrokoksiasasyon Prosesinde pH’ın enerji tüketimine etkisi

Grafik incelendiğinde, pH değerinin nötr olduğu koşullarda enerji tüketiminin en yüksek seviyeye ulaştığı görülmektedir. Deney sonuçlarına göre, atıksuyun pH = 11 olduğu durumda belirli zaman aralıklarında enerji tüketimi 3,20 kW·sa/m³ olarak belirlenmiştir. pH = 9 koşulunda enerji tüketim miktarı 3,44 kW·sa/m³ olarak elde edilmiştir. Atıksuyun pH = 7 değerinde gerçekleştirilen deneylerde enerji tüketimi 4,15 kW·sa/m³ olarak ölçülmüştür. pH = 5 koşulunda enerji tüketimi 3,78 kW·sa/m³ olarak hesaplanırken, pH = 3 değerinde yapılan deneylerde bu miktar 3,37 kW·sa/m³ olarak belirlenmiştir. Elde edilen veriler, elektrokoksiasasyon sürecinde pH’ın enerji gereksinimi üzerinde belirleyici bir etkiye sahip olduğunu ortaya koymaktadır.



Şekil 5. Ph'n enerji verimine etkisi

IV. TARTIŞMA

Bu çalışmada, elektrooksidasyon prosesi kullanılarak reaktif boyar maddelerin gideriminde sıcaklık, pH ve enerji tüketiminin etkileri incelenmiştir. Bulgular, prosesin performansının deneysel koşullara bağlı olarak önemli ölçüde değiştiğini göstermektedir.

Sıcaklığın renk giderimine etkisi değerlendirildiğinde, artan sıcaklıkla birlikte verimin yükseldiği gözlenmiştir. Bu durum, yüksek sıcaklıkların reaksiyon kinetiğini hızlandırarak radikal oluşumunu artırmasıyla açıklanabilir. Literatürde de benzer sonuçlar rapor edilmiştir; örneğin bor katkılı elmas (BDD) anot kullanılan çalışmalarda 50°C üzeri sıcaklıklarda yüksek renk giderim verimlerine ulaşılmıştır. Bu bulgu, çalışmamızdaki sonuçların literatürle uyumlu olduğunu göstermektedir.

pH parametresine ilişkin sonuçlar, elektrooksidasyonun asidik koşullarda daha etkin olduğunu ortaya koymuştur. pH=3 koşullarında elde edilen %98,65 verim, yüksek pH değerlerinde belirgin şekilde azalmıştır. Enerji tüketimi değerlendirmeleri, operasyonel koşulların yalnızca verimlilik değil, aynı zamanda prosesin sürdürülebilirliği açısından da kritik olduğunu göstermiştir. Yüksek sıcaklık ve düşük pH koşullarında daha kısa sürede yüksek giderim verimi elde edilmesi, enerji tüketimini azaltarak yöntemin ekonomik uygulanabilirliğini desteklemiştir. Bu durum, elektrooksidasyonun endüstriyel ölçekte uygulanabilirliğini artırabilecek önemli bir avantajdır.

Sonuç olarak, elde edilen bulgular elektrooksidasyon prosesinin reaktif boyar maddelerin arıtımında etkili bir yöntem olduğunu ve özellikle sıcaklık ile pH optimizasyonunun hem verimlilik hem de enerji tüketimi açısından belirleyici rol oynadığını göstermektedir. Ancak, farklı elektrot malzemeleri, gerçek atıksu örnekleri ve yan ürün analizleri üzerine yapılacak ileri çalışmalar, yöntemin çevresel ve ekonomik açıdan daha kapsamlı değerlendirilmesine katkı sağlayacaktır.

V. SONUÇLAR

Bu çalışmada, elektrooksidasyon prosesi kullanılarak reaktif boyar maddelerin renk gideriminde sıcaklık, pH ve enerji tüketiminin etkileri araştırılmıştır. Deneysel bulgular, prosesin etkinliğinin özellikle sıcaklık ve pH gibi operasyonel parametreler ile yakından ilişkili olduğunu ortaya koymuştur. Sıcaklık parametresi incelendiğinde, artan sıcaklığın reaksiyon hızını artırarak renk giderim verimini yükselttiği belirlenmiştir. 10°C'de %89,12 olan giderim verimi, 55°C'de %99,13'e ulaşmıştır. Bu durum, yüksek sıcaklıklarda elektrooksidasyon prosesinin daha hızlı ve verimli gerçekleştiğini göstermektedir.

pH'in etkisi değerlendirildiğinde, en yüksek renk gideriminin asidik koşullarda sağlandığı görülmüştür. pH=3 koşullarında %98,65 giderim elde edilirken, pH yükseldikçe verimin kademeli olarak azaldığı ve pH=11'de %77,78'e düştüğü tespit edilmiştir. Bu sonuç, elektrokoksiasyon prosesinin düşük pH değerlerinde daha etkin çalıştığını doğrulamaktadır.

Enerji tüketimi değerlendirmeleri, sıcaklık ve pH'in sadece renk gideriminde değil, aynı zamanda enerji verimliliğinde de belirleyici olduğunu ortaya koymuştur. Daha yüksek sıcaklık ve düşük pH koşullarında, kısa sürede yüksek giderim elde edilmesi enerji tüketiminin azalmasına katkı sağlamıştır.

Genel olarak, elektrokoksiasyon prosesi reaktif boyar maddelerin gideriminde etkin, güvenilir ve uygulanabilir bir yöntem olarak öne çıkmaktadır. Sıcaklık ve pH'in uygun aralıkta optimize edilmesi, prosesin hem verimlilik hem de enerji tüketimi açısından sürdürülebilirliğini artıracaktır.

TEŞEKKÜR

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Predicting the Surface Roughness of Cu/B-CrC Metal Matrix Composites Using Artificial Intelligence Model

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Abstract – The objective of this study is to predict the surface roughness values of copper matrix composites using an artificial intelligence model. For this purpose, Boron and Chromium carbide reinforcement particles were added to the copper matrix using the powder metallurgy method. The selected reinforcement particles were used to improve the mechanical and physical properties of copper. The reinforcement particles were added at specific ratios (0-5-10-15 wt%) and their effects on surface quality were investigated in detail. In addition, different cutting speeds (125-175 m/min) and feed rates (0.2-0.4 mm/rev) were selected as input parameters affecting surface roughness. The experimentally obtained surface roughness values were investigated using the Temporal Convolutional Network (TCN) artificial intelligence architecture. Since the TCN model has the ability to learn complex correlations in time-dependent and multivariate data, it can reveal the relationship between reinforcement ratios, surface quality, and cutting parameters with a high prediction rate. When the model performance was compared with statistical error rates and actual experimental results, a significant agreement was found between the measured results and the predicted results. The findings reveal that AI-based models can be safely used in the machinability of copper composites reinforced with reinforcement particles. Furthermore, the TCN architecture can be used as an effective tool in solving similar engineering problems.

Keywords – Cu/B-CrC Metal Matrix Composites, Predict, Surface Roughness, TCN, Artificial Intelligence.

I. INTRODUCTION

Copper (Cu), frequently used in industry, is preferred due to its high electrical and thermal conductivity, good formability, and corrosion resistance [1]. However, the low hardness of pure copper, its insufficient wear resistance, and loss of mechanical strength at high temperatures limit its use in many engineering applications [2]. Copper matrix composite materials have been developed to overcome these disadvantages. Copper composites are obtained by adding ceramic (Al₂O₃, SiC, B₄C, TiC, CrC, etc.), solid lubricant (graphite, MoS₂) or metallic (Ni, W, Ag) reinforcement phases to the copper matrix [3]. These additives improve copper's mechanical, tribological, and thermal properties, making it suitable for high-performance engineering applications [4]. Ceramic-based reinforcements generally increase hardness and wear resistance, while lubricating additives such as graphite reduce the coefficient of friction [5]. Methods such as powder metallurgy, sintering, mechanical alloying, and infiltration are commonly used in the production of copper matrix composites [6]. The powder metallurgy method is preferred, particularly because it ensures a homogeneous reinforcement distribution and has low production costs [7]. Copper composites find wide application in various industrial fields such as electrical brushes, sliding bearings, brake pads, high-temperature contacts, and aerospace components [8]. Today, new generation research such as hybrid reinforcement systems and artificial intelligence-based processability optimizations are being intensively pursued on these materials.

Compared to pure copper, reinforced copper composites are harder, have higher strength, and possess superior tribological properties [9]. Some ceramic reinforcements (such as Al_2O_3 , SiC , B_4C , CrC) cause cutting tool wear and increased cutting forces [10]. These unfavorable conditions lead to a decrease in surface quality, irregular chips, and increased costs [11]. The amount and size of reinforcing particles are quite important in workability [12]. High-hardness and coarse-grained reinforcements cause notch wear and micro-fractures on cutting tools, while low-ratio and fine-grained reinforcements exhibit better chip removal behavior. Additionally, machining parameters (cutting speed, feed rate, and chip depth) and cooling/lubrication conditions directly affect surface quality and tool life [13]. In recent years, hybrid reinforcements (e.g., lubricating additives such as graphite alongside hard ceramic phases) have been used to improve the machinability of copper composites, thereby reducing the friction coefficient and decreasing the load on cutting tools. Additionally, research has focused on predicting cutting parameters and determining optimal machining conditions using artificial intelligence-based optimization models (ANN, LSTM, TCN, etc.) [14]. The TCN architecture is based on convolutional layers, particularly using causal convolution and dilated convolution techniques [15]. The preservation of temporal causality demonstrates that output parameters depend solely on past inputs. The skip filtering applied to input data enables the extended convolution to learn long-term habits without requiring deeper networks. This allows the TCN architecture to effectively organize relationships in both the short and long term. Short training time, parallel computation, high prediction accuracy, and stable gradient flow make the TCN architecture advantageous. Time series prediction, signal processing, and fault diagnosis in engineering applications and production processes highlight the applicability of the TCN architecture.

In this study, metal matrix composite materials were produced by adding different weight fractions of reinforcement particles to pure copper. Predictions were made using the TCN artificial intelligence model to determine the surface quality of the produced composite samples.

II. MATERIALS AND METHOD

In a study we conducted in the past, detailed information was provided about the production and surface quality of copper composites reinforced with reinforcement particles [16]. This study creates a prediction model for surface roughness data using a deep learning architecture based on Temporal Convolutional Networks (TCN). Figure 1 shows the processing center and the samples produced.

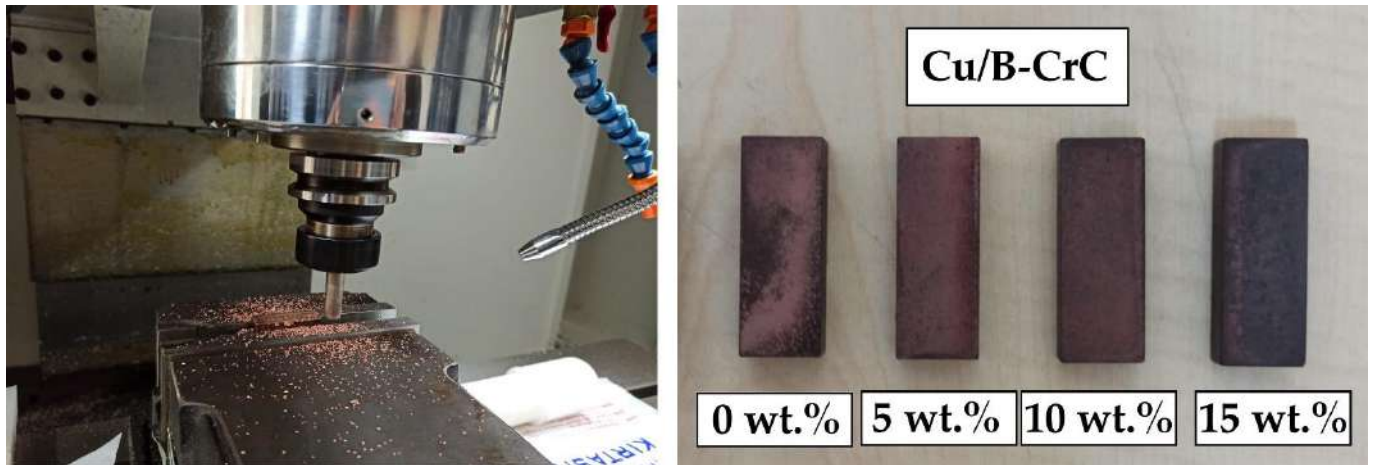


Fig. 1. Processing center and samples produced

The data set used contains surface roughness (R_a) measurements obtained from milling experiments conducted under different cutting parameters, covering a total of 324 different combinations. The experiment number was removed from the data, cutting speed, feed rate, and reinforcement ratio were determined as independent variables, and surface roughness was defined as the dependent variable. All data were scaled to the [0-1] range using the Min-Max normalization method to enable faster and more stable learning of the model, and then split into 80% training and 20% test data [17]. The flow chart is shown in Figure 2.

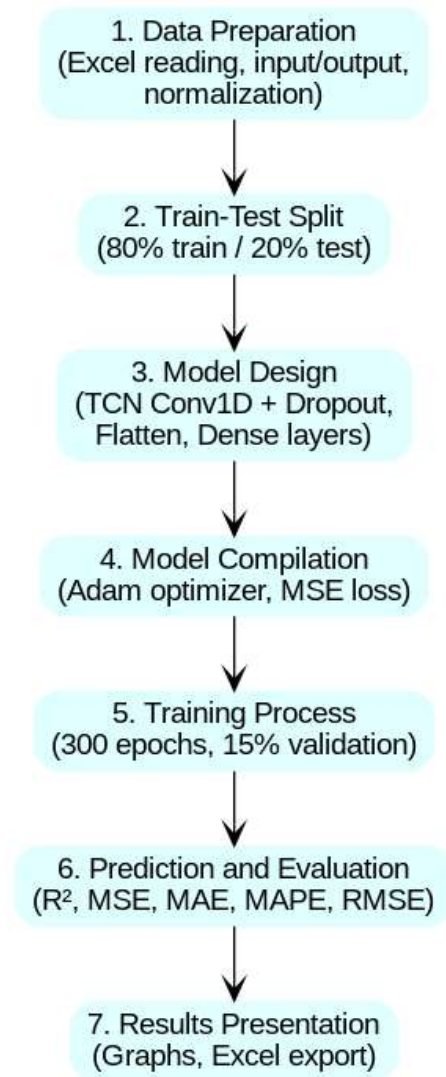


Fig. 2. Flowchart

III. RESULTS AND DISCUSSION

The graph shown in Figure 3 displays the loss values for both streams during the subsequent epochs of training. The X-axis represents the epoch count, while the Y-axis represents the loss. Generally, the two curves represent training and validation loss, respectively. However, the graph contains both blue (train) and red (test) curves; in some cases, these two curves represent the same data or may be average values obtained from multiple iterations/trials. Based on this, it is possible to divide the analysis into behavioral patterns and potential risks/areas for improvement. Initial sharp drop: A noticeable drop in losses is observed around epochs 1–5. This indicates that the weights are starting to learn quickly and the model is beginning to gain its basic representation capacity. Short-term fluctuations and red-green convergence: In the first few tens of epochs (e.g., 5–40 epochs), while the difference between test loss (red) and train loss (blue) is noticeable, short-term fluctuations may be observed. This may indicate a transient uncertainty in the model's generalization capacity or a period of mismatch with the data distribution.

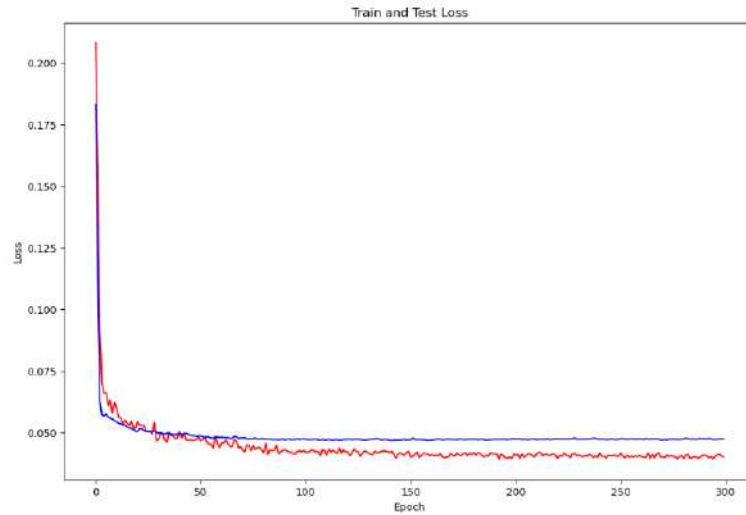


Fig. 3. The Dynamics of Training and Test Losses Over Time

Figure 4 shows a comparison between the surface roughness values predicted by the TCN model and the experimentally obtained observed values. The figure shows the relationship between the observed and predicted surface roughness values. The red dots represent the model's predictions, while the blue line indicates the ideal match with the observed values. The fact that the majority of the dots are distributed close to the reference line indicates that the model performs predictions with high accuracy. It was found that the surface roughness values in the 0–10 μm range are close to the observed data. However, some deviations are noticeable in roughness values of 15 μm and above. This indicates that the model may have limited generalization when used with data with high variance. Overall, it is seen that the TCN model can predict the surface roughness values of copper composites with a high accuracy rate. The model's R^2 value of 0.94 can be cited as evidence of a high level of fit. The low MSE (0.85) and RMSE (0.92) values support the closeness of the predicted values to the observed values. In particular, the MAE (0.65 μm) value indicates that the average absolute error amount is quite low and that the model's overall prediction errors are small. Furthermore, the MAPE being found to be 4.8% indicates that the model's predictions contain only low proportional deviations and proves that it is within acceptable error limits for industrial applications.

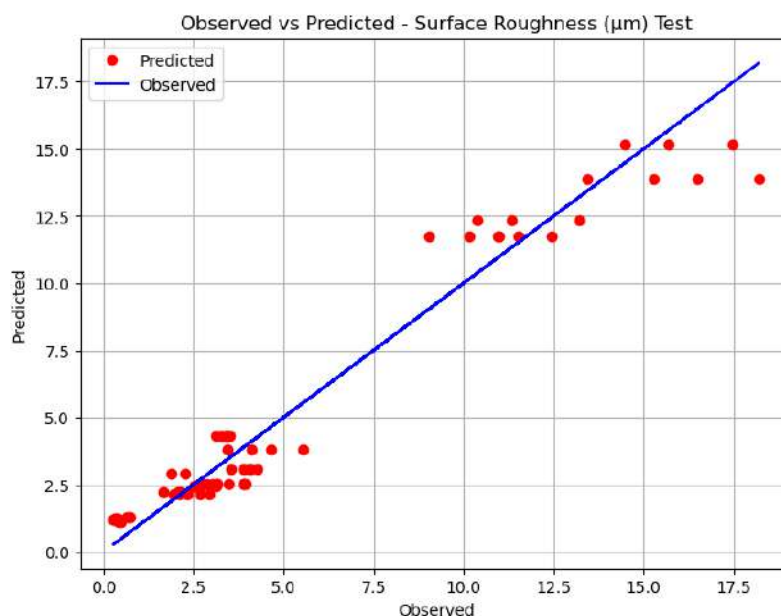


Fig. 4. Comparison of surface roughness values estimated from the TCN model with experimental observations

Figure 5 compares the surface roughness values observed according to test numbers (black line) and those predicted by the TCN model (red line). When the general trend is examined, it is seen that the model's predictions are quite consistent with the experimental data, and that fluctuations and sudden changes are largely captured correctly. The agreement between the predicted and observed values is particularly high in the test numbers ranging from 0 to 20 and from 40 to 60. However, partial deviations from the observed values occur in the predicted values at some points (e.g., 25–40 and after 60). These differences indicate that the model may lose accuracy in regions with high variance.

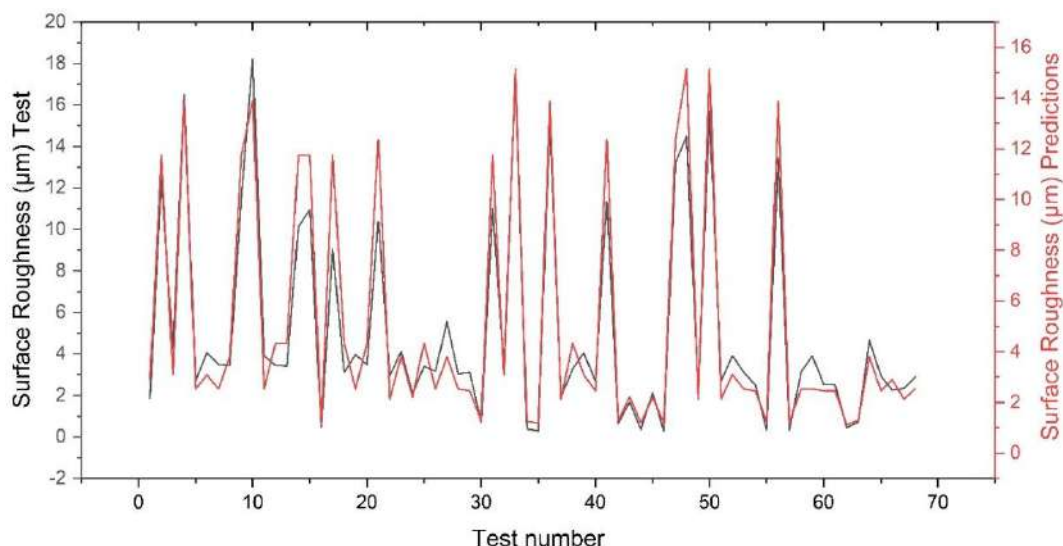


Fig. 5. Comparison of test results and prediction results

IV. CONCLUSION

In this study, hybrid composite materials were produced by adding reinforcement particles at different ratios into a copper matrix. Surface roughness estimates of the produced hybrid composites were predicted using the TCN architecture, and machinability tests were performed. As a result, when the obtained statistical performance indicators and graphical validation were evaluated together, it was determined that the TCN-based artificial intelligence model offered high reliability and accuracy in predicting surface roughness in copper matrix hybrid composites.

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Purpose-Based Analysis of Domestic Tourism Demand in Türkiye: Travel, Overnight Stays and Indexing Approach for the Period 2009–2024

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Abstract – The tourism sector is a strategically important area for economic growth and social interactions. This study examines domestic tourism movements in Türkiye for the period 2009–2024. Using data from the Turkish Statistical Institute (TURKSTAT), the study analyzed the number of trips, the number of overnight stays, and the average overnight stay on an annual basis, and further disaggregated them by holiday, visiting relatives, business, healthcare, and other purposes. Time-series graphs were created to visualize trends, and variables were indexed using 2009 as a base (2009=100). The findings indicate that domestic tourism in Türkiye is driven by family visits and leisure travel. The pandemic period (2020) led to a sharp decline in all indicators, but a recovery trend was observed in subsequent years. It was determined that despite its low volume, health tourism stands out with its long stays, while business travel remains limited. The study reveals both the economic and socio-cultural dynamics of tourism demand in Türkiye and offers strategic implications for tourism policies.

Keywords – Tourism Demand, Domestic Tourism, Travel Purpose, Overnight Stays, Index Analysis, Türkiye.

I. INTRODUCTION

The tourism sector is strategically important for many countries, providing economic growth, employment, and foreign exchange inflows [1]. Especially in developing economies, tourism is considered a factor that supports regional development and enhances the dynamism of the service sector [2]. Türkiye, with its natural, cultural, and historical riches, is a significant destination in global tourism, and tourism mobility plays a significant role in the country's development processes in terms of both its economic and socio-cultural impacts [3]. Indicators such as the number of trips, overnight stays, and average accommodations play a critical role in understanding both the magnitude of the economic contribution and visitor behavior in analyzing tourism demand [4]. Evaluating these indicators over time allows for the identification of long-term trends, structural breaks, and sectoral transformations [5], [6]. In particular, purpose-based travel segmentation (holiday, visiting relatives, business, health, etc.) makes it possible to understand not only the economic but also the socio-cultural dimensions of tourism [7].

One of the most significant disruptions in global tourism in recent years has been the COVID-19 pandemic. The pandemic sharply limited international and national travel, leading to an unprecedented decline in tourism demand [8], [9]. In Türkiye, 2020 tourism data also indicate a dramatic contraction in both travel and overnight stays [3]. However, recovery trends after 2021 demonstrate the tourism sector's relative resilience to crises [10], [11], [12].

This study aims to examine domestic tourism movements in Türkiye between 2009 and 2024. The study analyzes the annual number of trips, overnight stays, and average overnight stays based on specific purposes. Furthermore, an indexing method is applied using 2009 as a base. This approach assesses both long-term trends and the impact of external shocks such as pandemics on tourism. This approach aims to

contribute to the literature by revealing both the quantitative magnitudes and behavioral differences in tourism demand.

II. MATERIALS AND METHOD

This study examined domestic tourism activity in Türkiye for the period 2009–2024. The primary data for the study was obtained from the Tourism Statistics datasets published by TURKSTAT [3]. The data consisted of annual statistics on the number of trips, the number of overnight stays, and the average overnight stay. Additionally, subseries disaggregated by travel purpose (holiday, visiting relatives and friends, business, health, other) were included in the analysis.

Initially, descriptive statistical methods were applied during the analysis process, and annual data were visualized graphically to reveal trends. This type of time-series analysis is frequently used to reveal changes and breaking points in tourism demand [5], [6].

In the second stage, the data disaggregated by travel purpose was examined separately, and it was observed that visiting relatives and vacation trips were particularly decisive. This approach allows for the assessment of tourism demand not only at the aggregate level but also with its behavioral and socio-cultural dimensions [1], [4].

Subsequently, the indexing method was used, with 2009 (2009=100) used as the base year. This method allows for the comparison of relative changes in different variables (number of trips, number of overnight stays) on the same scale. Indexing is an important technique that makes long-term trends and shock effects visible in the tourism economy [2], [7]. The Python programming language was used for data visualization and analysis; specifically, the pandas library was used for data processing, and the matplotlib library was used for graphic production [13], [14].

In conclusion, the materials and methods section of this study is based on official statistical institute data. It was constructed on the basis of descriptive analyses on an annual basis and an indexing approach according to 2009. Thus, the long-term course of both volumetric and purpose-based differences in tourism demand was revealed in a holistic manner.

III. RESULTS

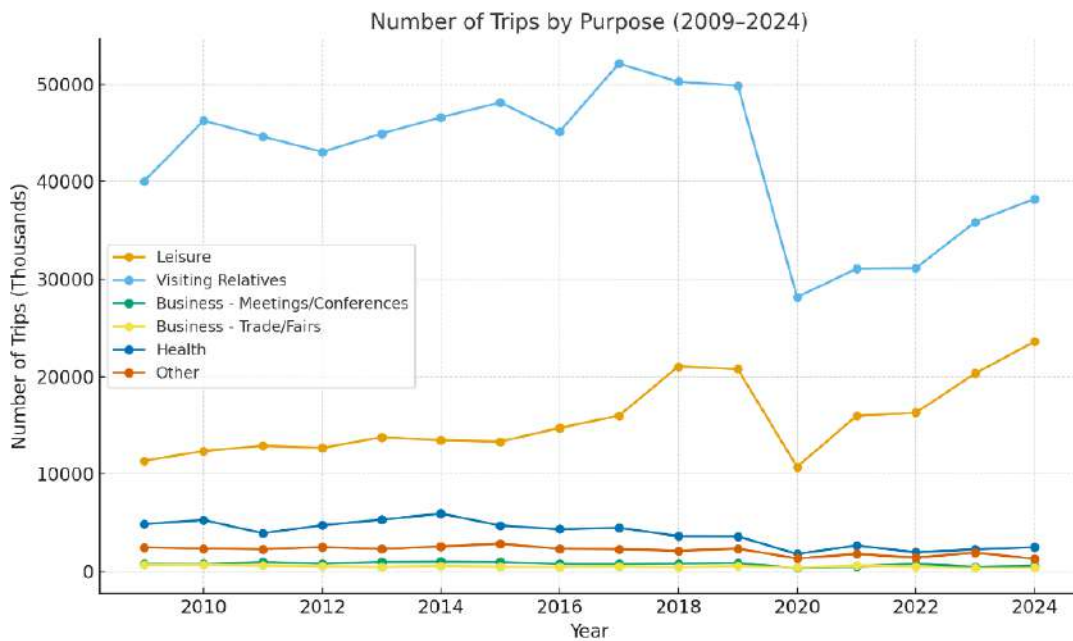


Fig. 1 Number of Trips by Purpose

According to Figure 1, travel figures by purpose between 2009 and 2024, it appears that trips to visit relatives and friends accounted for the largest share by far. These trips peaked at over 50,000 in 2017, declined below 30,000 in 2020 due to the pandemic, and then partially recovered in subsequent years. Leisure travel ranks second, showing a gradual increase from 2009 onward, reaching 20,000 in 2018, experiencing a sharp decline in 2020, and rising again to 23,000 by 2024. Health tourism, while relatively low in volume, hovered around 5,000 between 2009 and 2015, but fluctuated in the post-pandemic period. Business travel (meetings, conferences, trade fairs, etc.) remained quite low, generally below 2,000. Travel for other purposes also remained low and remained largely unchanged throughout the period. Generally, visiting relatives constitutes the largest portion of domestic travel in Türkiye, while the share of leisure travel has increased over time, while business and healthcare travel has remained relatively limited.

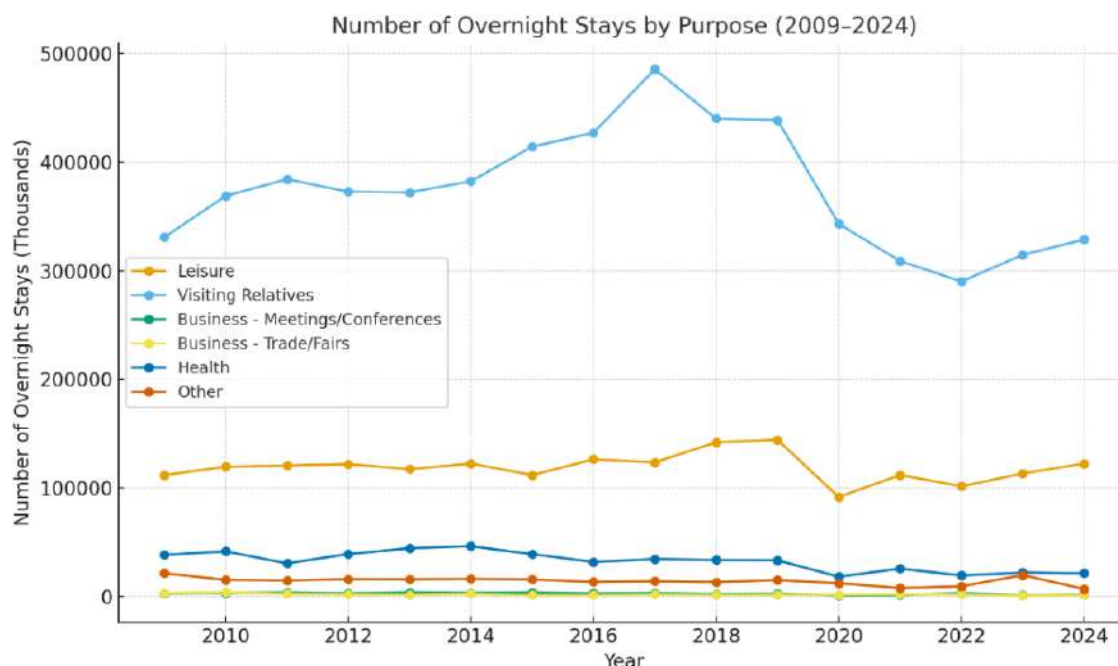


Fig. 2 Number of Overnight Stays by Purpose

Figure 2 illustrates that total overnight stays by travel purpose for the period 2009–2024, it is seen that trips to visit relatives and friends were clearly the most popular, reaching a peak of approximately 480,000 overnight stays in 2017. This type of travel experienced a significant decline in 2020, the year of the pandemic, but partially recovered in the following years. Vacation travel ranks second, fluctuating between 100,000 and 150,000 overnight stays. While on an upward trend in 2019, it experienced a sharp decline in 2020 and then began to rise again after 2021. Although health tourism has a relatively small share, it showed an upward trend in the mid-2010s and experienced fluctuations, particularly during the pandemic period. Business travel (meetings, conferences, fairs, etc.) remained at very low levels, rarely exceeding 20,000 overnight stays during the 2009–2024 period. Travel for other purposes remained modest, generally ranging from 10,000 to 20,000 overnight stays. Overall, the chart shows that overnight stays in Türkiye are driven by family visits and leisure travel, while business and health tourism remain relatively low.

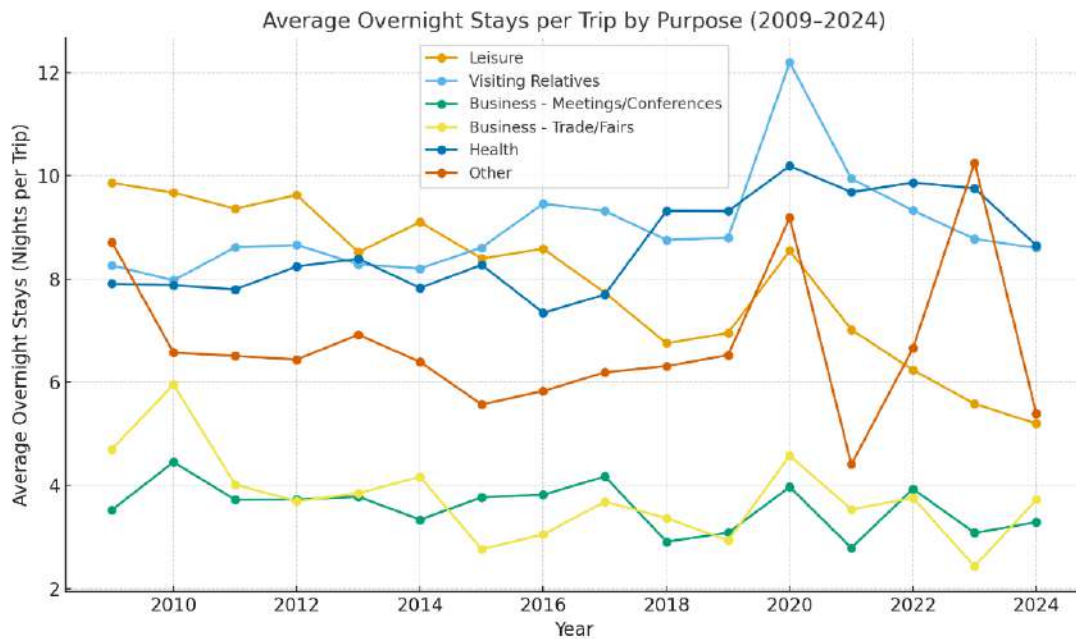


Fig. 3 Average Overnight Stays per Trip by Purpose

As shown in Figure 3, average overnight stays by travel purpose for the period 2009–2024, it is seen that leisure travel had the longest average stays, generally ranging between 8 and 10 nights. It is understood that leisure travel remained stable, particularly in the pre-pandemic period, but increased significantly in 2020, exceeding 9 nights. Travelers visiting relatives and friends had an average overnight stay of 3–5 nights and were notable for their relatively shorter stays. For business travel (meetings, conferences, trade fairs, etc.), the average stay remained stable at 3–4 nights, confirming that business travel is generally short-term. Health tourism, on the other hand, reached its highest level in 2020 (exceeding 12 nights) and remained around 9–10 nights in subsequent years, demonstrating that healthcare travel increased both for longer periods and during the pandemic. While other travel purposes remained stable at around 6–7 nights, they experienced a temporary surge in 2022. Overall, the graph demonstrates varying accommodation behaviors based on travel purposes, and the pandemic's pronounced impact on health tourism and leisure travel in particular.

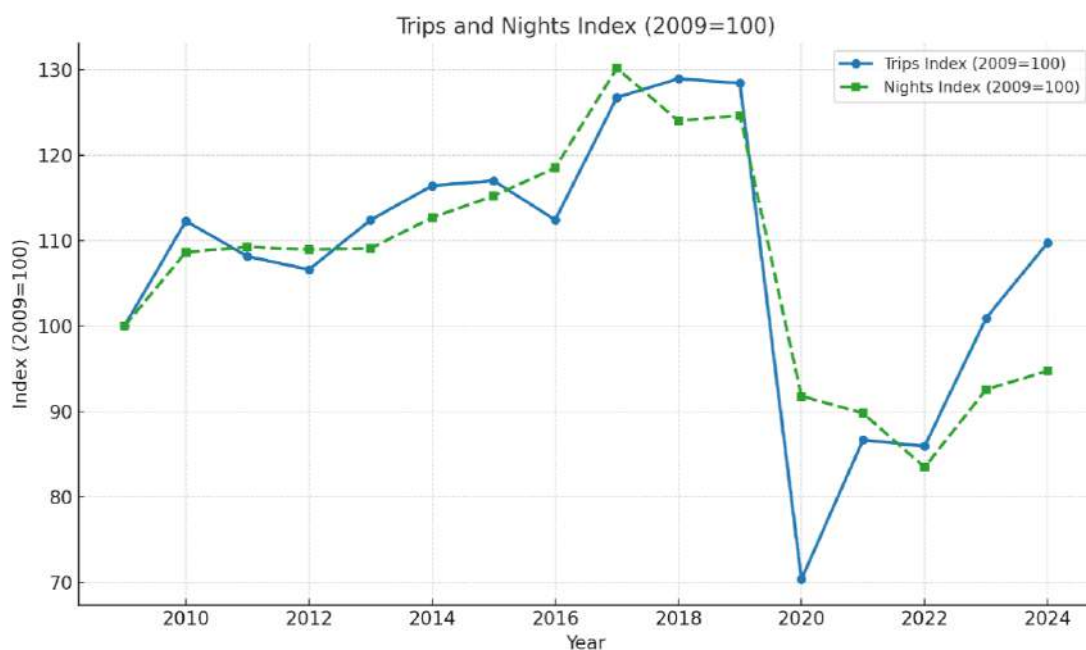


Fig. 4 Trips and Nights Index

The index chart in Figure 4, based on 2009, reveals the changes in tourism travel and overnight stays in Türkiye over the years. An examination of the chart reveals that both the travel and overnight stay indices exhibited a gradual upward trend throughout the 2010s, reaching their highest levels in 2019. In 2020, due to the impact of the COVID-19 pandemic, both indices experienced a dramatic decline, with the number of trips, in particular, falling well below 2009 levels. However, recovery began in 2021, and by 2024, index values were back above 2009. This demonstrates that despite the pandemic shock, Turkish tourism maintains its long-term growth trend.

IV. DISCUSSION

Findings from the 2009–2024 period reveal that domestic tourism demand in Türkiye exhibited significant fluctuations in both volumetric and behavioral dimensions. The gradual increase in travel and overnight stays observed in the 2010s suggests that tourism maintained its growth trend. However, 2020, due to the impact of the COVID-19 pandemic, created a sharp rupture in all indicators, with both travel and overnight stay indices falling well below the 2009 base year. This finding aligns with the literature demonstrating the high vulnerability of tourism to crises [8], [15]. However, the recovery process that began after 2021 indicates that the tourism sector has demonstrated long-term resilience [10].

Based on the distribution of trips by purpose, trips to visit relatives and friends are the determining factor in both total travel and total overnight stays. This demonstrates that strong family ties and social relationships are a key driver of tourism mobility in Türkiye. Travel for leisure purposes comes second, showing an upward trend, particularly after 2015. Despite experiencing a sharp decline during the pandemic, it began to rise again by 2024. This situation aligns with studies demonstrating the structural flexibility of tourism demand [4], [7]. While business travel remains low, health tourism exhibits a notable characteristic in terms of average length of stay. The fact that the average stay for health-related travel exceeded 12 nights during the pandemic demonstrates the diverse dynamics of this sector [16], [17].

Average overnight stay data also varies significantly depending on the purpose of travel. While longer stays of 8–10 nights are prominent in leisure travel, visiting relatives averaged around 3–5 nights. Business trips had the shortest stays (3–4 nights), confirming that business trips are generally short-term and functional. These findings support literature that emphasizes the need to examine tourism demand not only quantitatively but also in terms of behavioral diversity [1], [2].

V. CONCLUSION

This study examined domestic tourism movements in Türkiye between 2009 and 2024 in terms of the number of trips, the number of overnight stays, and the average length of stay. The findings point to several important conclusions. First, while there is a long-term growth trend in tourism, extraordinary circumstances such as pandemics can sharply disrupt this trend [9]. Second, travel to visit relatives and for leisure purposes plays a decisive role in both travel and overnight stays. Third, while business travel remains low, travel for healthcare purposes is strategically important due to the length of stay.

These results offer several strategic recommendations for tourism policies. Encouraging leisure travel, in particular, is crucial for increasing tourism revenues [2], [17]. Health tourism stands out as an area requiring development due to its longer length of stay and its greater resilience to crises. Furthermore, the high share of trips to visit relatives highlights the importance of shaping tourism infrastructure to support not only commercial but also sociocultural dynamics [1], [15]. Consequently, this study demonstrates that the different dimensions of tourism in Türkiye require a holistic analysis and that policymakers should develop strategies that consider both the economic and social aspects of tourism.

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Serological evidence of Caprine Arthritis Encephalitis Virus (CAEV) in goats from the North-West region of Albania

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Abstract – This investigation focused on evaluating the occurrence of caprine arthritis encephalitis (CAE) in goats from the North-West region of Albania, specifically from the Shkodër and Lezhë districts. The disease, caused by caprine arthritis encephalitis virus (CAEV), represents a chronic viral condition that produces long-term inflammatory lesions and contributes to notable economic losses in goat farming. Although CAE does not pose a zoonotic risk, systematic surveillance and preventive strategies remain crucial, underlining the importance of screening goat populations across Albania. For this purpose, serological testing was performed using the Maedi-Visna/CAEV Ab ELISA assay, which detects antibodies specific to CAEV. A total of 143 goats randomly sampled from 7 herds, were examined to estimate infection prevalence. The analysis showed that 22.4% of the animals were seropositive. The results indicate limited serological evidence of CAEV circulation within this region.

Keywords – Caprine Arthritis Encephalitis, Seroprevalence, Shkodër, Lezhë, Albania.

I. INTRODUCTION

Caprine Arthritis Encephalitis (CAE) is a chronic viral disease affecting goats, caused by the Caprine Arthritis Encephalitis Virus (CAEV), a member of the genus Lentivirus within the family Retroviridae [1]. The infection is lifelong and may remain subclinical for extended periods. Clinical manifestations include encephalomyelitis in kids and progressive arthritis in adult animals. Other signs commonly observed are mastitis, pneumonia, and reduced body condition [2], [3].

As a notifiable disease recognized by the World Organization for Animal Health (WOAH), CAE has significant economic consequences in affected regions. Infected goats typically produce lower milk yields, and the milk often exhibits reduced fat, protein, and lactose content along with elevated somatic cell counts, compromising both quality and market value [4], [5], [6], [7]. Furthermore, the presence of CAEV can restrict international trade and the exchange of genetic material, limiting access to breeding programs and animal germplasm [8], [9].

Understanding the prevalence and distribution of CAEV at both herd and regional levels is essential for implementing effective control measures and safeguarding goat health and productivity.

II. MATERIALS AND METHOD

Blood samples were collected from goat herds located in the North-West region of Albania, comprising four herds from the Shkodër district and three herds from the Lezhë district. A total of 143 goats were randomly selected for sampling across these herds. Blood was drawn from the jugular vein into 10 mL vacutainer tubes. The samples were subsequently centrifuged at 3,000 rpm for 5 minutes, and the separated sera were stored at -20°C until further analysis.

Serological testing for CAEV was performed using the MVV/CAEV Indirect ELISA kit (IDvet, France), which allows for the detection of antibodies against both Maedi-Visna Virus (MVV) and Caprine Arthritis Encephalitis Virus (CAEV). The assay is based on antigenic peptides derived from the transmembrane proteins (TM) of MVV/CAEV, specifically gp135 and p25.

Interpretation of results was conducted according to the manufacturer's instructions: samples with an S/P ratio $\geq 60\%$ were considered positive, those with S/P $\leq 50\%$ were considered negative, and samples with an S/P ratio between 50% and 60% were classified as doubtful.

III. RESULTS

Blood samples collected from 7 randomly selected herds in the North-West region of Albania, specifically from 3 herds in Lezhë and 4 herds in Shkodër districts, were tested for the presence of antibodies against SRLV using the Indirect ELISA method. Out of the 143 goats tested, 2 were found seropositive in Shkodër district and 30 in Lezhë district. The seroprevalence was 3.3% in Shkodër and 52.6% in Lezhë. The overall seroprevalence for the North-West region was 22.4% (95% CI: 15.6–30.8) (Table 1).

Table 1. The ELISA serological results for CAE seroprevalence in North-West Region of Albania.

District	Negative (N)	Negative (%)	Positive (N)	Positive (%)	Prevalence (%)	95% CI*
Shkodër	84	96.7	2	3.3	3.3	0.4-11.5
Lezhë	27	47.4	30	52.6	52.6	38.8-66.0
North-West Region	Negative (N)	Negative (%)	Positive (N)	Positive (%)	Prevalence (%)	95% CI*
	111	78.3	32	22.4	22.4	15.6-30.8

*The 95% confidence interval for the overall prevalence was estimated using the exact binomial method (Clopper–Pearson)

Serological testing for Caprine Arthritis Encephalitis Virus (CAEV) using ELISA revealed seropositive animals in 2 out of the 7 goat herds included in the study. This corresponds to a between-herd prevalence of 28.6%, while the overall individual-level seroprevalence was 22.4%, indicating that although only a subset of herds was affected, the infection is present in different geographical locations within the North-West region of Albania. Notably, one herd in Lezhë showed a very high within-herd prevalence (100%), while another herd in Shkodër presented a moderate level of infection (13.3%). All other herds tested negative. These findings highlight a heterogeneous distribution of CAEV among herds in the study area (Table 2).

Table 2. Within-herd serological results of CAE prevalence in goat herds from the North-West Region of Albania.

	Herd Size	No. of tested animals	No. of positive	Within-herd Prevalence%
Herd 1 (LE)	> 10	15	0	0.0
Herd 2 (LE)	> 10	12	0	0.0
Herd 3 (LE)	> 10	30	30	100.0
Herd 4 (SH)	> 10	20	0	0.0
Herd 5 (SH)	> 10	15	2	13.3
Herd 6 (SH)	> 10	30	0	0.0
Herd 7 (SH)	> 10	21	0	0.0
Total (7 herds)		143	32	22.4

IV. DISCUSSION

The present study contributes new insights into the epidemiology of CAEV in north-western Albania, focusing on the Shkodër and Lezhë districts. The overall seroprevalence was estimated at 22.4%, confirming that the virus is circulating in these areas and may represent a potential challenge for goat health and farm productivity. While this prevalence lies within the spectrum of previously reported values in the country, it remains lower than some of the highest figures published. For instance, [10] described 92% seroprevalence in a herd from Fushë-Krujë, while [11] documented values between 23.1% and 57.1% in Korçë. In the same region, [12] found 42.8%, whereas [13] and [14] reported 38.46% in Lezhë and 33.33% in Dibër, respectively. Such findings clearly show that CAEV is widely present across multiple Albanian regions, although the intensity of infection is highly variable.

Analysis at the district level revealed marked differences. In Shkodër, the seroprevalence reached 3.3% (95% CI: 0.4–11.5%), whereas in Lezhë it was considerably higher, at 52.6% (95% CI: 38.8–66.0%). Despite this apparent contrast, the overlapping confidence intervals suggest that the difference should be interpreted cautiously, as it may not represent a true statistical distinction. When combined, the data from both districts resulted in a regional prevalence of 22.4% (95% CI: 15.6–30.8%), which provides a more reliable overall estimate and reflects the variability observed within each district.

At the herd level, 2 of 7 herds (28.6%) were found to include seropositive animals, indicating that roughly one-third of herds in this region harbored infected goats. However, the distribution was uneven: within-herd prevalence ranged from moderate infection levels (13.3% in one Shkodër herd) to very high values (100% in one Lezhë herd). Most herds (71.4%) tested entirely negative, highlighting the patchy nature of infection and suggesting that CAEV is not yet endemic across all herds in northern Albania. The variability between and within herds is consistent with international findings. Previous studies have emphasized that transmission dynamics are strongly influenced by management practices, such as whether kids are allowed to suckle from adults, the adoption of individual feeding practices, herd size, and biosecurity strategies [15], [16]. The relatively modest levels of within-herd prevalence observed here may therefore reflect certain preventive practices that limit direct kid-to-doe contact and reduce the likelihood of viral spread.

Between-herd prevalence of 22.4% is consistent with values reported in Mediterranean countries with non-intensive goat production systems, where seroprevalence typically ranges between 10% and 30% [17], [18]. This finding suggests that although CAEV is present in Shkodër and Lezhë, it has not yet spread extensively across the regional goat population. Importantly, the identification of infected herds provides a valuable opportunity to apply control measures, including the segregation of positive animals, regular testing of replacement stock, and improvements in herd-level biosecurity [19].

Overall, the study highlights a distribution pattern characterized by focal clusters of infection within a minority of herds, while the majority remain negative. This focality is typical of regions where biosecurity is unevenly applied and inter-herd contact is limited [16]. Detecting such clusters is essential, since undetected positive herds may serve as hidden reservoirs and contribute to further spread. Continued surveillance, combined with targeted management interventions, will therefore be crucial to prevent CAEV from becoming more widespread in northern Albania. These findings provide an important epidemiological baseline and reinforce the need for coordinated national control strategies in Albanian goat populations.

V. CONCLUSION

This study represents the first comprehensive assessment of CAEV seroprevalence in goats from the Shkodër and Lezhë districts of north-western Albania. The overall prevalence was estimated at 22.4%, confirming the circulation of the virus in these areas. Importantly, the results revealed substantial heterogeneity: seroprevalence was higher in Lezhë compared to Shkodër, and within-herd prevalence ranged from entirely negative herds to one herd in which all tested animals were seropositive.

The focal distribution of infection indicates that CAEV is present but not yet endemic across all herds. These findings underscore the need for herd-level biosecurity measures, early detection strategies, and targeted management interventions, including the segregation of seropositive animals and the careful

monitoring of replacement stock. Overall, this study establishes a baseline for CAEV epidemiology in north-western Albania. Continued surveillance and targeted control strategies are essential to limit the spread of infection, reduce economic losses, and safeguard the health of goat populations in the region.

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Prediction of Tribological Behavior of Powder Metallurgy Cu/B-CrC Hybrid Composites via LSTM Models

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Abstract – The wear behavior of sintered materials is mostly studied experimentally, making it difficult to thoroughly understand the complex relationships between process parameters and tribological responses. To address this shortcoming, a study developed an LSTM-based deep learning model to predict weight loss, wear rate, and friction coefficient based on sintering and friction parameters. The input variables for the model were sliding distance, applied load, sliding speed, sintering time, and sintering temperature. The data were normalized using the StandardScaler method and divided into 80% training and 20% test epochs. The model was trained with a three-layer LSTM architecture for 300 epochs. According to the results, the model achieved high accuracy ($R^2 = 0.975$ and 0.982) for the weight loss and wear rate parameters, while slightly lower performance for the friction coefficient parameter ($R^2 = 0.802$). This difference is attributed to the sensitivity of the friction coefficient to surface topography and microstructure. This study demonstrates that deep learning techniques can reliably predict wear behavior, as an alternative to classical approaches based on experimental data. This architectural design, based on the prediction model, is highly significant in terms of tribological performance. It is also noteworthy that the use of artificial intelligence can also be applied in machinability applications.

Keywords – Hybrid Metal Matrix Composites, Prediction, Tribology, LSTM, Deep Learning.

I. INTRODUCTION

Products developed using advanced materials such as aluminum (Al), copper (Cu), magnesium (Mg), nickel (Ni), and titanium (Ti) — especially when these materials form the main matrix — are generally referred to as metal matrix composites (MMCs) [1]. These composites are gaining increased attention due to their superior mechanical strength and tribological properties, which make them highly suitable for demanding applications [2]. Among these materials, copper and its alloys stand out in recent literature as preferred matrix components [3]. In fact, when hard reinforcement particles are incorporated into copper-based matrices, the resulting composites can exhibit significantly enhanced strength and wear resistance [4]. Copper composites are particularly valued in sectors such as electronics and electrical engineering. [5, 6]. However, their usefulness extends far beyond those fields, finding applications in medical devices, railway systems, heat exchangers, and even aerospace components thanks to their high-performance characteristics [7]. In recent years, a growing number of studies have also explored the use of artificial intelligence — particularly models such as Long Short-Term Memory (LSTM) networks — to predict wear behavior in these composites. These predictive approaches aim to reduce testing costs and help optimize manufacturing conditions [8].

In this research, the primary goal is to use AI-based modeling to estimate the wear performance of a copper-matrix composite under varying conditions.

II. MATERIALS AND METHOD

This study presents a plan that shares the production stages and experimental data previously presented [9]. Experimental data were obtained under standard test conditions and cleaned of potential measurement errors prior to recording. Preprocessing steps were applied to the data, and input and output variables recorded in different units were normalized using the StandardScaler method. Thus, each parameter was transformed so that its mean was zero and its variance was one, eliminating the model's sensitivity to variables on different scales. The dataset was then split into training and test sets, randomly selected to be 80% training and 20% test. The training and test data were reshaped to suit the operation of LSTM networks. An LSTM-based deep learning model was used for prediction. The model consisted of three consecutive LSTM layers, each with 64 neurons. ReLU was selected as the activation function, and Dropout was applied at a rate of 15% after each layer to prevent overfitting. The return sequences=True parameter was used in the first two LSTM layers to preserve temporal dependencies, while the last LSTM layer was configured to produce a one-dimensional output. The output layer consists of a fully connected layer with three neurons that simultaneously predict the WL, WR, and CF values. The model was trained using the Adam optimization algorithm with a learning rate of 0.001, and MSE was set as the loss function. The training process was performed with 300 epochs and a batch size of 16. The entire data processing, modeling, and evaluation process was performed within a single, integrated code structure in the Python environment. All steps, from data entry to result visualizations, are summarized in the flow chart shown in Figure 1.

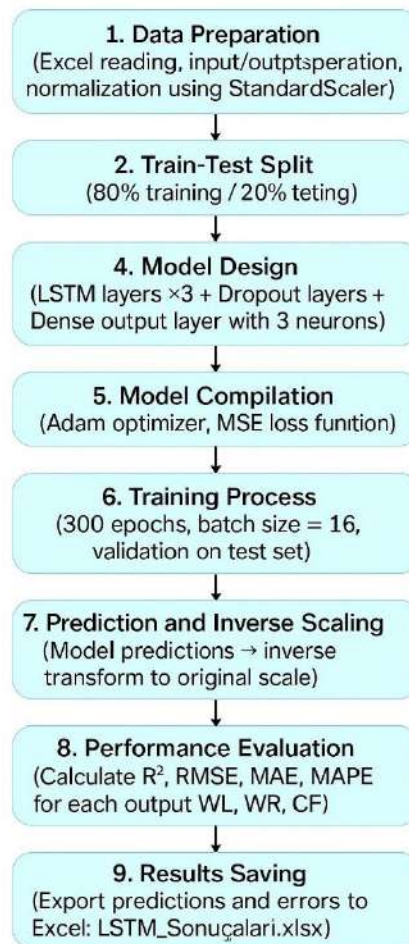


Fig. 1. Flow diagram

III. RESULTS AND DISCUSSION

When examining the results related to the model's training and validation losses (Figure 2), it is observed that the training loss rapidly decreases after approximately the 40th epoch and reaches a stable level, while the validation loss, despite being high initially, gradually decreases in subsequent epochs. In particular, the fact that the training and test curves run close to each other from the 100th epoch onwards indicates that the model has kept the overfitting problem under control [10]. This finding demonstrates that the LSTM architecture used was able to successfully learn the relationships between the input and output parameters in the wear test data.

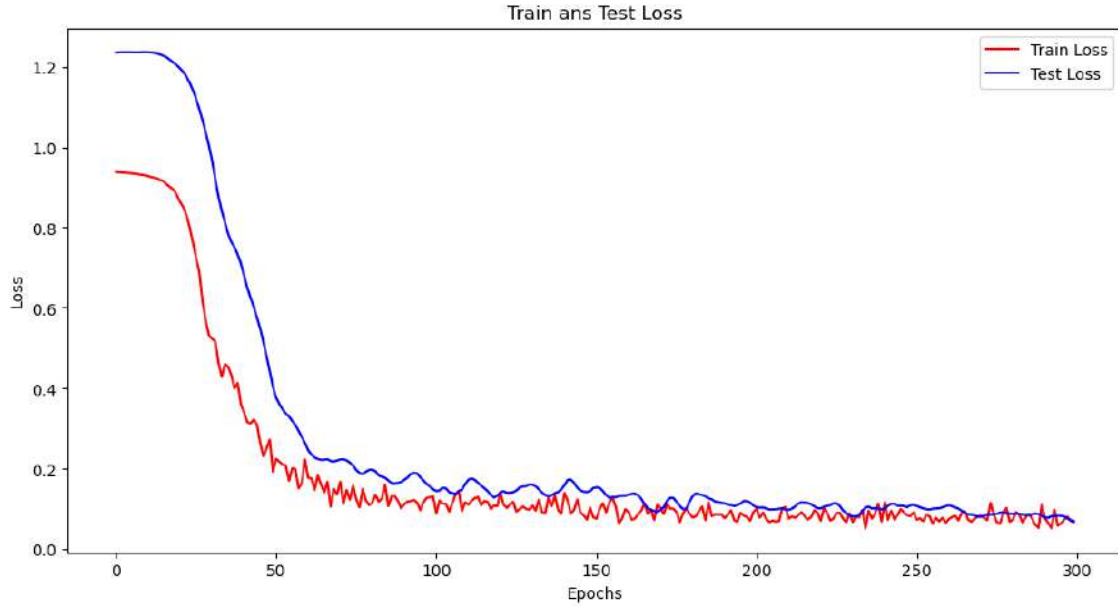


Fig. 2. The Dynamics of Training and Test Losses Over Time

The results obtained in weight loss (WL) predictions (Figure 3) show that the model can predict experimental data with high accuracy. Very low error rates such as RMSE = 0.00181, MAE = 0.00161, and MAPE = 8.39% reveal that the LSTM model can accurately capture the WL parameter. The R^2 value of 0.975 proves that the model explains approximately 97% of the experimental variance. This shows that the model is highly reliable even for parameters that vary within low value ranges, such as WL.

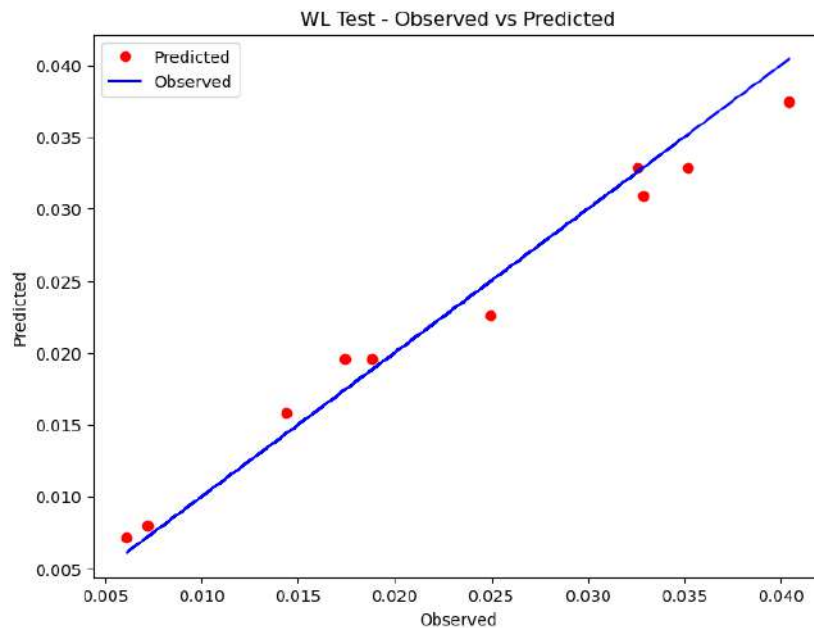


Fig. 3. Comparison of weight loss values estimated from the LSTM model with experimental observations

Wear rate (WR) prediction results also demonstrate strong performance (Figure 4). Although $RMSE = 1.25$ and $MAE = 1.01$ appear relatively high, this difference is acceptable considering the scale of the WR parameter. In particular, the low percentage error expressed as $MAPE = 6.40\%$ and the $R^2 = 0.982$ result indicate that the model reflects WR changes with high accuracy. The fact that the experimental and predicted values are clustered almost on a 1:1 linear line demonstrates that the model has a very strong generalization ability for the WR parameter [11].

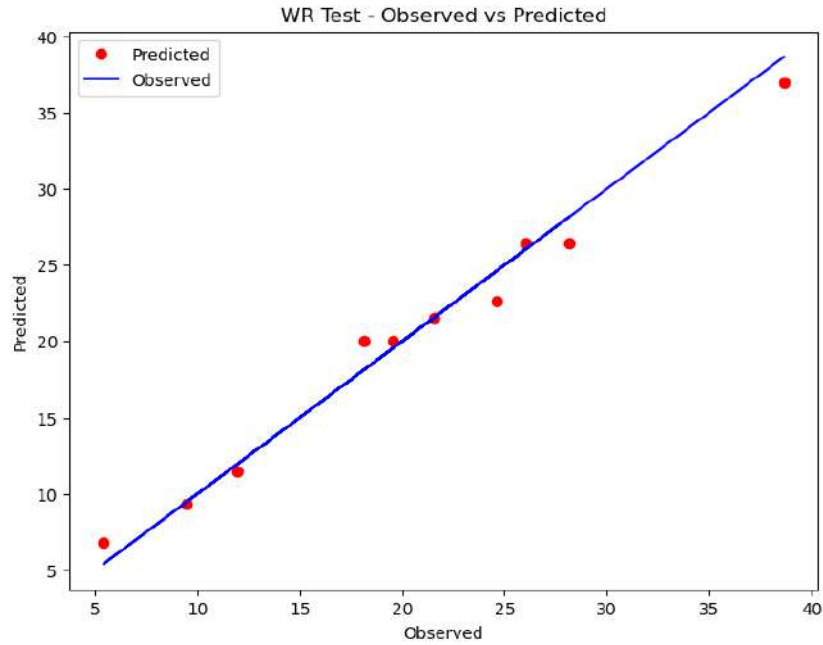


Fig. 4. Comparison of wear rate values estimated from the LSTM model with experimental observations

The results obtained for the coefficient of friction (CF) were relatively weaker compared to the other two parameters (Figure 5). Although the values $RMSE = 0.0307$, $MAE = 0.0269$, and $MAPE = 3.89\%$ are within acceptable error limits, the $R^2 = 0.802$ level indicates that the model's variance explanation power is limited in the CF parameter. The main reason for this is that the friction coefficient is sensitive to experimental conditions, and small changes can lead to large proportional differences. Nevertheless, the general trend in the distribution between the predicted and observed values is correctly reflected.

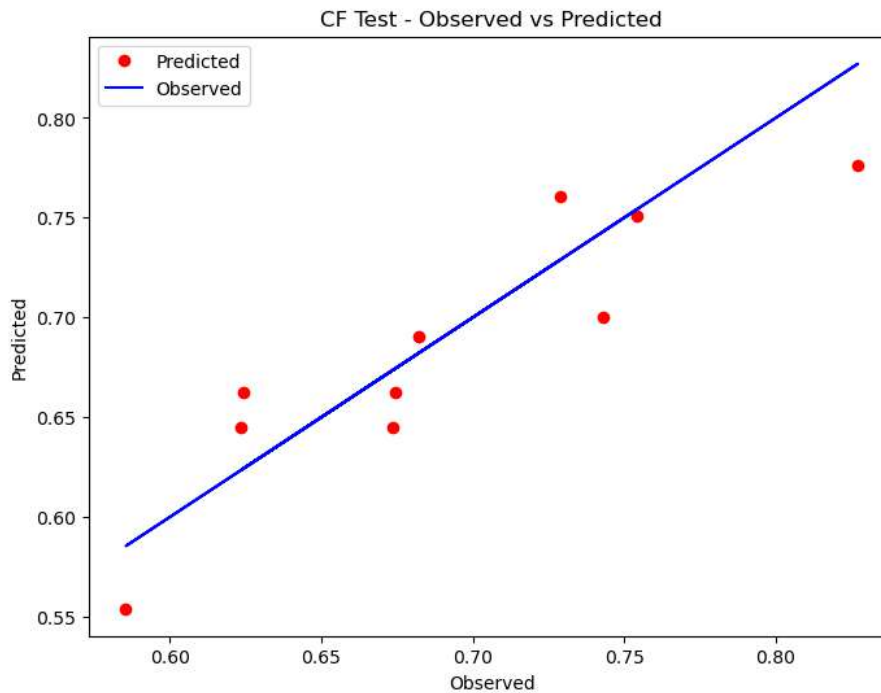


Fig. 5. Comparison of coefficient friction values estimated from the LSTM model with experimental observations

IV. CONCLUSION

Overall, it can be stated that the LSTM-based model yields highly accurate results in wear test data, particularly for the WL and WR parameters, while demonstrating acceptable performance for the CF parameter. The model's high R^2 values and low error rates demonstrate that tribological parameters can be reliably predicted using deep learning-based methods. These findings have the potential to contribute to predictive maintenance and optimization strategies in production processes, particularly in terms of early prediction of tool wear and modeling of friction behavior.

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BIM Modelleri ile Gerçek İnşaat Verileri Arasındaki Metraj Uyuşmazlıklarının Analizi: Revit ile Sonradan Modellenmiş Yapı Elemanları Üzerine Bir Durum Çalışması

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Özet – Bu çalışma, Autodesk Revit yazılımı ile oluşturulan bir BIM (Yapı Bilgi Modellemesi) modeli üzerinden, sahadan elde edilen gerçek metraj verileriyle karşılaştırmalı bir analiz sunmaktadır. Araştırma kapsamında, daha önce BIM süreci işletilmeden tamamlanmış bir yapının dijital modeli sonradan oluşturulmuş; bu model aracılığıyla elde edilen metraj çıktıları, inşa sürecinde kaydedilmiş saha metraj verileriyle karşılaştırılmıştır. Özellikle duvar tuğlası ve sıva gibi temel yapı bileşenlerinde, Revit'in yüzey alanı (m²) temelli hesaplama yöntemi ile sahadaki adet (birim) temelli ölçümler arasında belirgin farklılıklar gözlemlenmiştir. Elde edilen bulgular, modelde kullanılan yapı birimlerinin türü, model detay seviyesi (Level of Development- LOD) ve geometrik tanımların, metraj doğruluğu üzerinde doğrudan etkili olduğunu ortaya koymaktadır. Çalışma ayrıca, Türkiye'de BIM uygulamalarının mevcut durumu ve geleceğine ilişkin değerlendirmeler de sunmaktadır. 11 Mart 2025 tarihinde güncellenen Planlı Alanlar İmar Yönetmeliği ile, bina yaşam döngüsüne ait verilerin dijital ortama aktarılması ve ruhsat süreçlerinin BIM tabanlı olarak yürütülmesi zorunlu hale getirilmiştir. Bu yasal düzenlemeyle birlikte, Türkiye'de dijitalleşmeye yönelik önemli bir dönüşüm başlamıştır. Bu bağlamda, BIM modelleme ile sahadan elde edilen veriler arasında yapılacak uyumluluk analizleri, teknik ve organizasyonel düzeyde karşılaşılabilecek sorunları önceden öngörmek açısından kritik önem taşımaktadır. Özellikle veri dönüşüm katsayılarının belirlenmesi, uygulama detaylarının dijital ortama doğru şekilde aktarılması ve modelin güncellik düzeyi gibi unsurlar, zorunlu BIM uygulamaları çerçevesinde dikkate alınması gereken temel parametrelerdir. Sonuç olarak, bu çalışma yalnızca mevcut bir uygulamayı analiz etmekle kalmayıp; aynı zamanda politika yapıcılar ve uygulayıcılar için modelleme standartlarının geliştirilmesi, birimsel veri uyumunun sağlanması ve süreç boyunca doğrulama mekanizmalarının kurulmasına yönelik somut öneriler sunarak literatüre ve sektörel dönüşüme katkı sağlamaktadır.

Anahtar Kelimeler – Yapı Bilgi Modellemesi (BIM), BIM Uygulamaları, Planlı Alanlar İmar Yönetmeliği, BIM Zorunluluğu, Dijital Ruhsat Süreçleri, Dijital İnşaat, Türkiye'de Bina Yönetmelikleri.

I. GİRİŞ

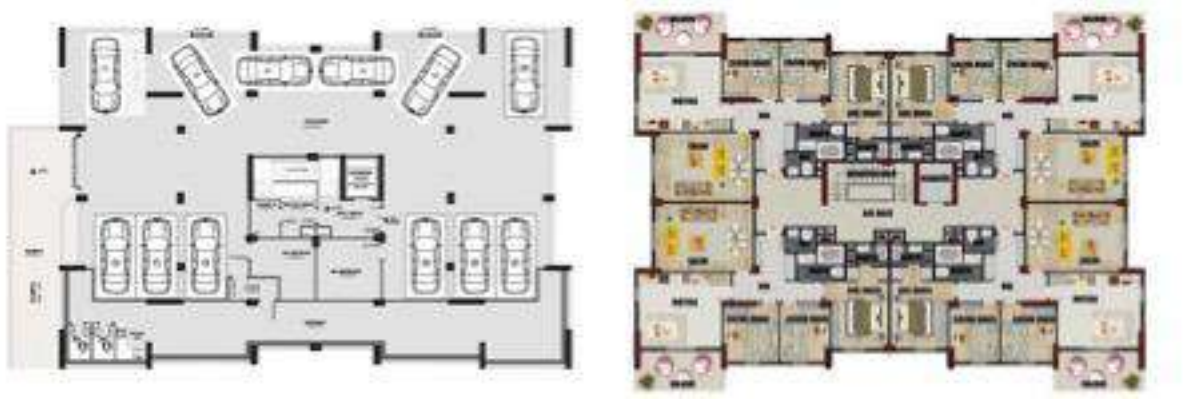
Bina Bilgi Modellemesi (BIM), inşaat sektöründeki dijital dönüşüm sürecinin merkezinde yer almakta ve özellikle planlama, görselleştirme, metraj, maliyet tahmini ve bütçe kontrolü gibi yönetimsel süreçlerde önemli katkılar sunmaktadır [1]. Büyük ölçekli ve karmaşık projelerde BIM'in sunduğu üç boyutlu modelleme olanakları, disiplinler arası koordinasyonu kolaylaştırmakta; hata oranını düşürmekte ve süreçlerin daha etkin yönetilmesini sağlamaktadır. Ayrıca, otomatik veri entegrasyonu ve gerçek zamanlı görselleştirme yetenekleri hem maliyet yönetiminde hem de proje planlamasında önemli

iyileştirmeler sağlamaktadır. BIM, yalnızca geometrik modellemekten ibaret olmayıp çok boyutlu bir veri yönetimi altyapısı sunmaktadır. 3B (geometri) boyutunun ötesinde, zaman (4B), maliyet (5B), sürdürülebilirlik (6B), tesis işletme (7B) ve iş sağlığı güvenliği (8B) boyutları da modele entegre edilerek proje yönetimi daha kapsamlı şekilde yürütülebilmektedir [2]. Bu bağlamda BIM'in bu boyutlu yapısı, gelişen ihtiyaçlara göre yeni boyutlarla sürekli genişlemektedir. Parametrik modelleme yeteneği ile BIM, yapı elemanlarının birbirleriyle olan ilişkilerini tanımlar ve nesne yönelimli çizim sistematığı ile veri yönetimini otomatikleştirir. Bu sistem sayesinde projede kullanılan her bir eleman (örneğin bir kapı), fiziksel ve işlevsel özellikleriyle birlikte modellenerek projede ortak bir dil oluşturur [3]. BIM'in önemli katkılarında biri de birlikte çalışabilirlik özelliğidir. Tasarım, yapım ve bakım süreçlerinde farklı disiplinlerin ortak bir dijital ortamda bilgi alışverişi yapabilmesini sağlayarak veri senkronizasyonunu artırır. Ancak pratikte, BIM modellemesi yapılmadan tamamlanan projelerde sonradan oluşturulan dijital modeller ile sahada gerçekleşen uygulama verileri arasında birimsel, geometrik ve bilgi temelli uyumsuzluklar yaşanabilmektedir. Bu uyumsuzluklar, modelden elde edilen metraj ve maliyet hesaplarının doğruluğunu etkileyerek karar verme süreçlerinde belirsizliklere neden olur. Geleneksel proje planlama ve yönetim süreçlerinin, genellikle BIM tabanlı dijital modellerle tam olarak entegre edilememesi, projelerde zaman ve maliyet sapmalarına neden olabilmektedir. BIM, bu uyumsuzlukların önüne geçerek süreçlerin daha etkin yönetilmesine katkı sağlamakta ve zaman tasarrufu açısından önemli avantajlar sunmaktadır. Smith ve Tardif'in [4] gerçekleştirdiği çalışmada, BIM'in özellikle maliyet tahmini süreçlerinde sağladığı doğruluk ve otomasyon olanakları vurgulanmaktadır. Revit gibi yazılımlarla geliştirilen BIM modelleri üzerinden yürütülen maliyet kontrol analizlerinde, otomatik veri entegrasyonu ve maliyet sapması analizleri sayesinde daha doğru öngörüler elde edildiği ve proje değişikliklerinin modele hızlı bir şekilde yansıtılabildiği ifade edilmiştir. Bu bulgular, BIM'in yalnızca görsel modelleme değil, aynı zamanda stratejik karar destek aracı olarak da kullanılması gerektiğini ortaya koymaktadır.

Türkiye'de yapı üretim süreçlerinde dijitalleşmeye yönelik önemli bir adım olarak, 11 Mart 2025 tarihli Planlı Alanlar İmar Yönetmeliği değişikliğiyle yapı ruhsatı eki proje, resim, hesap ve raporların, yapı bilgi modellemesi (BIM) standartlarına uygun şekilde hazırlanarak elektronik ortamda kaydedilmesi, kontrol edilmesi, onaylanması ve arşivlenmesi hükme bağlanmıştır [5] (Planlı Alanlar İmar Yönetmeliği, Madde 5/2–30, 2025). Aynı tarihli Çevre, Şehircilik ve İklim Değişikliği Bakanlığı duyurusuna göre [6], BIM sistemine geçişle birlikte bina yaşam döngüsüne ait verilerin dijital ortama aktarılması, üç boyutlu yapı modelleri aracılığıyla görselleştirilerek yönetilmesi ve ruhsat süreçlerinin tamamının dijital ortamda yürütülmesi amaçlanmaktadır. Bu düzenlemeler, yapıların çevresel etkilerinin azaltılmasını, karbon ayak izinin hesaplanmasını ve sürdürülebilirlik hedeflerine ulaşılmasını desteklemektedir. Bu doğrultuda Türkiye'de dijital inşaat süreçlerinin benimsenmesi ve sürdürülebilir yapılaşmanın teşviki açısından BIM tabanlı uygulamalar kritik bir rol üstlenmektedir.

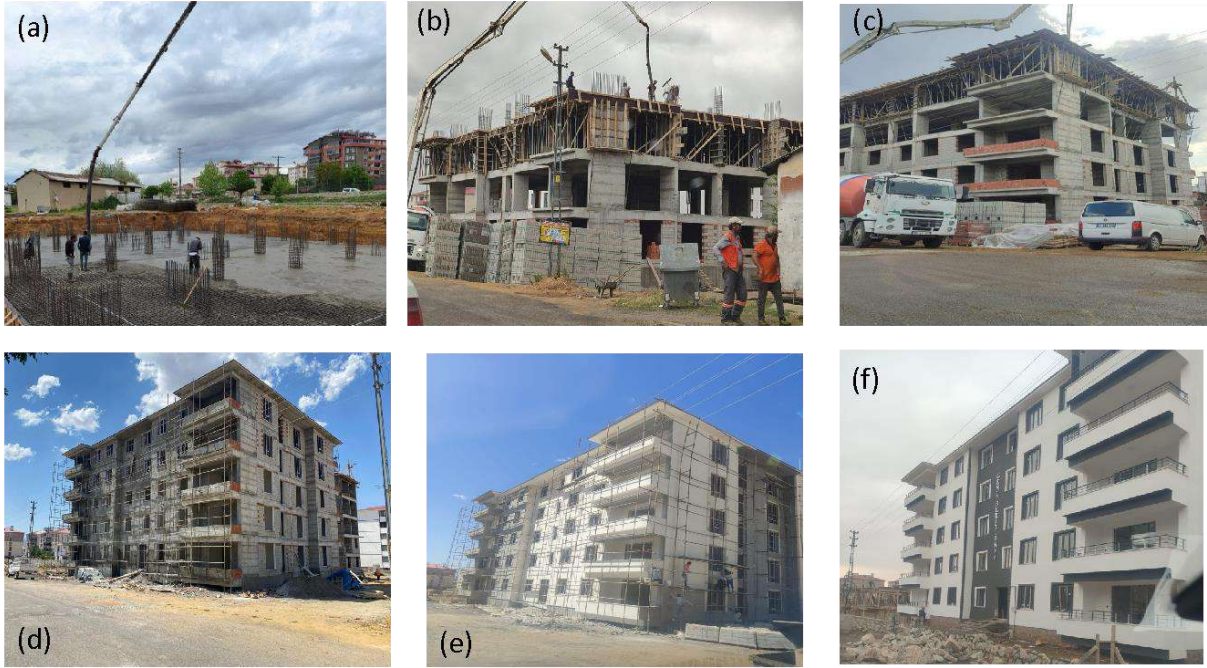
Bu çalışmanın temel amacı, BIM süreci yürütülmeden tamamlanmış bir yapının Autodesk Revit yazılımı aracılığıyla dijital modelinin oluşturulması ve bu modelden elde edilen metraj ve maliyet çıktılarının gerçek inşaat verileri ile karşılaştırılması yoluyla olası uyumsuzlukların analiz edilmesidir. Örnek olay olarak Bingöl ili Genç ilçesi Kültür Mahallesi, Ada No: 674, Parsel No: 8 konumunda yer alan bir apartman yapısı seçilmiş; yapının temelden kaba inşaat aşamasına kadar olan üretim verileri değerlendirilmiştir. BIM modeli üzerinden elde edilen nicel çıktılar, sahadan alınan manuel metraj ve maliyet verileri ile karşılaştırılmış, özellikle tuğla ve sıva gibi yapı bileşenlerinde Revit'in yüzey alanına dayalı (m²) hesaplama yaklaşımı ile şantiyede kullanılan adet bazlı ölçüm birimleri arasındaki farklar incelenmiştir. Analiz sonuçları, modelde tanımlanan yapı elemanlarının geometrik temsil biçimi, detay seviyesi (LOD) ve kullanılan birim sisteminin metraj doğruluğu üzerinde belirleyici etkileri olduğunu ortaya koymuştur.

Çalışma, 11 Mart 2025 tarihinde yürürlüğe giren Planlı Alanlar İmar Yönetmeliği değişikliği ile kamu projelerinde BIM kullanımını zorunlu hale getiren yasal düzenlemeler (Madde 5/2–30, 2025) ve Çevre, Şehircilik ve İklim Değişikliği Bakanlığı'nın aynı tarihli duyurusu doğrultusunda [6], yapı yaşam döngüsü verilerinin dijital ortama aktarımı, elektronik ruhsat süreçleri ve çok boyutlu veri yönetimi bağlamında model-dogruluk, birim dönüşümü ve veri uyumluluğu gibi konularda politika ve uygulama düzeyinde öneriler sunmaktadır.



Şekil 2. Referans bina kat planları

Bina bodrum + zemin + 4 normal kat olmak üzere toplam 6 kattan oluşmakta ve toplamda 20 adet bağımsız bölüme sahiptir. Her katta 4 adet daire bulunmakta olup, her bir daire 109,25 m² brüt alana sahiptir. İnşaat sürecinden çekilmiş fotoğraflara dair görüntüler Şekil 3’de verilmektedir.



Şekil 3 (a,b,c,d,e,f). Referans bina yapım aşamaları görüntüleri

B. BIM için Kullanılan Yazılım

İnşaat projelerinde maliyet tahmini ve malzeme planlamasının temelini oluşturan metraj hesapları, doğruluk ve süreklilik açısından büyük önem taşımaktadır. Geleneksel olarak manuel yöntemlerle yürütülen bu süreçler, yüksek hata riski barındırmakta ve zaman açısından verimsiz olabilmektedir. Bu noktada, Yapı Bilgi Modellemesi (BIM) teknolojileri, özellikle proje planlaması ve maliyet yönetimi açısından alternatif bir yaklaşım sunmaktadır. BIM, farklı senaryoları dijital ortamda simüle ederek proje yöneticilerinin karar alma süreçlerine destek olabilmekte; metraj, zaman ve bütçe kontrolü gibi konularda daha güvenilir ve entegre çözümler üretmektedir [8].

Son yıllarda BIM tabanlı yaklaşımların yaygınlaşmasıyla birlikte, metraj işlemleri de dijital ortama taşınmış ve yazılımsal entegrasyonlarla yürütülmeye başlanmıştır. Bu doğrultuda Autodesk Revit gibi BIM uyumlu yazılımlar, üç boyutlu model verilerinden doğrudan metraj üretme kapasitesi ile öne çıkmaktadır. Revit, hem yapı elemanlarının geometrik özelliklerini hem de ilişkili malzeme ve miktar

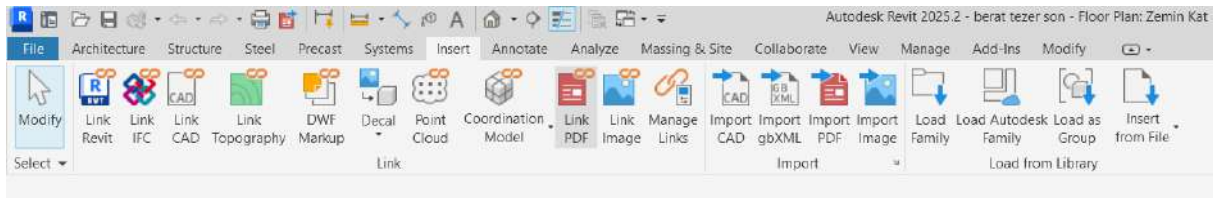
bilgilerini analiz edebilen parametrik bir sistem sunar. Literatürde Revit ve BIM tabanlı metraj yöntemlerinin manuel yöntemlere kıyasla daha yüksek doğruluk ve zaman verimliliği sağladığına dair çeşitli akademik çalışmalar bulunmaktadır. Örneğin, Brigham Young Üniversitesi'nde yapılan bir yüksek lisans tezinde, Revit yazılımı ile yapılan metraj işlemlerinin, kıyaslanan diğer yazılıma göre daha kısa sürede tamamlandığı ve eşdeğer doğruluk seviyelerinde sonuçlar elde edildiği rapor edilmiştir [9]. Benzer şekilde, Autodesk tarafından yayımlanan bir raporda, Revit'in malzeme metrajları oluşturma ve bu verileri elektronik tablolara aktarma yetenekleri sayesinde maliyet tahmin süreçlerinde doğruluğu artırdığı ve manuel hataları azalttığı belirtilmektedir [10]. Ayrıca, BIM tabanlı metraj yöntemlerinin doğruluğunu artırmaya yönelik çalışmalar da literatürde yer almaktadır. Örneğin, ScienceDirect'te yayımlanan bir makalede, BIM modellerinden elde edilen metrajların doğruluğunu artırmak için önerilen yöntemler ele alınmıştır [11]. Bu çalışmalar, Revit ve BIM tabanlı metraj yöntemlerinin, manuel yöntemlere kıyasla daha hızlı ve doğru sonuçlar sunduğunu göstermektedir. Ancak bu etkinliğin proje türüne, modelin detay seviyesine ve kullanıcı deneyimine bağlı olarak değişkenlik gösterebileceği de vurgulanmaktadır.

Bu çalışma, geleneksel (manuel) metraj yöntemleri ile Revit tabanlı dijital metraj hesaplamalarının karşılaştırmalı analizine odaklanmaktadır. Çalışmanın temel amacı, bu iki yöntemin farklı yapı elemanları üzerindeki çıktılarının teknik parametreler açısından kıyaslanması yoluyla sektördeki dijital dönüşüme ampirik katkı sunmaktır.

C. Referans Bina BIM Modeli Oluşturma Süreci

Modelleme süreci, yapının ruhsatlı mimari projesinden elde edilen kat planları temel alınarak başlatılmıştır. Bu planlar Autodesk Revit ortamına entegre edilmiş ve binanın dijital modeli oluşturulmuştur. Revit aracı AEC (Architecture, Engineering & Construction) sektöründe yaygın kullanılmasından dolayı BIM aracı olarak seçilmiştir. Model teknik çizimler, raporlar ve inşaatın uygulama aşamasında sahada görevli olan inşaat mühendisinden alınan malzeme bilgilerine göre üç boyutlu hale getirilmiştir. Projenin temel verileri olan katların sayısı, yükseklikleri yanı sıra malzeme bilgileri gibi gerekli bilgiler veri olarak aktarılmıştır.

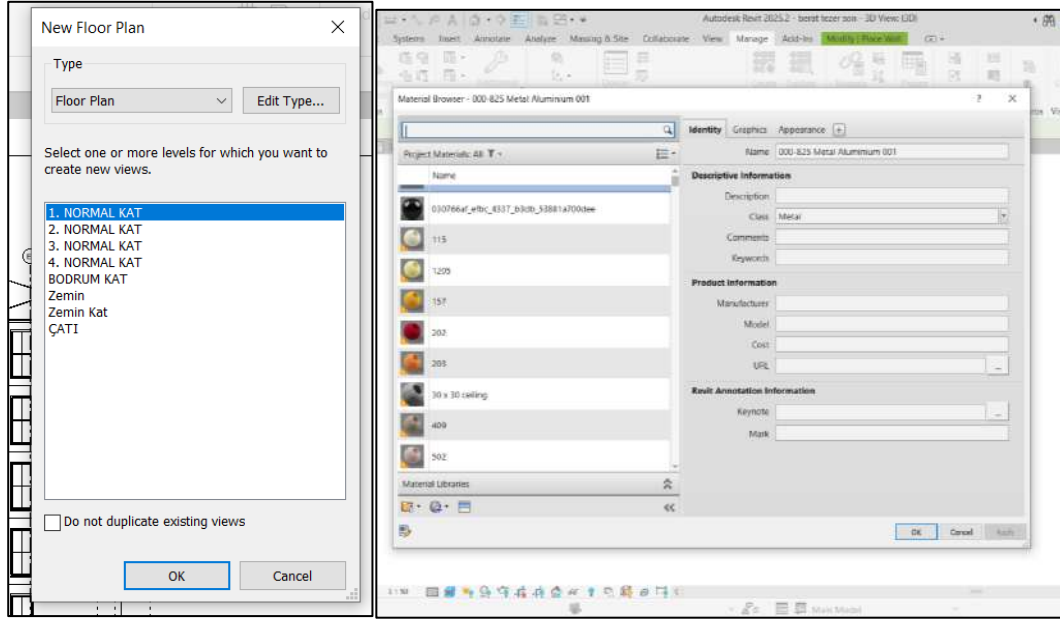
Çalışma kapsamında metraj ve model doğrulama işlemleri gerçekleştirilmeden önce, ilgili yapının BIM ortamında modellenmesi Autodesk Revit yazılımı kullanılarak gerçekleştirilmiştir. İlk aşamada, yazılım arayüzü üzerinden Models sekmesi altından mimari modelleme şablonu seçilerek çizim ortamı oluşturulmuştur. Ardından, Units ayarları düzenlenmiş ve proje genelinde kullanılacak ölçü birimi sistemi (metrik) tanımlanmıştır. Revit, katman bazlı bir çalışma mantığına sahip olduğundan, her katın planı AutoCAD (.dwg) formatında kat bazında ayrı ayrı kaydedilmiştir. Bu dosyalar, Revit ortamına iki farklı yöntemle entegre edilebilmektedir: Insert > Import CAD ya da Insert > Link CAD seçenekleri ile. Bu çalışmada, AutoCAD dosyalarında daha sonra yapılabilecek olası güncellemelerin Revit modeli ile eş zamanlı yansıtılabilmesi amacıyla Link CAD yöntemi tercih edilmiştir. Şekil 4'de iki boyutlu bir autocad çiziminin revit ortamına aktarımına ait ekran görüntüsü yer almaktadır.



Şekil 4. Autodesk Revit arayüzünde 2B (dwg) çizim dosyasının modele eklenmesine ilişkin “Insert” sekmesi görünümü

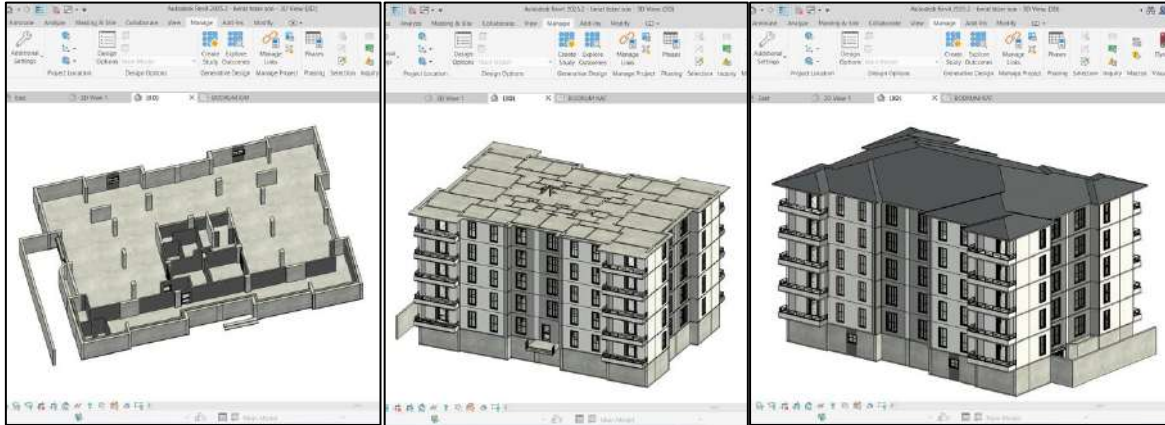
Modellemede kullanılacak kat seviyeleri ve adlandırmaları, Revit arayüzünde yer alan Project Browser-Görünüş (Elevations) sekmesi üzerinden oluşturulmuş ve her kata ait yükseklik bilgileri girilerek kat isimleri belirlenmiştir. Katların plan düzleminde görünebilmesi için ise View -Plan Views -Floor Plan komutu ile tüm katlar seçilmiş ve bu işlem sonucunda Project Browser -Floor Plans alanında her kat görünür hale getirilmiştir (Şekil 5a). Yapının taşıyıcı sistem aksları, dwg altlığı üzerinden yerleştirilen referans çizgileri (Grid) yardımıyla oluşturulmuştur. Kat planları hazırlandıktan sonra modelleme

işlemine geçilmiş; gerekli mimari elemanların tanımlanabilmesi için Manage > Materials sekmesi altındaki Materials bölümünden malzeme kütüphanesi oluşturulmuş, elemanlara uygun malzeme tanımları yapılmıştır (Şekil 5b). Bu sayede, daha sonra yapılacak metraj ve malzeme karşılaştırmalarında kullanılacak parametrelerin doğruluğu sağlanmıştır.



Şekil 5. (a) Revit ortamında kat planı görünümünün oluşturulması; (b) Malzeme kütüphanesinin tanımlanması arayüzü.

Modelleme sürecinde öncelikle bodrum kat (şekil 6a), ardından zemin kat ve birinci normal kat planları oluşturulmuş (şekil 6b); duvarlar, kapılar, pencereler, kat merdivenleri ve cephe kaplamaları gibi mimari bileşenler modele entegre edilmiştir (şekil 6b, c). Bu katlar, tamamlandıktan sonra diğer katlar kopyalanarak çoğaltılmış, yapının üç boyutlu modeli tamamlanmıştır (şekil 6c).



Şekil 6. (a) Bodrum kat planının modellenmesi, (b) Yapıya mimari elemanların eklenmesi ve katların çoğaltılması, (c) Üç boyutlu tamamlanmış bina modeli görünümü

Sonuç olarak, kat bazlı tüm mimari elemanlar tanımlanmış ve Revit ortamında yapının parametrik BIM modeli oluşturulmuştur. Bu model, metraj karşılaştırması, malzeme değerlendirmesi ve model-doğruluk kontrol süreçleri için temel teşkil etmektedir.

III. MEVCUT BİNA METRAJ VERİLERİ İLE BIM MODELİ ARASINDAKİ METRAJ FARKLILIKLARININ İNCELENMESİ

A. Yapıya Ait Metraj ve Maliyet Verileri

Çalışmada incelenen yapıya ait maliyet kalemlerine ilişkin nicel veriler, ilgili yapının müteahhidinden sağlanan metraj ve hakediş tablosuna dayanmaktadır (Tablo 1).

Tablo 1. İncelenen yapıya ait metraj verileri

İMALATIN ADI	MİKTAR	BİRİMİ	FİYATI	TUTAR
BETON	1300	M³	₺3.100,00	₺4.030.000,00
DEMİR ÇELİK	135	TON	₺25.500,00	₺3.442.500,00
KALIP İŞÇİLİK	4070	M²	₺450,00	₺1.831.500,00
DUVAR İŞÇİLİK	5000	M²	₺120,00	₺600.000,00
DEMİR İŞÇİLİK	4070	M²	₺180,00	₺732.600,00
SIVA MALZEMELİ	7500	M²	₺200,00	₺1.500.000,00
RUHSAT HARCİ	3650	M²	₺70,00	₺255.500,00
YAPI DENETİM HARCİ	3650	M²	₺150,00	₺547.500,00
PROJE ÜCRETİ	3650	M²	₺100,00	₺365.000,00
KAPI	-	-	₺1.200.000,00	₺1.200.000,00
MOBİLYA	-	-	₺1.800.000,00	₺1.800.000,00
KERESTE	-	-	₺160.000,00	₺160.000,00
PWC	-	-	₺1.000.000,00	₺1.000.000,00
ÇATI	-	-	₺120.000,00	₺120.000,00
ELEKTRİK	-	-	₺225.000,00	₺225.000,00
MEKANİK	-	-	₺1.200.000,00	₺1.200.000,00
DOĞALGAZ	-	-	₺400.000,00	₺400.000,00
YALITIM	-	M²	₺200.000,00	₺200.000,00
SERAMİK PARKE	-	M²	₺1.500.000,00	₺1.500.000,00
KORKULUK	300	M	₺250,00	₺75.000,00
TUĞLA	110000		₺6,00	₺660.000,00
YALITIM XPS	1450	M²	₺60,00	₺87.000,00
YALITIM İŞÇİLİK	2000	M²	₺230,00	₺460.000,00
OTOPARK HARCİ	4		₺120.000,00	₺480.000,00
ŞAB	2	KAMYON	₺6.500,00	₺13.000,00
ÇİMENTO	1000	ADET	₺200,00	₺200.000,00
KUM	2	KAMYON	₺6.500,00	₺13.000,00
BOYA+ASTAR	7500	M²	₺95,00	₺712.500,00
SİGORTA	-	-	₺1.750.000,00	₺1.750.000,00
BOYA KUTU	100	-	₺2.750,00	₺275.000,00
KOMBİ	20	-	₺25.000,00	₺500.000,00
ASANSÖR	-	-	₺1.200.000,00	₺1.200.000,00
ÇEVRE DÜZENLEME	-	-	₺400.000,00	₺400.000,00

Tablo, kaba ve ince inşaat süreçlerine ait birim fiyatlar, miktarlar ve toplam tutarları içermektedir. Ele alınan yapı için hazırlanan tablo, betonarme imalatlar, yalıtım uygulamaları, doğrama, sıva, boya,

mekanik ve elektrik tesisatları, çatı, asansör, çevre düzenlemesi ve diğer tüm yapıım bileşenlerini kapsamaktadır. Toplam 30'dan fazla imalat kalemini içeren bu tablo, proje maliyetlerinin hem birimsel hem de toplam bazda analizine olanak sağlamaktadır. Bu veriler, Autodesk Revit ile dijital model üzerinden elde edilen metraj çıktıları ile karşılaştırılarak, aralarındaki farklar bulguların devamında değerlendirilmiştir.

B. Autodesk Revit ile Malzeme tanımlama süreci

Bu bölümde, Autodesk Revit 2025 yazılımı kullanılarak oluşturulan BIM modelinden alınan metraj verileri örnek duvar elemanları üzerinden detaylı şekilde sunulmaktadır. Her bir yapı elemanı hem Revit ortamında hem de mimari çizimlerin yapıldığı AutoCAD platformunda referanslanarak karşılaştırmalı biçimde analiz edilmiştir. Bu yaklaşım, dijital modelde tanımlanan malzeme kalınlıkları, yüzey kaplamaları ve detay seviyesinin sahadaki mimari projeye uygunluğunu test etmeyi amaçlamaktadır. Duvar malzemesi tanımlamasında mimari proje detayı ve revitte oluşturulma süreci gösterilmektedir (Şekil 7).



Şekil 7. (a) Revit ortamında 10 cm kalınlığındaki sıvalı tuğla duvarın katman tanımı ve malzeme özellikleri, (b) Aynı duvar elemanının AutoCAD ortamında mimari projedeki referans çizimi

Şekil 7(a)'da Revit 2025 programında modellenen 10 cm kalınlığındaki sıvalı bir duvarın malzeme tanımı ve katman yapısı görülmektedir. İlgili yapı elemanının fiziksel özellikleri, parametre tablosu üzerinden tanımlanmıştır. Şekil 7 (b)'de aynı duvar elemanının AutoCAD ortamındaki referans çizimi sunulmuştur. Burada duvarın yerleşimi, alanı ve konumlandırıldığı mahallin (örneğin mutfak) sınırları detaylandırılmıştır. Aynı şekilde 15 cm kalınlığındaki tuğla duvar çizim aşamaları Şekil 8'de verilmektedir.



Şekil 8. (a) Revit ortamında 15 cm kalınlığında sıvalı iç bölme duvarın tanımı, (b) Aynı duvarın AutoCAD mimari çizimdeki konum ve mahal ilişkisi.

Şekil 8 (a)'da 15 cm kalınlığında sıvalı bir iç bölme duvarın Revit modeli üzerinde tanımı yer almaktadır. Şekil 8 (b)'de bu duvarın AutoCAD projesindeki yeri gösterilmiştir. Karşılaştırmada duvar

kalınlığı ve yerleşimi ile Revit modelindeki tanım arasında birebir uyum sağlandığı görülmektedir. Aşağıda verilen şekil 9’da ise 20 cm kalınlığındaki dış duvarın tanımı verilmektedir.



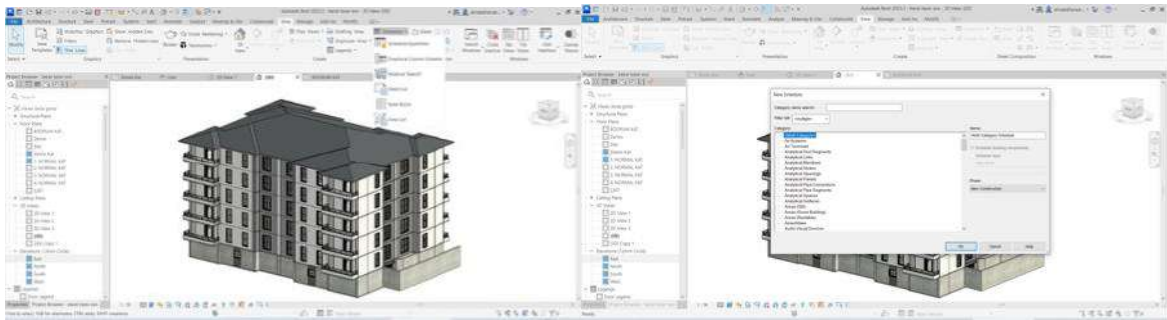
Şekil 9. (a) Revit modelinde bağımsız olarak tanımlanan 3 cm kalınlığındaki dış sıva katmanı, (b) Aynı katmanın AutoCAD çiziminde duvarla olan ilişkisinin gösterimi

Şekil 9 (a) ve (b)’de daha kalın dış duvar örneğini temsil etmektedir. Bu tip duvarlar genellikle taşıyıcı özelliktedir ve hem ısı hem ses yalıtımını içerecek şekilde katmanlandırılmıştır. Şekil 9 (a)’da revit modelinde bağımsız olarak tanımlanan 3 cm kalınlığındaki sıva katmanı gösterilmiştir. Şekil 9(b)’de ise bu katmanın AutoCAD çizimi ile nasıl eşleştiği incelenmiştir. Bu inceleme, sıvanın ayrı bir malzeme olarak mı yoksa duvar bileşeni içinde mi değerlendirileceği sorusuna yanıt sunmaktadır.

Bu görsel karşılaştırmalar, Autodesk Revit üzerinden elde edilen metraj verilerinin model doğruluğunun yanı sıra AutoCAD tabanlı projelerle entegrasyonundaki güçlü yönlerini ve olası uyumsuzluk noktalarını belirlemeyi hedeflemektedir. Böylece, BIM sürecinde oluşturulan verilerin sahadaki projelerle örtüşme düzeyi daha analitik biçimde değerlendirilmiştir.

C. Autodesk Revit ile Metraj Çıkarma

Bu çalışmada, yapı bilgi modeli üzerinden nicel verilerin çıkarılmasına yönelik olarak Autodesk Revit 2025 yazılımının sunduğu metraj (quantity takeoff) araçları kullanılmıştır. Metraj işlemleri, Revit yazılımı içinde yer alan “View” sekmesi altındaki “Schedules” komutu aracılığıyla başlatılmıştır. Bu komut altında sunulan altı farklı seçeneğin arasından “Schedules/Quantities” bölümü seçilerek sayısal veri içeren yapı bileşenlerinin listelenmesine olanak tanınmıştır. Bu özelliklerin tanımlamalarının yapıldığı arayüz görüntüleri Şekil 10 ‘da verilmektedir.



Şekil 10. Metraj oluşturma ayarlamaları arayüz görüntüsü

Schedules/Quantities, modelde yer alan sayılabilir elemanların (örneğin duvar, pencere, kapı, döşeme vb.) özelliklerine göre sınıflandırılarak miktarlarının hesaplanmasına ve listelenmesine olanak tanıyan güçlü bir araçtır. Bu özellik, yapı elemanlarına ilişkin detaylı analizlerin yapılabilmesi, maliyet hesaplarının oluşturulabilmesi ve malzeme doğrulamalarının sağlanabilmesi açısından oldukça kritiktir.

Revit’ teki komut seçildikten sonra kullanıcıya, projede tanımlı olan tüm kategoriler (Categories) listelenmektedir. Bu listeden metrajı alınmak istenen yapı bileşeni seçildikten sonra, tabloya dahil edilecek parametreler tanımlanmıştır. Bu çalışmada, “Family and Type”, “Cost”, “Height”, “Count” ve

“Level” gibi öznitelikler seçilmiş; böylece elemanların tipi, maliyet değeri, yüksekliği, adedi ve yer aldığı kat bilgisi gibi özellikleri tabloya yansıtılmıştır.

Veri organizasyonu yapıldıktan sonra sistem, kullanıcı tanımlı bu parametreler doğrultusunda otomatik olarak yapı elemanlarının metrajını listelemiştir. Bu listeleme işlemi sonucunda her bir bileşenin adedi ve ilgili kat düzlemi içerisindeki konumu, yapı tipi ve diğer özellikleri tablo halinde görüntülenmiştir. Tablonun görüntüsü Şekil 11’de verilmektedir.

<View List>				
A	B	C	D	E
View Name	Title on Sheet	Scale Value 1:	Sheet Number	Family and Type
Zemin Kat		50	A100	Floor Plan: Floor Plan
Zemin Kat		50		Ceiling Plan: Ceiling Plan
1. NORMAL KAT		50	A100	Floor Plan: Floor Plan
1. NORMAL KAT		50		Ceiling Plan: Ceiling Plan
North		50	A100	Elevation: 12mm Circle
East		50	A100	Elevation: 12mm Circle
South		50	A100	Elevation: 12mm Circle
West		50	A100	Elevation: 12mm Circle
Site		50		Floor Plan: Floor Plan
{3D}		50		3D View: 3D View
Zemin		50		Floor Plan: Floor Plan
Zemin		50		Ceiling Plan: Ceiling Plan
Zemin		50		Structural Plan: Structural Plan
3D View 1				3D View: 3D View
3D View 2				3D View: 3D View
3D View 3				3D View: 3D View
{3D} Copy 1		50		3D View: 3D View
2. NORMAL KAT		50		Floor Plan: Floor Plan
2. NORMAL KAT		50		Ceiling Plan: Ceiling Plan
2. NORMAL KAT		50		Structural Plan: Structural Plan
3. NORMAL KAT		50		Floor Plan: Floor Plan
3. NORMAL KAT		50		Ceiling Plan: Ceiling Plan
3. NORMAL KAT		50		Structural Plan: Structural Plan
4. NORMAL KAT		50		Floor Plan: Floor Plan
4. NORMAL KAT		50		Ceiling Plan: Ceiling Plan
4. NORMAL KAT		50		Structural Plan: Structural Plan
BODRUM KAT		50		Floor Plan: Floor Plan
BODRUM KAT		50		Ceiling Plan: Ceiling Plan
BODRUM KAT		50		Structural Plan: Structural Plan
ÇATI		50		Floor Plan: Floor Plan
ÇATI		50		Ceiling Plan: Ceiling Plan
ÇATI		50		Structural Plan: Structural Plan

Şekil 11. Revit programından alınan metraj verilerinin görüntüsü.

Sonuç olarak, Revit ortamında modellenmiş yapıdan sayısal verilerin çıkarılması işlemi, manuel müdahaleye ihtiyaç duyulmadan, model verilerine doğrudan bağlı olarak gerçekleştirilmiş ve elde edilen veriler, doğruluk oranı yüksek ve BIM tabanlı maliyet/planlama analizlerinde kullanılabilir bir formatta elde edilmiştir.

D. Duvar Tuğlası ve Sıva Kalemlerine Ait Metraj Karşılaştırması

Yapı maliyetlerinin doğru tahmini ve kaynakların etkin kullanımı için metraj hesaplarının güvenilirliği büyük önem taşımaktadır. Geleneksel olarak iki boyutlu çizimler ve saha deneyimine dayalı olarak gerçekleştirilen manuel metraj hesapları, kullanıcıya bağlı hata payı yüksek bir yöntemdir. Buna karşılık, Yapı Bilgi Modellemesi (BIM) esaslı yazılımlar, üç boyutlu modeller üzerinden otomatik ve entegre ölçüm olanağı sağlayarak hata oranlarını minimize etmektedir. Karşılaştırma, aynı yapıya ait iki farklı metraj yöntemi ile yapılmıştır. İlk olarak, manuel metraj hesapları klasik ölçüm ve hesaplama teknikleriyle Excel tablosu üzerinden elde edilmiştir. İkinci olarak, Autodesk Revit yazılımı kullanılarak yapı modeli oluşturulmuş ve yazılımın yerleşik metraj araçlarıyla otomatik olarak tuğla ve sıva metrajı çıkarılmıştır. Manuel metraj tablosuna göre yapı için hesaplanan tuğla miktarı 110.000 adet, sıva miktarı ise 3650 m² olarak belirlenmiştir. Revit modelinden çıkarılan metraj dosyasında ise, tuğla uygulama alanlarına karşılık gelen duvar alanları ve kalınlıklar temel alınarak hem yüzey alanları hem de hacimsel bazda daha detaylı bir hesaplama yapılmıştır. Revit verilerine göre dış sıva alanları örnek olarak 1.59 m², 0.38 m², 3.71 m² gibi değerlerle ayrı ayrı listelenmiş; toplam alan yazılımdan doğrudan elde edilmiştir.

BIM (Revit) ile yapılan metraj hesaplamalarında veriler genellikle m² (alan) veya m³ (hacim) birimlerinde sunulurken, manuel hesaplamalarda iş kalemleri adet (örneğin tuğla gibi) üzerinden

değerlendirilir. Bu durum doğrudan karşılaştırmayı zorlaştırırsa da birimsel uyumsuzlukların karşılaştırmalı analizini nasıl yaparız üzerine öneriler geliştirilmesine olanak tanımaktadır.

Tuğla ölçüleri göz önüne alınarak revitte m2 olarak verilen tuğla metrajı için adet olarak verilen manuel metraj çizelgesindeki değere dönüştürmek için aşağıdaki yol izlenebilmektedir. Bu dönüşüm ile Revit'te m² bazlı verilen alan, manuel'deki adet verisiyle eşdeğer birimlere dönüştürülerek karşılaştırılabilir hale gelir. Bu yaklaşımla, Revit çıktısındaki toplam tuğla kaplama alanı şu şekilde adet bazına çevrilebilir.

Bu çalışmada incelenen projede, manuel metraj çıktılarında toplamda 110.000 adet tuğla kullanıldığı belirtilmiştir. Aynı yapının Autodesk Revit yazılımı kullanılarak oluşturulan BIM modeli üzerinden elde edilen metraj verileri ise metrekare (m²) cinsindedir. Revit verilerine göre, farklı kalınlıktaki tuğla duvarlara ilişkin yüzey alanları aşağıdaki tabloda verilmiştir (Tablo 2).

Tablo2. Tuğla duvarların yüzey alanları

Duvar Kalınlığı	Sıvalı Yüzey Alanı (m ²)	Sıvasız Yüzey Alanı (m ²)	Toplam Yüzey Alanı (m ²)
10 cm	1971,73	42,70	2014,43
15 cm	918,92	146,63	1065,55
20 cm	1011,43	14,39	1025,82
25 cm	125,90	-	125,90
35 cm	14,50	-	14,50
Revit metraj sonuçlarından elde edilen toplam tuğla yüzey alanı			4246,2

Bu veriler, Revit modeli üzerinde farklı duvar tiplerinin ayrı ayrı tanımlandığını ve her bir duvar türünün yüzey alanının bireysel olarak hesaplandığını göstermektedir. Özellikle Revit, hem iç hem dış yüzey kaplamalarını bağımsız bileşenler olarak değerlendirmekte ve duvar kalınlığına göre bu yüzeyleri farklı malzeme katmanlarıyla ilişkilendirmektedir. Bu durum, metrekare cinsinden raporlanan alanların, sahadaki gerçek uygulamada karşılığı olan tuğla adetleriyle doğrudan karşılaştırılabilmesi için birim dönüşümü yapılmasını gerektirir.

Bu bağlamda, Türkiye'de yaygın olarak kullanılan 13,5'lik yatay delikli blok tuğla türü esas alınmış ve tuğla üretici firmasının teknik verilerine göre, 1 m² duvar için yaklaşık 25 adet tuğla kullanıldığı kabul edilmiştir (Şekil 12).



Şekil 12. Yatay delikli blok tuğla ölçüleri [13]

Bu dönüşümle Revit çıktısı olan toplam 4246,20 m² duvar yüzeyi aşağıdaki şekilde tuğla adedine çevrilmiştir:

$$\text{Tuğla Adedi} = \text{Toplam Yüzey Alanı (m}^2\text{)} \times 25 \text{ adet/m}^2$$

$$\text{Tuğla Adedi} = 4246,20 \times 25 = 106.155 \text{ adet}$$

Bu hesaplama sonucuna göre, manüel metrajda bildirilen 110.000 adet tuğla, Revit modelinden hesaplanan 106.155 adet ile oldukça yakın bir değere ulaşmaktadır. Bu da modelleme ve birim dönüşümünün doğru şekilde yapıldığını göstermektedir. Bu durum, BIM tabanlı metraj hesaplamalarının

detaylı, katman bazlı ve otomatik yapılabildiğini, manuel metrajda ise hesapların bütüncül ve özet şekilde gerçekleştirildiğini ortaya koymaktadır. Ayrıca BIM modellemesi, sadece yüzey alanı değil; hacim, malzeme yoğunluğu ve harç dahil pek çok bileşeni dikkate alarak detaylı analiz yapılmasını mümkün kılar.

Tablo 1. Sıva malzemesinin revit ve manuel metraj değerlerinin karşılaştırılması

Kaynak	Sıva Kalınlığı	Alan (m ²)
Revit Çıktısı	2 cm	1129,72
	3 cm	474,73
	Toplam	1604,45
Manuel Metraj	Belirtilmemiş	7500

Bu veriler kapsamında:

- Revit modeli üzerinden hesaplanan toplam sıva alanı: 1604,45 m²
- Manuel hesaplama ile belirtilen toplam sıva alanı: 7500 m²
- Fark: 7500 – 1604,45 = 5895,55 m²

Bu fark oldukça büyüktür ve yaklaşık %79 oranında bir eksiklik göstermektedir.

Sıva metrajları arasındaki belirgin farkın birkaç temel nedeni olabilir. Öncelikle, Revit modelinde yalnızca bazı duvarlara sıva katmanı atanmış olması muhtemeldir. Bu durumda, tüm yüzeylere sıva tanımlanmadığından toplam metraj Revit çıktısında eksik görünebilir. Ayrıca, Revit verilerinde 2 cm ve 3 cm kalınlıkta sıva alanları ayrı ayrı hesaplanmışken, manuel metrajda bu ayırım yapılmamış ve toplam alan tek kalemde 7500 m² olarak belirtilmiştir. Bu farklılık, iki yöntem arasındaki hesaplama sistematiklerinden kaynaklanmaktadır.

Revit modelinin detay seviyesi de bu farkta etkili olabilir. Eğer model, LOD (Level of Detail) açısından düşük seviyedeysse, yalnızca duvarın ana yapısı modellenmiş ve kaplama detayları göz ardı edilmiş olabilir. Öte yandan, manuel metrajlar genellikle şantiye şartlarında hızlıca yapılır ve çoğunlukla projedeki kaplama yüzeylerinin yaklaşık oranlarına dayalı tahminlere dayanır. Bu durum da manuel metrajda daha yüksek bir toplam değer ortaya çıkmasına neden olabilir.

Son olarak, sıva alanı tanımındaki farklılık da önemli bir etkidir. Revit çıktıları genellikle pencere ve kapı boşluklarını düşerek net yüzey alanını verirken, manuel hesaplamalarda brüt alanlar baz alınmış olabilir. Tüm bu nedenler birlikte değerlendirildiğinde, BIM tabanlı metraj ile manuel metrajlar arasında görülen farkın yalnızca teknik değil, aynı zamanda metodolojik olduğunu söylemek mümkündür.

Bu karşılaştırma, BIM modellerinden elde edilen çıktılar ile geleneksel manuel metrajlar arasındaki farkların sadece nicel değil, aynı zamanda kavramsal farklılıklardan da kaynaklandığını göstermektedir. Bu tür analizlerde:

- BIM modelinde tüm sıva yüzeylerinin tanımlandığından emin olunmalı,
- Kullanılan LOD düzeyi artırılmalı,
- Manuel metrajın kapsamı net olarak tanımlanmalı,
- Her iki yöntemin birimlerine ve kapsam tanımlarına dikkat edilmelidir.

Sonuç olarak, bu çalışma BIM tabanlı metraj verilerinin, sahada uygulanan manuel metrajlar ile doğru birim dönüşüm katsayıları kullanılarak karşılaştırılabileceğini ve bu yaklaşımın, projelerde maliyet doğruluğu, malzeme planlaması ve inşaat yönetimi açısından önemli avantajlar sağlayabileceğini göstermektedir.

IV. SONUÇ VE ÖNERİLER

Bu çalışma, BIM modeli ile gerçek saha verileri arasındaki metraj farklılıklarını somut verilerle ortaya koymuş ve bu farkların nedenlerine ilişkin kapsamlı analizler sunmuştur. Autodesk Revit üzerinden elde edilen dijital metraj çıktıları ile sahadaki hakediş tablolarının karşılaştırılması, özellikle birimsel dönüşüm gerektiren yapı elemanlarında anlamlı farkların ortaya çıktığını göstermiştir. Bu bulgular, sahadan

bağımsız olarak üretilen BIM modellerinin doğruluk oranının, kullanılan ölçü birimlerine, modelin detay seviyesine (LOD) ve veri kaynaklarının bütünlüğüne doğrudan bağlı olduğunu ortaya koymaktadır.

Bu bağlamda, BIM uygulamalarının etkili ve güvenilir bir biçimde kullanılabilmesi için bir dizi stratejik öneri geliştirilebilir. Öncelikle, BIM modellerinde kullanılan birim dönüşüm katsayıları ile ölçüm mantığının, sahada yaygın olarak kullanılan yöntemlerle uyumlu hale getirilmesi gerekmektedir. Bunun yanı sıra, kullanılacak BIM modelleri için minimum modelleme düzeylerinin (LOD) tanımlanması ve bu düzeylerin proje başlangıcında kontrol edilmesi büyük önem taşımaktadır. BIM tabanlı metraj sonuçlarının sahadan elde edilen verilerle karşılaştırılarak doğrulama prosedürlerinin oluşturulması, modelin güvenilirliğini artıracaktır. Ayrıca, BIM kullanıcılarının sadece yazılım bilgisi değil, aynı zamanda saha uygulamaları, hakediş süreçleri ve maliyet hesaplamaları konularında da yetkinliğe sahip olması sağlanmalıdır.

Türkiye’de yürürlüğe giren yeni mevzuatlar kapsamında, 11 Mart 2025 tarihinde güncellenen Planlı Alanlar İmar Yönetmeliği ile yapı ruhsatı eki belgelerin BIM formatında hazırlanması zorunlu hale getirilmiştir. Bu değişiklik, yapı üretim süreçlerinin dijitalleşmesi adına önemli bir adımdır. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı tarafından yapılan açıklamalara göre, BIM sistemi ile yapıların yaşam döngüsüne ait veriler dijital ortamda yönetilecek, ruhsat süreçleri tamamen elektronik ortamda yürütülecek ve bu sayede sürdürülebilir yapılaşma hedeflerine katkı sağlanacaktır. Bu düzenlemeler, çevresel etkilerin azaltılması, karbon ayak izinin hesaplanması ve kaynakların verimli kullanımı açısından da önem taşımaktadır.

Çalışmanın sonunda elde edilen bulgular, BIM modeli ile saha uygulamaları arasında oluşabilecek veri uyumsuzluklarının yalnızca teknik değil, aynı zamanda yönetsel bir boyut taşıdığını göstermektedir. Bu nedenle, yeni yapılacak projelerde BIM süreci, projenin en erken tasarım aşamasından itibaren entegre biçimde başlatılmalı; metraj doğruluğu, maliyet tahmini ve veri aktarımı gibi süreçler bütüncül bir yaklaşımla ele alınmalıdır. BIM’in ruhsat süreçleriyle uyumlu hale getirilmesi için belediyeler ve ilgili kamu kurumlarının dijital altyapısı güçlendirilmeli, personelin BIM modellerini değerlendirebilecek teknik yeterliliğe sahip olması sağlanmalıdır. Ayrıca, daha önce BIM süreci uygulanmadan tamamlanmış yapıların arşivlenmesi ve dijitalleştirilmesine yönelik geriye dönük modelleme stratejileri geliştirilmelidir. Bu tür stratejiler, Türkiye’de BIM zorunluluğunun sürdürülebilir ve etkili bir biçimde uygulanmasına katkı sağlayacaktır.

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Effect of Artificial Roughness Geometry on Heat Transfer Improvement in Flat-Plate Solar Air Collectors

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Abstract- Air solar collectors are widely employed in low-temperature thermal applications, where artificial roughness or internal fins are often introduced to improve heat transfer. However, these enhancements typically result in greater aerodynamic resistance, which can compromise system efficiency. This study focuses on the aerodynamic behavior of **zigzag ribs with perforations**, integrated into the airflow channel of a flat-plate solar collector.

The primary objective is to assess the pressure drop characteristics induced by this rib geometry and to establish empirical correlations that link aerodynamic losses to key influencing parameters. The analysis accounts for air thermophysical properties, collector geometry, and rib dimensions, providing a systematic evaluation of the factors contributing to flow resistance. Simulations are conducted across a Reynolds number range of 2,000–20,000, which represents a moderately turbulent regime typical of solar air heating systems.

The findings highlight the trade-off between enhanced convective heat transfer and increased pressure drop. By quantifying this balance, the study offers practical design guidelines for optimizing rib geometries to achieve higher overall efficiency. The empirical correlations developed herein serve as predictive tools for engineers and researchers, enabling the design of solar air collectors that integrate advanced internal configurations while minimizing energy losses.

Keywords: Solar Air Collector, Internal Fins, Artificial Roughness, Zigzag Ribs With Perforations, Pressure Drop, Reynolds Number, Aerodynamic Resistance, Empirical Correlations.

I. INTRODUCTION

Solar air collectors (SACs) are widely applied in drying, space heating, and hybrid photovoltaic/thermal (PV/T) systems. Their performance strongly depends on heat transfer efficiency within the absorber duct. Introducing artificial roughness, particularly rib structures, is one of the most effective methods to enhance heat transfer. Ribs disrupt the boundary layer and promote turbulence, thereby increasing the heat transfer coefficient. However, this improvement often comes at the cost of higher pressure drops, which may reduce overall thermo-hydraulic performance. Optimizing rib geometries is therefore crucial to achieve a balance between heat transfer enhancement and flow resistance.

Extensive research has investigated geometric modifications, including ribbing, perforations, and porous structures. Maji and Choubey (2020) highlighted their ability to increase surface area and turbulence, though with pressure penalties. Rani and Tripathy (2022) reported a 22.03% increase in efficiency with semi-circular loops, while Farhan et al. (2020) demonstrated that corrugated metal foam fins improved exergy efficiency up to 44%. Wang et al. (2020) used S-shaped ribs with

interstices, enhancing thermal efficiency from 13% to 48%. Other studies reported improvements with baffles (Ahmadinejad et al., 2022), twisted ribs combined with nanofluids (Fattahi, 2021), and optimized rib roughness (Kumar Dwivedi and Choudhary, 2022; Yadav and Bhagoria, 2013). Further contributions include porous fins under magnetic and radiation effects (Madhura et al., 2020), rectangular ribs in cylindrical collectors (Abu-Hamdeh et al., 2020), jet impingement (Elwekeel et al., 2024), serrated dimples (Salman et al., 2021), hole plate arrangements (Song et al., 2023), graphene-based nanopaint (Dharmaraj et al., 2023), and spring-like fins (Arunkumar et al., 2020). More complex configurations, such as V-shaped ribs (Promvonge, 2010), combined turbulators (Chompookham et al., 2010), trapezoidal corrugations (Krishna et al., 2024), and hybrid PCM-enhanced collectors (El-Fakharany et al., 2024), have also demonstrated significant performance gains.

Despite these advances, many studies remain limited to single rib geometries or fixed parameters, offering restricted applicability under real operating conditions. In this context, the present work investigates a novel rib configuration consisting of zigzag ribs with perforations arranged beneath the absorber plate. The main challenge lies in accurately evaluating their dynamic behavior, as small geometric variations can lead to substantial changes in both heat transfer and pressure loss.

II. MATERIALS AND METHOD

II. 1. EXPERIMENTAL SETUP AND MEASUREMENT INSTRUMENTS

The experimental setup investigated in this study consists of a flat-plate solar air collector developed at Mohamed Khider University of Biskra (Algeria) (Figure 1). The system was specifically designed for hydrodynamic analysis under forced convection conditions, without consideration of thermal performance. The collector has a length of 150 cm, a width of 50 cm, and an air channel thickness of 2.5 cm between the absorber plate and the bottom insulation. It is mounted at an inclination to maximize solar irradiation, although only the airflow characteristics are examined here.

Air circulation is provided by an industrial suction fan connected to a variable frequency drive, allowing precise control of the flow rate and enabling the investigation of different flow regimes. To characterize the hydraulic behavior, several instruments are integrated into the setup. A differential pressure sensor is positioned between the inlet and outlet to directly measure the pressure drop (ΔP) induced by the ribbed configurations, which is essential for evaluating hydraulic resistance. In addition, a digital anemometer (PCE-TA30) measures the air velocity at the outlet, ensuring accurate determination of the mass flow rate, while a speed controller regulates the fan operation.



Figure. 1. Outdoor experimental setup of the solar air collector and measurement instruments.

The airflow channel is equipped with zigzag ribs with perforations (Figure 2). This geometry is intended to promote turbulence and localized recirculation zones, thereby influencing the pressure drop and flow distribution. The setup thus provides a controlled framework for evaluating the hydraulic impact of rib geometry in solar air collectors.



Fig. 2. Zigzag ribs with perforations

II.2. EXPERIMENTAL PROCEDURE

The experiment was conducted by first fixing the ribs on the absorber plate to guide airflow inside the solar collector. Air was then drawn through the channel using a fan or suction device, with flow rate controlled by a variable frequency drive. The outlet air velocity was measured using a digital anemometer, while the pressure drop between the inlet and outlet was recorded with a differential pressure sensor.

II.3. EXPERIMENTAL GEOMETRIC PARAMETERS

The geometric parameters employed in the experiment are clearly presented in Figure 3 and detailed in Table 1, which together provide a comprehensive description of the collector's configuration and airflow channel characteristics.

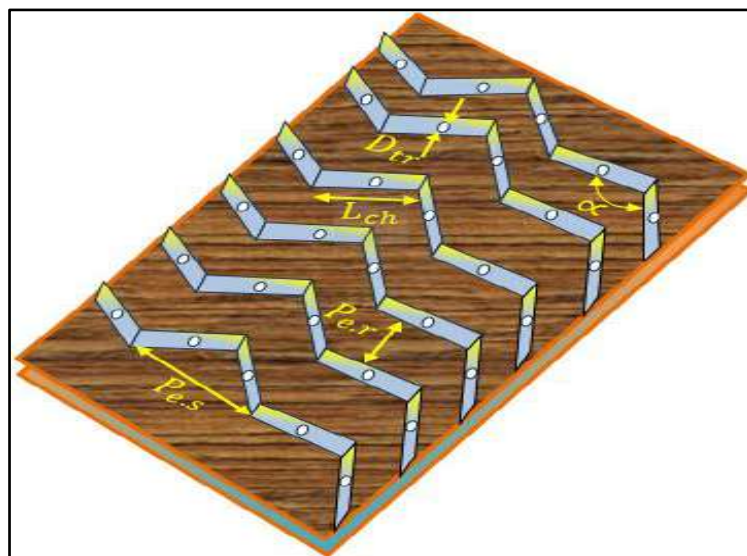


Fig.3. Geometrical Parameters Used in the Experiment"

Table 1. Geometric characteristics of the ribs.

Configurations	L_{ch} [m]	ε [m]	D_{tr} [m]	P_{er} [m]	P_{es} [m]	α [°]
Configuration 1	0,08	0,02	0,005	0,065	0,12	97,18
Configuration 2	0,08	0,02	0,008	0,065	0,12	97,18
Configuration 3	0,08	0,02	0,01	0,065	0,12	97,18
Configuration 4	0,08	0,02	0,005	0,065	0,13	108,68
Configuration 5	0,08	0,02	0,008	0,065	0,13	108,68
Configuration 6	0,08	0,02	0,01	0,065	0,13	108,68
Configuration 7	0,08	0,02	0,005	0,13	0,12	97,18
Configuration 8	0,08	0,02	0,008	0,13	0,12	97,18
Configuration 9	0,08	0,02	0,01	0,13	0,12	97,18
Configuration 10	0,08	0,02	0,005	0,13	0,13	108,68
Configuration 11	0,08	0,02	0,008	0,13	0,13	108,68
Configuration 12	0,08	0,02	0,01	0,13	0,13	108,68
Configuration 13	0,08	0,02	0,005	0,195	0,12	97,18
Configuration 14	0,08	0,02	0,008	0,195	0,12	97,18
Configuration 15	0,08	0,02	0,01	0,195	0,12	97,18
Configuration 16	0,08	0,02	0,005	0,195	0,13	108,68
Configuration 17	0,08	0,02	0,008	0,195	0,13	108,68
Configuration 18	0,08	0,02	0,01	0,195	0,13	108,68
Configuration 19	0,08	0,02	0,008	0,26	0,12	97,18
Configuration 20	0,08	0,02	0,01	0,26	0,12	97,18

III. RESULTS

III.1. EXPERIMENTAL FINDINGS

Through the experiments, hundreds of results were obtained, with Tables 2 and 3 presented as representative samples of these results.

Table 2. Experimental Findings for Configuration 1

t [h]	T_e [°C]	T_s [°C]	ΔP [Pa]	V_{exp} [m/s]	Q_v [m³/s]	V_{int} [m/s]
11:00	34,2	62,8	9,90	5,63	0,01105	4,15
11:15	36,4	65,5	20,18	8,56	0,01681	6,32
11:30	37,2	68,4	43,85	11,06	0,02172	8,17
11:45	37,8	70,1	54,40	13,16	0,02584	9,72
12:00	38,3	69,2	69,2	15,51	0,03044	11,45
12:15	39,1	68,9	81,50	16,98	0,03334	12,54
12:30	39,8	68,4	95,44	18,58	0,03648	13,72
12:45	40,6	67,9	113,65	19,64	0,03855	14,5

Table 3. Experimental Findings for Configuration 2

t [h]	T_e [°C]	T_s [°C]	ΔP [Pa]	V_{exp} [m/s]	Q_v [m³/s]	V_{int} [m/s]
13:15	39,8	53	9,41	5,67	0,01114	3,83
13:30	40	54	18,75	8,56	0,01681	5,79
13:45	40,2	52,6	42,43	11,03	0,02166	7,46
14:00	40,4	51,4	53,45	13,16	0,02584	8,90
14:15	40,8	50,5	67,02	15,51	0,03044	10,48
14:30	40,2	50,1	79,61	18,14	0,03561	12,27
14:45	39,5	48,5	92,12	19,15	0,03759	12,95
15:00	38,9	46,5	110,32	19,93	0,03912	13,48

III.2. ANALYTICAL RESULTS AND EVALUATION

III.2. 1. DIMENSIONAL ANALYSIS

III.2. 1. 1. EQUATION DEVELOPMENT FOR QUANTIFYING PRESSURE LOSSES

To derive the relationships between pressure losses induced by the ribs, their geometric characteristics, and the physical properties of the flowing fluid, the method of dimensional analysis was employed, specifically utilizing the Vaschy-Buckingham π -theorem. This approach enabled the formulation of a generalized correlation based on the primary physical dimensions. The resulting expression can be written as:

$$\Delta P = \Delta P(\rho, D_H, V, \mu, \varepsilon, D_{tr}, L, P_{e,r}, P_{e,ch}, P_{e,s}, L_{ch}) \quad (1)$$

According to the Vaschy-Buckingham theorem, this system can be reduced to eight independent dimensionless groups. Here, L denotes either a characteristic length or the overall length of the solar collector, depending on the context.

$$\frac{\Delta P}{L} = [\pi \cdot k \cdot \rho^\alpha \cdot D_H^\beta \cdot V^\gamma \cdot \mu^x \cdot \varepsilon^y \cdot D_{tr}^z \cdot P_{e,r}^t \cdot L_{ch}^w \cdot P_{e,s}^m \cdot P_{e,ch}^n] \quad (\text{Sène et al., 2022}) \quad (2)$$

π : Indicates a product.

By substituting the fundamental dimensions into Equation (2) and equating both sides, a system of three equations is obtained. Substituting the solutions of this system back into Equation (2) yields the following relationship:

$$\Delta P = k \cdot \frac{L}{D_H} \cdot \rho \cdot V^2 \cdot \left[\left(\frac{\rho \cdot V \cdot D_H}{\mu} \right)^{-x} \cdot \left(\frac{\varepsilon}{D_H} \right)^y \cdot \left(\frac{D_{tr}}{D_H} \right)^z \cdot \left(\frac{P_{e,r}}{D_H} \right)^t \cdot \left(\frac{L_{ch}}{D_H} \right)^w \cdot \left(\frac{P_{e,s}}{D_H} \right)^m \cdot \left(\frac{P_{e,ch}}{D_H} \right)^n \right] \quad (3)$$

According to the Darcy–Weisbach law, we have

$$\Delta P = \frac{1}{2} \cdot f \cdot \frac{L}{D_H} \cdot \rho \cdot V^2 \quad (\text{Avci \& Karagoz, 2019}) \quad (4)$$

Equation (3) becomes:

$$\Delta P = \frac{1}{2} \cdot \frac{L}{D_H} \cdot \rho \cdot V^2 \cdot \left[\left(\frac{\rho \cdot V \cdot D_H}{\mu} \right)^{-x} \cdot \left(\frac{\varepsilon}{D_H} \right)^y \cdot \left(\frac{D_{tr}}{D_H} \right)^z \cdot \left(\frac{P_{e,r}}{D_H} \right)^t \cdot \left(\frac{L_{ch}}{D_H} \right)^w \cdot \left(\frac{P_{e,s}}{D_H} \right)^m \cdot \left(\frac{P_{e,ch}}{D_H} \right)^n \right] \quad (5)$$

$$\Delta P = \frac{1}{2} \cdot \frac{L}{D_H} \cdot \rho \cdot V^2 \cdot \left[(Re)^{-x} \cdot \left(\frac{\varepsilon}{D_H} \right)^y \cdot \left(\frac{D_{tr}}{D_H} \right)^z \cdot \left(\frac{P_{e,r}}{D_H} \right)^t \cdot \left(\frac{L_{ch}}{D_H} \right)^w \cdot \left(\frac{P_{e,s}}{D_H} \right)^m \cdot \left(\frac{P_{e,ch}}{D_H} \right)^n \right] \quad (6)$$

Identifying the general equation for pressure losses enables us to derive a coefficient, denoted as f , which we can obtain using the following expression:

$$f = \left[(Re)^{-x} \cdot \left(\frac{\varepsilon}{D_H} \right)^y \cdot \left(\frac{D_{tr}}{D_H} \right)^z \cdot \left(\frac{P_{e,r}}{D_H} \right)^t \cdot \left(\frac{L_{ch}}{D_H} \right)^w \cdot \left(\frac{P_{e,s}}{D_H} \right)^m \cdot \left(\frac{P_{e,ch}}{D_H} \right)^n \right] \quad (7)$$

By applying a straightforward derivation of equation (6), we obtain:

$$\ln \left(\frac{2 \Delta P D_H}{L \rho V^2} \right) = \left[\begin{aligned} & -x \ln(Re) + y \ln \left(\frac{\varepsilon}{D_H} \right) + z \ln \left(\frac{D_{tr}}{D_H} \right) + \\ & t \ln \left(\frac{P_{e,r}}{D_H} \right) + w \ln \left(\frac{L_{ch}}{D_H} \right) + m \ln \left(\frac{P_{e,s}}{D_H} \right) + n \ln \left(\frac{P_{e,ch}}{D_H} \right) \end{aligned} \right] \quad (8)$$

Equation (6) links the pressure drop to air density, flow velocity, and key dimensionless groups that describe rib geometry. The term ρV^2 represents dynamic pressure, while the function accounts for how rib height, spacing, and pitch affect turbulence and resistance. This form helps generalize the effect of geometry on pressure losses for various configurations.

To examine the empirical relationship between the pressure change (ΔP), the physical properties of the fluid, and the geometric parameters of the ribs and the channel, the experimental data were substituted into equation (8), leading to the following system of equations:

$$[A_{i,j}] \cdot X = [B] \quad \text{lique is } \begin{cases} i = 1, \dots, n \\ j = 1, \dots, 7 \\ n = 90 \end{cases}$$

We see that the matrix $A_{i,j}$ is non-square.

We solve this system using the least square method:

$$[A_{i,j}]^T \cdot [A_{i,j}] \cdot X = [A_{i,j}]^T \cdot [B]$$

$$\begin{bmatrix} i = 1, \dots, n \\ j = 1, \dots, 7 \\ n = 90 \\ [A_{i,j}]^T : \text{Matrix transpose of } [A_{i,j}] \end{bmatrix}$$

We derive a set of equations:

$$[A_{i,j}]^T \cdot [A_{i,j}] X = [A_{i,j}]^T \cdot [B] = [C_{k,m}] \cdot X = [D_{l,f}] \quad (9)$$

$$\begin{bmatrix} k = 1, \dots, 7 \\ m = 1, \dots, 7 \\ l = 1, \dots, 7 \\ f = 1 \end{bmatrix}$$

After solving the system of equations (equation (9)), the obtained solutions are substituted into equation (6), yielding the following relationship.

$$\Delta P = \frac{1}{2} \frac{L}{2D_H} \rho \left[(R_e)^{-0.006} \cdot \left(\frac{\varepsilon}{D_H} \right)^{1.4919} \cdot \left(\frac{D_{tr}}{D_H} \right)^{1.3561} \cdot \left(\frac{P_{e,r}}{D_H} \right)^{-0.8357} \cdot \left(\frac{L_{ch}}{D_H} \right)^{-2.0609} \cdot \left(\frac{P_{e,s}}{D_H} \right)^{0.0661} \cdot \left(\frac{P_{e,ch}}{D_H} \right)^{2.3569} \right] V^2 \quad (10)$$

And therefore:

$$f = \left[(R_e)^{-0.006} \cdot \left(\frac{\varepsilon}{D_H} \right)^{1.4919} \cdot \left(\frac{D_{tr}}{D_H} \right)^{1.3561} \cdot \left(\frac{P_{e,r}}{D_H} \right)^{-0.8357} \cdot \left(\frac{L_{ch}}{D_H} \right)^{-2.0609} \cdot \left(\frac{P_{e,s}}{D_H} \right)^{0.0661} \cdot \left(\frac{P_{e,ch}}{D_H} \right)^{2.3569} \right] \quad (11)$$

The equation (10) is applicable under turbulent flow conditions.

$$\Delta P = \frac{1}{2} \frac{L}{2D_H} \rho \left[(R_e)^{-0.186} \cdot \left(\frac{\varepsilon}{D_H} \right)^{2.489} \cdot \left(\frac{D_{tr}}{D_H} \right)^{2.3931} \cdot \left(\frac{P_{e,r}}{D_H} \right)^{-0.8456} \cdot \left(\frac{L_{ch}}{D_H} \right)^{-1.0819} \cdot \left(\frac{P_{e,s}}{D_H} \right)^{1.354} \cdot \left(\frac{P_{e,ch}}{D_H} \right)^{1.98569} \right] V^2 \quad (12)$$

And therefore:

$$f = \left[(R_e)^{-0.186} \cdot \left(\frac{\varepsilon}{D_H} \right)^{2.489} \cdot \left(\frac{D_{tr}}{D_H} \right)^{2.3931} \cdot \left(\frac{P_{e,r}}{D_H} \right)^{-0.8456} \cdot \left(\frac{L_{ch}}{D_H} \right)^{-1.0819} \cdot \left(\frac{P_{e,s}}{D_H} \right)^{1.354} \cdot \left(\frac{P_{e,ch}}{D_H} \right)^{1.98569} \right] \quad (13)$$

The applicability of equation (12) is restricted to laminar flow conditions.

III.3. GRAPHICAL ILLUSTRATION OF RESULTS

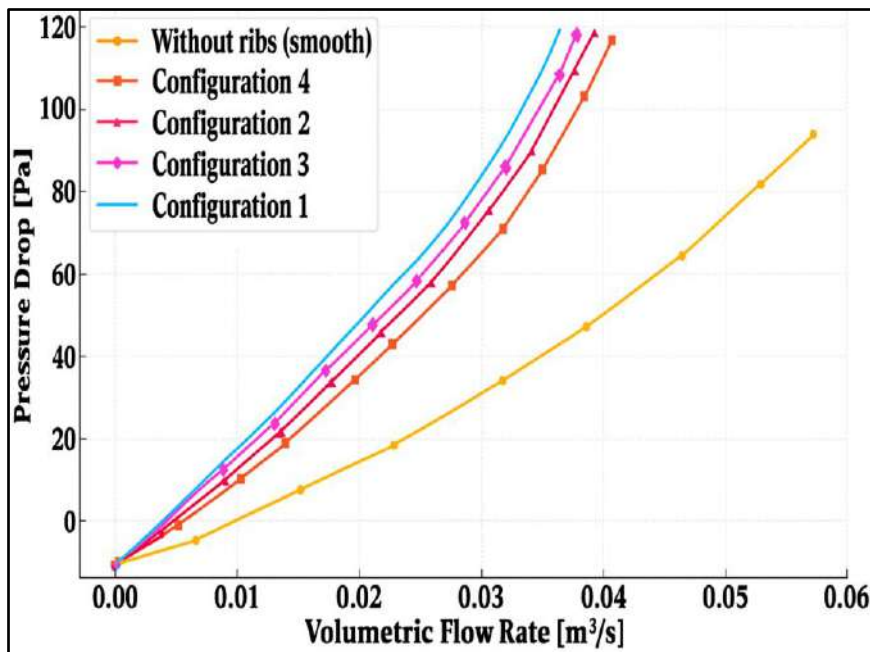


Fig. 4. Pressure Drop as a Function of Volumetric Flow Rate for Smooth and Ribbed Configurations in a Solar Air Collector

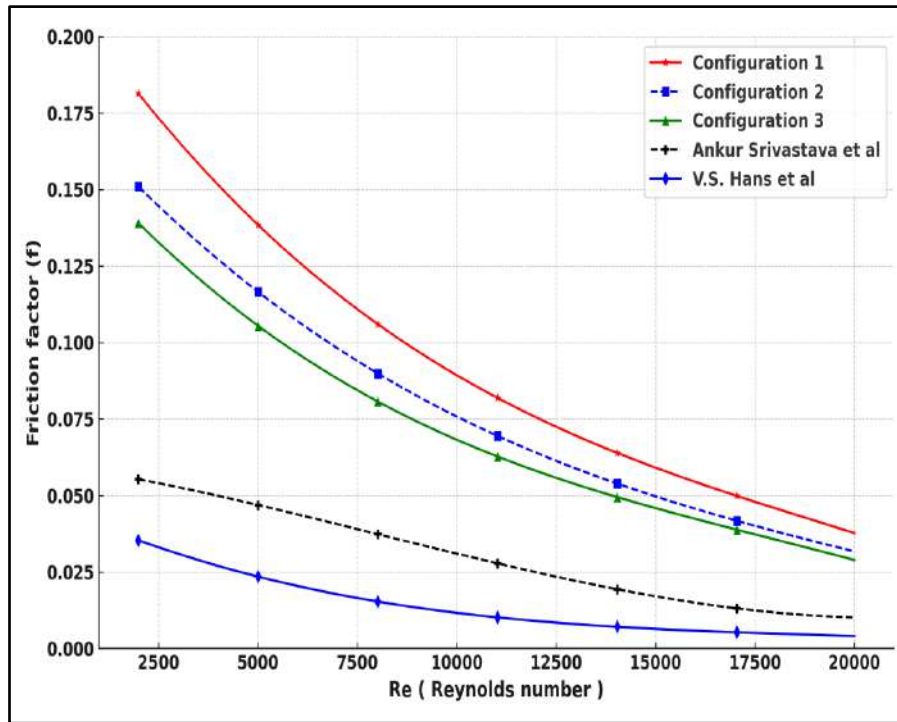


Fig. 5. Variation of Friction Factor with Reynolds Number for Different Rib Configurations

IV. DISCUSSION

The results in Figure 4 show that the smooth channel exhibits the lowest pressure drop, while the addition of ribbed configurations significantly increases hydraulic resistance due to turbulence and recirculation effects. Among the studied cases, Configuration 1 produces the highest losses, whereas Configuration 4 is comparatively less penalizing. These findings confirm the trade-off between enhanced heat transfer and increased pumping power, highlighting the importance of optimizing rib geometry for balanced thermo-hydraulic performance.

Figure 5 shows that the friction factor decreases with increasing Reynolds number for all configurations, which is consistent with the expected hydrodynamic behavior. Among the tested cases, Configuration 1 exhibits the highest frictional losses, while Configuration 3 provides a more balanced performance with reduced pressure drop at higher Reynolds numbers.

A good agreement is observed between our results and those reported in the literature. The general trend in Figure 5 follows the correlations of Ankur Srivastava et al. and V.S. Hans et al., although our configurations show higher values due to the introduction of artificial roughness. This concordance confirms the reliability of our measurements and highlights that the enhanced turbulence induced by the modified geometries leads to friction levels comparable to previously published studies.

V. CONCLUSION

This experimental study examined the influence of zigzag ribs with perforations on the thermo-hydraulic performance of a flat-plate solar air collector. The results demonstrated that the inclusion of ribs significantly enhanced heat transfer due to increased turbulence and boundary-layer disruption. However, this improvement was accompanied by higher pressure drops, indicating greater hydraulic resistance. The findings highlight the inherent trade-off between thermal enhancement and energy losses caused by additional pumping power requirements. Overall, the study provides valuable

insights into the design and optimization of ribbed solar air collectors, offering a reference for future work aimed at achieving an optimal balance between thermal efficiency and hydraulic performance.

NOMENCLATURES

ρ	Density of the air.	[kg/m ³]
D_H	Hydraulic diameter.	[m]
Q_v	Volumetric flow	[m ³ /s]
V	Air speed.	[m/s]
V_{ext}	External air speed	[m/s]
V_{in}	Internal air speed	[m/s]
μ	Dynamic viscosity	[Kg/m. s]
ε	Absolute roughness	[m]
$L_c = L$	Duct length.	[m]
l_c	Width of absorber.	[m]
$P_{e.ch}$	Steps between the ribs.	[m]
$P_{e.r}$	Steps between two successive rows of ribs [m].	[m]
L_{ch}	Length of a rib.	[m]
$P_{e.s}$	Pitch between rib summands in	[m]
$P_{e.t}$	pitch between holes	[m]
D_{tr}	hole diameter	[m]
f	The coefficient of friction	--
λ	Thermal conductivity	[W/m. K]
T_s	Fluid outlet temperature	[°C]
T_e	Fluid inlet temperature	[°C]
ΔT	Temperature difference	[°C]
t	Sampling time	[hours]
ΔP	Pressure difference	[Pascal]
Re	Number of Reynolds	--

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SAHİPLİK YAPISININ AR-GE HARCAMALARI ÜZERİNDEKİ ROLÜ: BORSA İSTANBUL'DAN BULGULAR

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Özet – Bu çalışmada, sermaye yapısının Ar-Ge harcamaları üzerinde anlamlı bir etkisinin olup olmadığı araştırılmıştır. Bu doğrultuda, 2012-2023 döneminde Borsa İstanbul'da kesintisiz işlem gören 72 firmaya ait finansal ve finansal olmayan verilerden yararlanılmıştır. Çalışmada Ar-Ge harcamaları bağımlı değişken olarak kullanılırken; sahiplik yapısı göstergelerinden olan kurumsal, yönetsel ve yabancı sahiplik oranları ise bağımsız değişken olarak kullanılmıştır. Ayrıca, Ar-Ge harcamaları üzerinde etkisi olduğu düşüncesinden hareketle kaldıraç oranı, firma büyüklüğü ve PD/DD oranı ise kontrol değişkenleri olarak modele dahil edilmiştir. Çoklu doğrusal regresyon analizinin kullanıldığı çalışmada, kurumsal sahiplik oranının Ar-Ge harcamaları üzerinde pozitif ve istatistiksel olarak anlamlı bir etkisinin olduğu belirlenmiştir. Ancak, sahiplik yapısının diğer göstergeleri olarak kullanılan yönetsel ve yabancı sahiplik oranları ile Ar-Ge harcamaları arasında istatistiksel olarak anlamlı bir ilişki elde edilememiştir.

Anahtar Kelimeler – Sahiplik Yapısı, Ar-Ge Harcamaları, Borsa İstanbul.

I. GİRİŞ

Küreselleşmenin etkisiyle yoğunlaşan rekabet ortamı, firmaları Ar-Ge ve inovasyon çalışmalarına yönelmeye itmektedir. Bu doğrultuda işletmeler, yenilikçi ve teknolojik ürün ile süreç geliştirmenin bir zorunluluk haline geldiğini kavramış; Ar-Ge ve inovasyon çalışmalarına daha fazla yatırım yapmaya yönelmişlerdir [7].

Ar-Ge, en genel ifadeyle, toplum ve kültüre ilişkin bilgi birikimini artırmak ve mevcut bilgiyi yeni alanlarda değerlendirmek amacıyla yürütülen yaratıcı ve sistematik faaliyetler aracılığıyla, işletmelerin yenilikçi ürün ve süreçler geliştirme çabalarını ifade etmektedir [5]. Bu bağlamda rekabetçi iş ortamında faaliyetlerini sürdüren firmalar tarafından yapılan Ar-Ge harcamaları değer oluşturma ve büyüme fırsatlarını yakalamada stratejik bir öneme sahiptir. Ancak, söz konusu bu harcamalar uzun vadeli ve belirsizlik içeren bir niteliğe sahip olduğu için kısa vadede firmaların nakit akışlarında ve karlılık düzeylerinde dalgalanmalara neden olarak riskli bir yapı sergileyebilmektedir [4]. Bu noktada, Ar-Ge harcamalarının taşıdığı stratejik öneme rağmen yüksek risk ve belirsizlik içermesi nedeniyle firmaların bu tür yatırımlara ilişkin kararlarını etkileyen içsel ve dışsal birçok faktörün incelenmesini gerekli kılmaktadır. Söz konusu bu faktörlerden biri de firma sahiplik yapısıdır.

Sahiplik yapısı, işletmeye ait öz kaynakların hissedarlar arasında hangi oranlarda dağıldığını gösteren yapısal bir özelliktir. Örneğin, bazı işletmelerde öz kaynakların büyük bir bölümü belirli bir aile tarafından kontrol edilirken, bazılarında bu paylar kurumsal ya da yabancı yatırımcıların elinde bulunabilmektedir. Dolayısıyla, bir firmanın sahiplik yapısı hem işletmenin genel işleyişini hem de stratejik karar alma süreçlerini önemli ölçüde şekillendirebilmektedir [1]. Bu bağlama sahiplik yapısının, firmaların risk algılarını, yatırım önceliklerini ve uzun vadeli stratejik yönelimlerini etkilemesi, Ar-Ge harcamalarının

miktarı ve yönü üzerinde de belirleyici olabileceği yönünde bir beklenti oluşturmaktadır. Bu amaçla çalışmada, sahiplik yapısının Ar-Ge harcamaları üzerindeki etkisi incelenmiştir. 2012-2023 döneminde Borsa İstanbul'a kote olan 72 firmaya ait verileri kullanılarak gerçekleştirilen regresyon analizi neticesinde Ar-Ge harcamaları ile kurumsal sahiplik oranı arasında pozitif ve istatistiksel olarak anlamlı bir ilişki olduğu; ancak yönetsel ve yabancı sahiplik oranlarının Ar-Ge harcamaları üzerinde anlamlı bir etki yaratmadığı sonucuna varılmıştır.

II. LİTERATÜR TARAMASI

Literatürde Ar-Ge harcamaları ile sahiplik yapısı arasındaki ilişkiye odaklanan temel çalışmalar aşağıda sunulmuştur.

[11], Çin'de borsaya kote olan firmalar için sahiplik yoğunluğu, yönetsel sahiplik ve kurumsal sahipliğin Ar-Ge harcamaları üzerindeki etkisini araştırmışlardır. 780 firmanın 2000-2005 yılları arasındaki verilerinden yararlanılan çalışmada sahiplik yoğunluğu ve yönetsel sahipliğin Ar-Ge harcamaları üzerinde negatif bir etkisinin olduğu ancak kurumsal sahipliğin Ar-Ge harcamaları üzerinde pozitif bir etkisinin olduğu tespit edilmiştir.

[6], sermaye yapısının yenilikçi faaliyetleri üzerindeki etkisini belirlemek amacıyla gerçekleştirdikleri çalışmalarında İtalya'da faaliyetlerini sürdüren 2000 üretici firmasından yararlanmışlardır. Elde edilen bulgular, sahiplik yoğunluğunun Ar-Ge faaliyetlerini olumsuz etkilediğini ortaya koymuştur.

[10], 2005-2007 döneminde Çin'de faaliyetlerini sürdüren firmaların sahiplik yapıları ile Ar-Ge faaliyetleri arasındaki ilişkiyi incelemişlerdir. Yapılan analizler neticesinde, yabancı sahiplik ile Ar-Ge faaliyetleri arasında negatif yönlü bir ilişki olduğu tespit edilmiştir.

[8], 2000-2005 döneminde İtalya Borsasına kayıtlı firmaların sahiplik yapısı ile Ar-Ge harcamaları arasındaki ilişkiyi incelemişlerdir. 363 firma verisinin kullanıldığı çalışmada, kurumsal sahiplik ile Ar-Ge harcamaları arasında pozitif ve anlamlı bir ilişki olduğu ortaya konmuştur.

[3], sahiplik yapısının Ar-Ge harcamaları üzerindeki etkisini incelemişlerdir. Borsa İstanbul'a kayıtlı 112 imalat işletmesi üzerine yaptıkları çalışmada yabancı sahiplik ile Ar-Ge harcamaları arasında negatif yönlü bir ilişki olduğu sonucuna varılmıştır.

[2], kaldıraç ve yabancı sahipliğin Ar-Ge yatırımları ve firma performansı üzerindeki etkisini incelemişlerdir. 2008-2016 döneminde Borsa İstanbul'da işlem gören 125 imalat firması üzerinde yaptıkları çalışma sonucunda yabancı sahipliğin Ar-Ge yatırımları ve firma performansı arasındaki ilişkiyi olumlu yönde etkilediği tespit edilmiştir.

[4], İspanya'da borsaya kote şirketlerden oluşan bir örneklem üzerinden sahiplik yapısı ile Ar-Ge yatırımları arasındaki ilişkiyi incelemişlerdir. Yapılan analizler, kurumsal sahiplik ile Ar-Ge harcamaları arasında pozitif bir ilişki olduğunu ancak sahiplik yoğunluğunun Ar-Ge harcamaları üzerinde herhangi bir etkisinin olmadığını ortaya koymuştur.

[9], Ar-Ge yatırımları ile sahiplik yapısı arasındaki ilişki incelediği çalışmada, Borsa İstanbul'da işlem gören 22 firmanın 2012-2020 dönemi verilerinden yararlanmıştır. Yapılan analizler sonucunda, kurumsal sahiplik ile Ar-Ge yatırımları arasında negatif; buna karşın sahiplik yoğunluğu ile Ar-Ge yatırımları arasında pozitif yönlü bir ilişki elde edilmiştir.

III. METODOLOJİ

Bu çalışmada, sahiplik yapısı ile Ar-Ge harcamaları arasındaki ilişkiyi tespit etmek amaçlanmıştır. Bu doğrultuda, Borsa İstanbul’a kote olan 72 firmanın 2012-2023 dönemine ilişkin verilerden faydalanılmıştır. İlgili dönemlerde verisine ulaşılamayan ve Ar-Ge harcamaları “0” olan firmalar ile varlık yapıları farklılık gösteren finansal firmalar analiz dışında tutulmuştur. Çalışma doğrultusunda kullanılan finansal verilere Finnet veri tabanından, sahiplik yapısına ilişkin verilere ise firmaların resmî web sayfalarında yer alan faaliyet raporlarından ulaşılmıştır.

A. Araştırma Modeli ve Değişkenler

Sahiplik yapısı ile Ar-Ge harcamaları arasındaki ilişkiyi test etmek amacıyla çoklu doğrusal regresyon analizi yapılmış ve aşağıdaki ekonometrik model oluşturulmuştur:

$$AR\_GE = \beta_0 + \beta_1 KURUMSAL + \beta_2 YONETSEL + \beta_3 YABANCI + \beta_4 KALD + \beta_4 BUY + \beta_4 PD/DD + \epsilon_i$$

Modelde yer alan tüm değişkenlere yönelik açıklamalar Tablo 1’deki gibidir:

Tablo 1. Değişkenlere İlişkin Açıklamalar

Değişken Türü	Değişken	Hesaplama Yöntemi
Bağımlı Değişken	AR_GE	Ar-Ge harcamalarının doğal logaritması ile ölçülmüştür.
Bağımsız Değişken	KURUMSAL	Firmanın toplam sermayesi içindeki kurumsal yatırımcıların payı
Bağımsız Değişken	YONETSEL	Firmanın toplam sermayesi içindeki yöneticilerin payı
Bağımsız Değişken	YABANCI	Firmanın toplam sermayesi içindeki yabancı yatırımcıların payı
Kontrol Değişkeni	KALD	Toplam Borçlar/Toplam Varlıklar
Kontrol Değişkeni	BUY	Firma toplam varlıklarının doğal logaritması
Kontrol Değişkeni	PD/DD	Piyasa Değeri / Defter Değeri

IV. BULGULAR

Tablo 2, analiz kapsamında kullanılan tüm değişkenlere ilişkin tanımlayıcı istatistikleri göstermektedir.

Tablo 2. Tanımlayıcı İstatistikler

	Gözlem	Ortalama	Std. Sapma	Minimum	Maksimum
AR_GE	864	6,513	0,911	2,32	8,66
KURUMSAL	864	0,394	0,282	0,00	0,96
YONETSEL	864	0,101	0,199	0,00	0,98
YABANCI	864	0,098	0,217	0,00	0,98
KALD	864	0,525	0,230	0,06	1,14
BUY	864	8,923	0,715	7,14	10,79
PD/DD	864	2,515	4,249	0,00	70,52

Tabloya bakıldığında AR_GE harcamalarının ortalamasının 6,513 olduğu görülmektedir. Sahiplik yapısı göstergeleri olarak ele alınan kurumsal sahiplik oranının ortalama değeri 0,394, yönetsel sahiplik oranının ortalama değeri 0,101 ve yabancı sahiplik oranının ortalama değeri ise 0,098’dir. Kontrol değişkenleri olan KALD, BUY ve PD/DD değişkenlerinin ortalama değerlerinin ise sırasıyla 0,525, 8,923 ve 2,515 olduğu görülmektedir.

Tablo 3. Korelasyon Matrisi

	AR-GE	KURUMSAL	YONETSEL	YABANCI	KALD	BUY	PD/DD
AR GE	1	0,256**	-0,234**	0,079*	0,112**	0,647**	0,085*
KURUMSAL	0,256**	1	-0,539**	-0,297**	-0,050	0,339**	0,071
YONETSEL	-0,234**	-0,539**	1	-0,199**	-0,076	-0,375**	-0,034
YABANCI	0,079*	-0,297**	-0,199**	1	0,158**	0,109**	0,061
KALD	0,112**	-0,050	-0,076	0,158**	1	0,169**	0,263**
BUY	0,647**	0,339**	-0,375**	0,109**	0,169**	1	0,043
PD/DD	0,085*	0,071	-0,034	0,061	0,263*	0,043	1

**, * %1 ve %5 düzeyinde anlamlılığı ifade etmektedir.

Tablo 3'te bulunan korelasyon matrisi incelendiğinde, AR_GE harcamaları ile kurumsal ve yabancı sahiplik oranları arasında pozitif; yönetsel sahiplik oranı ile de negatif ve anlamlı bir ilişki olduğu görülmektedir. Ayrıca, çoklu doğrusal bağlantı sorununun varlığı araştırılmış ve bu amaçla tüm bağımsız değişkenler arasındaki korelasyon katsayıları incelenmiştir. Elde edilen sonuçlara göre, değişkenler arasındaki korelasyon katsayılarının 0,75'in altında olması nedeniyle çoklu doğrusal bağlantı sorununun bulunmadığı sonucuna ulaşılmıştır.

Tablo 4. Analiz Sonuçları

Değişkenler	Katsayı	Std. Hata	t değeri	Olasılık
Değişkenler	Katsayı	Std. Hata	t değeri	Olasılık
KURUMSAL	0,258	0,137	1,888	0,059
YONETSEL	0,259	0,185	1,400	0,162
YABANCI	0,178	0,150	1,192	0,234
KALD	-0,029	0,127	-0,225	0,822
BUY	0,810	0,0431	8,869	0,000***
PD/DD	0,011	0,0071	,683	0,093
C (SABİT)				
Gözlem sayısı: 864 Düzeltilmiş R ² : 0,420 F değeri: 78,768***				
***, **, * %1, %5 ve %10 düzeyinde anlamlılığı ifade etmektedir.				

Tablo 4'te yer alan bulgular incelendiğinde modelin bir bütün olarak anlamlı olduğu (F değ= 78,768***) ve bağımsız değişkenlerin bağımlı değişkende meydana gelen değişimlerin yaklaşık %42'sini açıklama gücüne sahip olduğu görülmektedir (Düzeltilmiş R²: 0,420). Tahmin bulguları incelendiğinde, AR_GE harcamaları ile sahiplik yapısı göstergelerinden olan kurumsal sahiplik oranı arasında pozitif ve istatistiksel olarak anlamlı bir ilişki olduğu görülmektedir. Yani, analiz kapsamında kullanılan firmaların kurumsal sahiplik oranlarında meydana gelen artışlar AR_GE harcamalarında da artışa neden olmaktadır. Ancak, sahiplik yapısının diğer göstergeleri olan yönetsel ve yabancı sahiplik oranları ile AR_GE harcamaları arasında istatistiksel olarak anlamlı ilişkiler tespit edilememiştir. Kontrol değişkenleri olarak kullanılan BUY ve PD/DD değişkenleri ile AR_GE harcamaları arasında pozitif yönlü ve istatistiksel olarak anlamlı ilişkiler elde edilirken; KALD değişkeninin AR_GE harcamaları üzerinde herhangi bir etkisinin olmadığı belirlenmiştir.

V. SONUÇLAR

Bu çalışmada, sahiplik yapısının AR_GE harcamaları üzerinde herhangi bir etkisinin olup olmadığı test edilmiştir. Bu doğrultuda, 2012-2023 döneminde Borsa İstanbul’da aralıksız işlem gören 72 firmaya ait veriler kullanılarak çoklu doğrusal regresyon analizi gerçekleştirilmiştir. Çalışmada AR_GE harcamaları bağımlı değişken olarak kullanılırken; kurumsal, yönetsel ve yabancı sahiplik oranları ise bağımsız değişkenler olarak ele alınmıştır. Ayrıca, AR_GE harcamaları üzerinde etkisi olabileceği düşüncesiyle KALD, BUY ve PD/DD değişkenleri de modele kontrol değişkenleri olarak dahil edilmiştir.

Analiz sonuçlarına göre AR_GE harcamaları ile kurumsal sahiplik oranı arasında pozitif yönlü ve istatistiksel olarak anlamlı bir ilişki olduğu belirlenmiştir. Bu sonuç, kurumsal yatırımcıların kısa vadeli kazanç beklentilerinden çok uzun vadeli değer yaratma hedeflerine odaklanmaları sayesinde, firmaların yenilikçi faaliyetlere yönelmelerini teşvik ettikleri şeklinde yorumlanabilir. Literatürde yer alan önceki çalışmaların [11], [8], [4] sonuçlarıyla da örtüşen bu bulgu, kurumsal sahiplik oranındaki artışın firmaların yenilikçi faaliyetlerini destekleyerek rekabet avantajı kazanmalarına katkı sağladığını ortaya koymaktadır. Ancak bu bulgunun aksine sahiplik yapısının diğer göstergeleri olan yönetsel ve yabancı sahiplik oranları ile AR_GE harcamaları arasında herhangi bir ilişki tespit edilememiştir. Kurumsal sahipliğin aksine, yönetsel ve yabancı sahiplik oranlarının AR_GE harcamaları üzerinde herhangi bir etkisinin bulunmaması farklı yatırımcı gruplarının risk algıları ve beklentileri arasındaki farklılıkları da ortaya koymaktadır.

Her araştırmada olduğu gibi bazı sınırlılıkları bulunan bu çalışmada elde edilen bulgular doğrultusunda, gelecek çalışmalarda daha geniş veri setlerinin kullanılması, farklı sahiplik türlerinin modele dahil edilmesi ve sektörel farklılıkların göz önünde bulundurulması, sahiplik yapısı ile Ar-Ge harcamaları arasındaki ilişkinin daha kapsamlı incelenmesine olanak sağlayabilir.

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Tourism Expenditures in Türkiye: Trends, Seasonality, and Index Analysis (2012–2024)

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Abstract – The tourism sector is strategically important for the economic growth and sustainable development of countries. This study aims to examine the evolution of tourism expenditures and average per capita expenditure indicators in Türkiye between 2012 and 2024. The data used in the study were obtained from the official statistics of the Turkish Statistical Institute (TURKSTAT). Three main methods were applied in the analyses: (i) time-series trend analysis revealed long-term trends in annual changes; (ii) quarter-based analysis assessed seasonality effects on tourism expenditures, particularly determining that the third quarter, corresponding to the summer months, is the period with the highest expenditures; and (iii) index analysis (2012=100) comparatively examined the relative changes in total tourism expenditures and per capita expenditures. The findings reveal that total tourism expenditures tend to increase in the long term, but average per capita expenditures have not increased to the same extent. Political developments in 2016 and the COVID-19 pandemic in 2020 led to sharp declines in both annual and quarter-based indicators. Although a strong recovery was observed in the post-2021 period, average per capita spending was still below the 2012 baseline by 2024. These results demonstrate that the growth of tourism revenues in Türkiye is largely due to the increase in the number of visitors, and that policies to increase per capita spending are needed for sustainable growth.

Keywords – Tourism Expenditure, Per Capita Spending, Time Series Analysis, Seasonality, Index Analysis.

I. INTRODUCTION

The tourism sector is recognized as one of the most important sectors in terms of global economic growth, employment creation, and foreign exchange inflow [1], [2]. Tourism revenues, particularly for developing countries, have positive impacts on the balance of payments and are becoming an important component of sustainable development policies [3]. Furthermore, average per capita expenditure, as well as the quantitative increase in tourism revenues, is a critical indicator of the sector's economic contribution [4]. Studies on tourism demand and spending behavior in the literature indicate that the sector is highly sensitive to both external shocks (economic crises, political developments, natural disasters, pandemics) and internal factors (pricing policies, destination quality, service diversity) [5], [6]. For instance, the political and security issues experienced in Turkey in 2016 led to a substantial decrease in tourism revenues. Similarly, the global contraction in Turkish tourism, which was caused by the 2020s pandemic, resulted in a significant decline [7]. Despite this, the sector has a high capacity for recovery, and rapid increases are observed in post-crisis periods [8], [9].

Türkiye is among the world's leading destinations with its geographical location, cultural heritage, and tourism diversity. However, it is observed that the increase in total tourism revenues is not always reflected in per capita expenditures [10]. This situation demonstrates that focusing solely on visitor numbers in

tourism policies is not sufficient; strategies aimed at increasing per capita expenditures must also be developed [11].

The aim of this study is to analyze changes in Türkiye's tourism expenditures and average per capita expenditures using TÜİK data for the period 2012–2024, revealing long-term trends, seasonal effects, and structural differences. This will assess the tourism sector's vulnerabilities and strengths, aiming to contribute to sustainable tourism strategies for policymakers.

II. MATERIALS AND METHOD

The data used in this study were obtained from the official statistics titled “Tourism Expenditure and Average Expenditure Per Capita, 2012–2024,” published by the TURKSTAT. The data set includes both annual total data and detailed values divided into quarters (I, II, III, and IV). The study is based on two main variables: tourism expenditure (thousand US dollars) and average expenditure per capita (US dollars). First, long-term trends in both indicators were examined using time-series graphs using annual data. Time-series analysis is a frequently used method to visualize changes in data over time and identify trends [1], [13]. Then, the seasonal effects on tourism revenues were evaluated through quarterly analyses. Identifying seasonal patterns is widely used in tourism research, particularly in understanding demand fluctuations [5], [8]. In the final stage, an index analysis was conducted using 2012 as the base year, and relative changes were calculated for both total tourism expenditure and average per capita expenditure, assuming 2012 = 100. The indexing method is frequently used in economics and tourism literature to ensure comparability of series at different scales [1], [2]. These methods allow for a systematic examination of the structural characteristics and vulnerabilities of Türkiye's tourism revenues, revealing both long-term trends and seasonal fluctuations.

III. RESULTS

This section presents and examines in detail the results of the analyses conducted in the study.

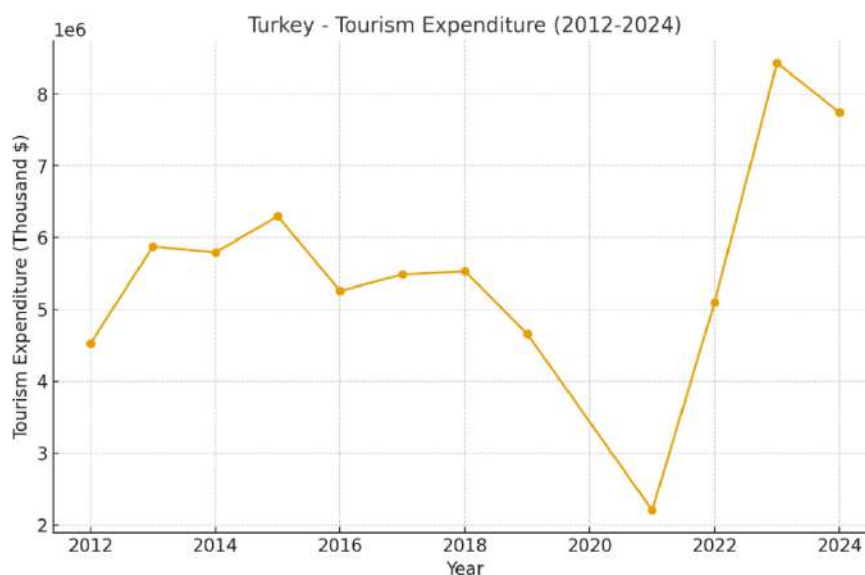


Fig. 1 Tourism Expenditure (2012-2024)

An examination of the graph in Figure 1 showing tourism expenditures for the period 2012–2024 reveals a fluctuating but generally increasing trend in Türkiye's tourism expenditures. Expenditures, which were approximately \$4.5 billion in 2012, reached \$6.3 billion in 2015, reaching one of the highest levels of the period. However, a sharp decline was experienced due to political and economic developments in 2016, and this trend continued with limited recoveries until 2019. In 2020, due to the global impact of the COVID-19 pandemic, tourism expenditures declined dramatically, falling to \$2.2 billion, clearly demonstrating the

tourism sector's vulnerability to external shocks. The recovery, which began in 2021, accelerated particularly in 2022 and 2023, reaching a peak of \$8.4 billion in 2023. Despite a slight decline in 2024, spending remains well above the historical average, indicating that the sector is entering a strong recovery phase.

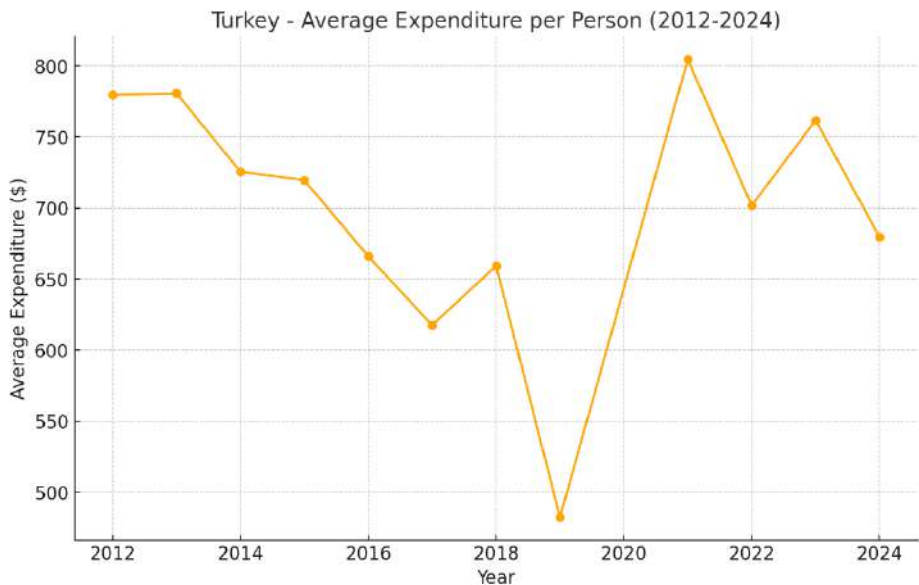


Fig. 2 Average Expenditure per Person (2012-2024)

A review of average per capita expenditures for the period 2012–2024 in Figure 2 shows that, unlike tourism expenditures, the series follows a more irregular and fluctuating course. Expenditures, which remained stable at approximately \$780 in 2012 and 2013, entered a significant downward trend starting in 2014, falling to \$620 in 2017. Although a brief recovery occurred in 2018, a sharp decline occurred in 2019, reaching the lowest value of the analysis period at \$480. This dramatic decline points to the impact of both global economic conditions and structural changes in the tourism market. A rapid upward trend is noted after 2020, with the highest value for the period exceeding \$800 in 2021. However, this increase was not sustainable, it fell to \$700 in 2022, recovered again in 2023 and remained around \$760, and then fell to \$680 in 2024, presenting a fluctuating outlook.

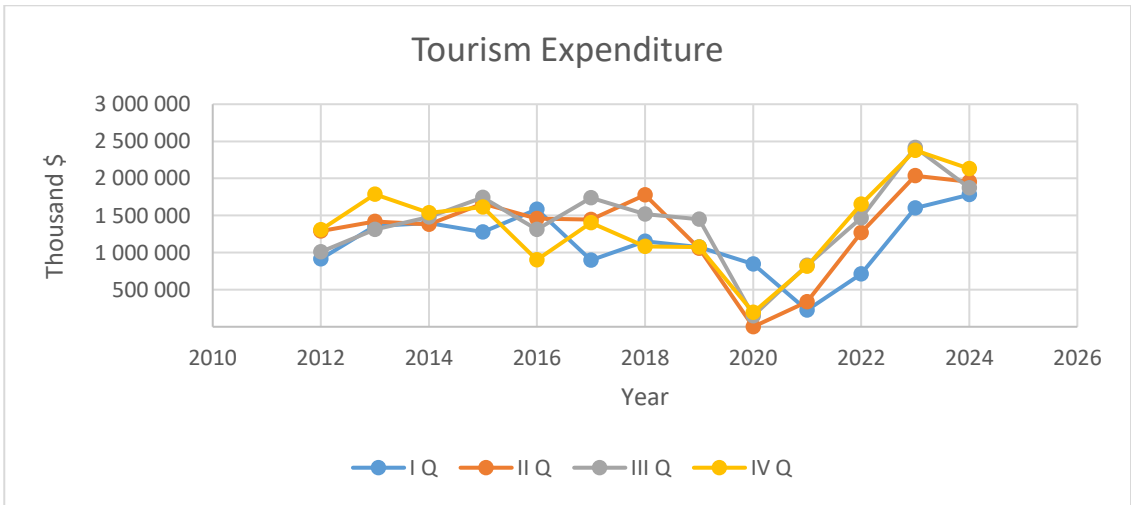


Fig. 3 Tourism Expenditures by Annual Quarters

Figure 3 indicates that quarterly tourism expenditures for the period 2012–2024 display similar trends across all four quarters, with the third quarter (July–September) recording higher values than the others. This clearly demonstrates that summer is the busiest period for Turkish tourism. While a relatively balanced

increase was observed across all quarters between 2012 and 2015, a decline was observed across all quarters in 2016 due to political and economic factors. While there were partial recoveries until 2019, a dramatic decline occurred across all quarters in 2020 due to the COVID-19 pandemic, leading to a sharp contraction in the tourism sector, regardless of the quarter. A recovery trend began again in 2021, with strong increases recorded across all quarters in 2022 and 2023. The high values in the third and fourth quarters, in particular, indicate that seasonality in tourism persisted in the post-crisis period. Although there will be fluctuations between quarters in 2024, tourism expenditures are seen to be well above the 2012 level throughout the entire period.

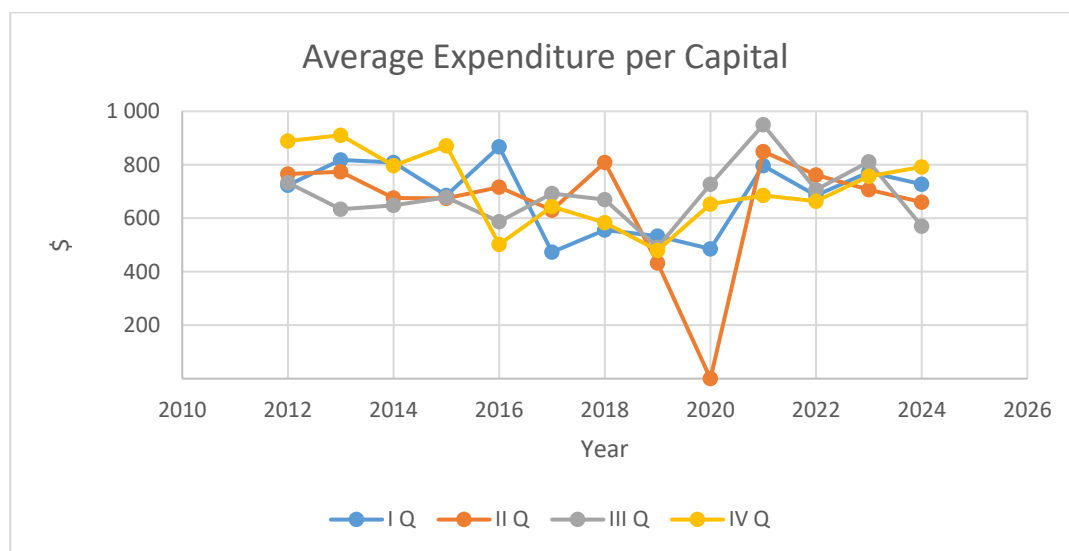


Fig. 4 Average per Capita Expenditure by Annual Quarter

An examination of the average per capita expenditures by quarter for the period 2012–2024 in Figure 4 reveals a highly fluctuating trend across the years, with no apparent stability. During the 2012–2015 period, higher per capita expenditures were noted, particularly in the fourth quarter (October–December) compared to the other quarters. However, in 2016 and 2017, these values decreased significantly across all quarters. While a relatively even distribution was observed in 2019, a dramatic decline was experienced in the second quarter (April–June) in 2020 due to the COVID-19 pandemic, with the lowest value recorded for the entire analysis period. This suggests that pandemic restrictions had the greatest impact on the tourism sector during the spring-summer period. Recovery began after 2021, with per capita expenditures exceeding \$900 in some quarters; however, this increase was not consistent, and fluctuations persisted between quarters in the following years.

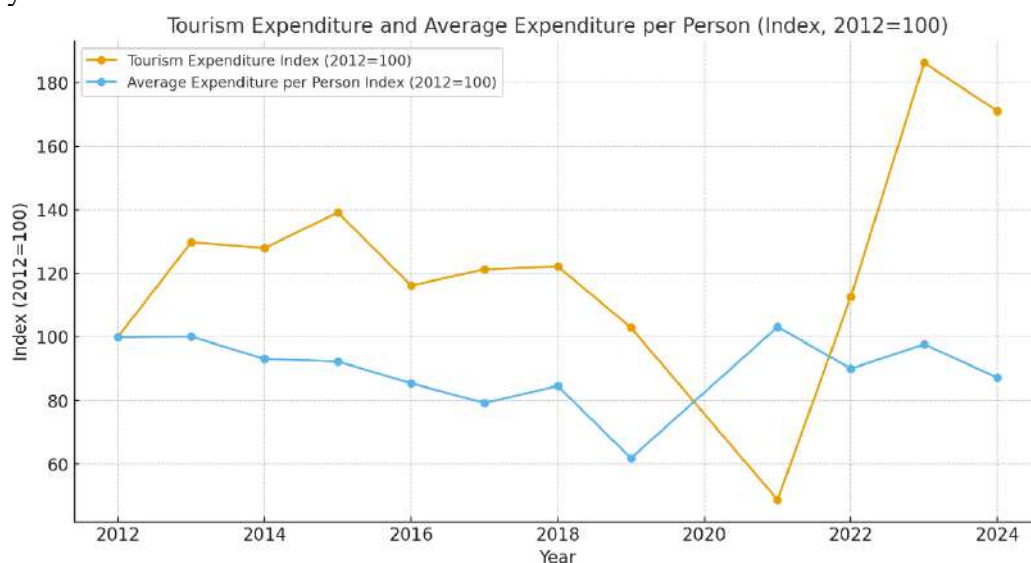


Fig. 5 Tourism Expenditure vs. Per Capita Spending Index (2012=100)

The index graph in Figure 5, based on 2012, clearly demonstrates that total tourism expenditure and average per capita expenditure exhibit divergent trends. After 2012, the tourism expenditure index rose, reaching 140 in 2015. Although it declined in 2016, it recovered in 2017 and 2018. However, due to the pandemic, it fell to 50 in 2020, recording its lowest value during the period. A strong recovery began in 2021, and in 2023, the index reached 185, reaching its peak for the analysis period. In contrast, the per capita expenditure index generally declined after 2012, falling to 62 in 2019. Despite experiencing brief recoveries after 2020, it remained below the base value of 100 as of 2024.

IV. DISCUSSION

Analysis of tourism data from 2012 to 2024 shows that Türkiye's tourism revenues, while fluctuating, are on a long-term upward trend. Annual tourism expenditures peaked in 2015 and experienced sharp declines due to political and economic developments in 2016 and the impact of the COVID-19 pandemic in 2020. However, a strong recovery was observed after 2021, and tourism expenditures reached their highest level in history in 2023. This trend demonstrates that Turkish tourism is vulnerable to external shocks but has a high capacity for recovery.

Average per capita expenditure data, however, exhibited a different dynamic than total tourism expenditures, generally following a fluctuating course. Per capita expenditure, which was relatively high between 2012 and 2015, exhibited a declining trend between 2016 and 2019, reaching its lowest level in the analysis period in 2019. Although a brief increase occurred in 2021, the fact that this indicator remains below the 2012 baseline value as of 2024 suggests that the total revenue increase is largely due to the increase in tourist numbers.

Quarter-by-quarter analyses clearly reveal the seasonality in tourism. The third quarter (July–September), in particular, regularly saw the highest tourism expenditures, while the first quarter (January–March) remained at its lowest levels. This seasonality effect disappeared during the pandemic but resurfaced after 2021. Average per capita spending also exhibited significant fluctuations on a quarterly basis, with dramatic declines particularly observed in the second quarter of 2020.

The index analysis (2012=100) also supports the findings. While the tourism expenditure index rose to 185 in 2023, indicating a significant increase, the per capita expenditure index remained below the 2012 level. This divergence demonstrates that growth in Türkiye's tourism revenues is driven by quantity, not quality. Therefore, it's clear that tourism strategies should focus not only on visitor numbers but also on policies that increase per capita spending.

V. CONCLUSION

This study analyzed changes in Türkiye's tourism expenditures and average per capita spending on an annual and quarterly basis between 2012 and 2024. The findings revealed a long-term upward trend in total tourism revenues, but per capita spending did not support this increase. It was determined that the tourism sector contracted rapidly, particularly during periods of global crises such as pandemics, but subsequently managed to recover strongly.

The results highlight two important points regarding Türkiye's tourism policies:

1. Resilience and recovery capacity: While the sector is vulnerable to external shocks, it has the potential for rapid recovery.
2. The need to increase per capita spending: For growth in tourism revenues to be sustainable, quality-focused strategies should be developed to increase spending levels rather than focusing solely on tourist numbers.

In conclusion, while quantitative growth has been achieved in Türkiye's tourism revenues, qualitative growth requires diversifying the tourist profile, implementing policies targeting high-income groups, and increasing the added value of tourism products.

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Optimization of Exopolysaccharide Production by Lactic Acid Bacteria under Different Culture Conditions

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Abstract – This study was conducted to determine the exopolysaccharide (EPS) production capacities of seven different lactic acid bacteria (LAB) strains and to optimize their culture conditions. LAB-derived EPSs are natural polymers with significant biological and functional properties, making them valuable for food technology and biopolymer production. The strains *Enterococcus faecium*, *Lactobacillus sakei*, *Lactococcus garvieae*, *Lactococcus lactis cremoris*, *Lactococcus lactis*, *Weissella confusa*, and *Lactobacillus plantarum* were evaluated using MRS medium. According to the results, the highest EPS yield was obtained from *L. lactis cremoris* (652.00 ± 44.00 mg/L). Optimization of the carbon source revealed that sucrose produced the highest yield compared to glucose and fructose, while yeast extract was found to be significantly superior to other nitrogen sources. At concentrations of 15% sucrose and 5% yeast extract, the EPS amount reached 8415.67 ± 444.83 mg/L. The strain showed a broad tolerance within the pH range of 5.5–8.0, with optimal production observed at 37–40 °C and maximum yield achieved after 96 hours of incubation. Statistical analyses (ANOVA and Tukey HSD) indicated that different parameters had significant effects on EPS production. These findings demonstrate that *L. lactis cremoris* is a suitable biotechnological source for high-yield EPS production and that the produced EPS has potential as a functional additive in sustainable bioplastic development.

Keywords – Lactic Acid Bacteria, Exopolysaccharide (EPS), Optimization, Sustainable Biopolymer, Environmental Biotechnology, Bioplastic Production, Carbon And Nitrogen Sources.

I. INTRODUCTION

Lactic acid bacteria (LAB) are safe microorganisms that have been used in food fermentation for centuries. In recent years, studies on exopolysaccharides (EPS) produced by LAB have intensified, leading to a better understanding of their effects on food structure and human health [1]. EPS enhance the texture, viscosity, and stability of fermented dairy and bakery products, thereby extending shelf life while also modulating host health through regulation of the gut microbiota [1]. Therefore, LAB-derived EPSs hold strategic importance not only for food technology but also for probiotic and functional food applications. EPS synthesized by LAB can be structurally linear or branched. Linear glucans are connected via β-1,6 or β-1,4 glycosidic linkages, whereas branched EPS exhibit more complex three-dimensional configurations due to the presence of side chains [2], [3], [4]. These structural variations influence polymer solubility, viscosity, and rheological properties [2], [3]. Furthermore, EPSs are classified as homopolysaccharides or heteropolysaccharides based on the number of saccharide types. Homopolysaccharides consist of repeating glucose or fructose units, while heteropolysaccharides contain multiple sugars such as glucose, galactose, and mannose, and this composition determines their biological activities [5].

The biological functions of LAB-EPSs are highly diverse. They may exhibit antioxidant, immunomodulatory, antibacterial, hypoglycemic, and probiotic properties [6], [7]. EPSs also play a vital role in bacterial survival by forming a mucoid layer that protects LAB cells from antibiotics and toxic compounds [8]. In food applications, LAB-EPSs act as natural thickeners and stabilizers, improving viscosity, reducing syneresis, and enhancing mouthfeel in fermented milk products. Recent studies have reported that bacterial EPSs are used as coatings or edible films for fruits and vegetables, extending their shelf life [9]. In this context, EPSs emerge as promising biopolymers capable of replacing artificial additives in line with the clean-label concept.

The pharmaceutical and biomedical potential of EPSs is also remarkable. Due to their biocompatible and biodegradable nature, they can be used in drug delivery systems and have been reported to promote wound healing [10]. Depending on their structure, certain EPSs can interact with immune cells, regulate cytokine production, and strengthen immune responses [11], [12].

Numerous parameters affect EPS yield during LAB fermentation. The carbon source, serving as a precursor for sugar nucleotides, is the most critical factor [13], [14]. Nitrogen source type, pH, temperature, and agitation rate also play crucial roles by influencing glycosyltransferase activity [1]. While most LABs grow optimally between 25–40 °C, EPS synthesis is often favored at 30 °C and pH 6–6.5 for specific strains [15]. Extended fermentation periods may reduce EPS yield due to enzymatic degradation; hence, optimization of time and conditions is essential [16].

In this study, EPS production by seven different LAB strains — *Enterococcus faecium*, *Lactobacillus sakei*, *Lactococcus garvieae*, *Lactococcus lactis cremoris*, *Lactococcus lactis*, *Weissella confusa*, and *Lactobacillus plantarum* — was investigated using MRS (De Man–Rogosa–Sharpe) medium, and culture conditions were optimized. The goal was to obtain a valuable biopolymer for EPS-based edible film and bioplastic materials. The superior biofunctional properties and sustainable production potential of LAB-derived EPSs open new horizons in environmental biotechnology and food safety.

II. MATERIALS AND METHOD

In this study, seven different lactic acid bacteria (LAB) strains isolated from food-derived samples and preserved in the culture collection of the Molecular Biology and Genetics Laboratory at Muş Alparslan University were used for EPS production and optimization. The strains included *Enterococcus faecium*, *Lactobacillus sakei*, *Lactococcus garvieae*, *Lactococcus lactis cremoris*, *Lactococcus lactis*, *Weissella confusa*, and *Lactobacillus plantarum* [17], [18]. Each strain was activated in MRS medium through a two-step cultivation process until reaching the logarithmic growth phase, after which cultures were standardized to approximately 10^8 CFU/mL to ensure comparable initial cell densities.

For nitrogen source optimization, the basic composition of MRS medium was maintained, while peptone, yeast extract, and beef extract were tested at a concentration of 2% (w/v). The results indicated that yeast extract provided the highest EPS yield for most strains. Therefore, a concentration gradient of yeast extract ranging from 1% to 5% (w/v) was applied [3], [19], [20].

For carbon source optimization, sucrose, lactose, glucose, and fructose were tested at 5% (w/v). The highest EPS production was observed in sucrose-containing media. Subsequently, sucrose concentrations between 5% and 20% (w/v) were evaluated, and the effects of increased viscosity and osmotic pressure on mass transfer at higher concentrations were analyzed [4], [20], [21].

In the optimization of process parameters, the best nitrogen and carbon conditions were kept constant, while pH (5.5–7.0), temperature (25–37 °C), and incubation time (24–72 h) were varied [3], [19]. At the end of fermentation, EPS was precipitated with ethanol after centrifugation at 4 °C, followed by deproteinization using trichloroacetic acid (TCA), washing with diethyl ether, and drying at 37 °C [3], [19], [20]. The obtained EPS fractions were evaluated in terms of purity, drying efficiency, and redissolution capacity, and the optimum production conditions were determined based on these parameters.

All experimental data were statistically analyzed using one-way ANOVA and Tukey's HSD test, with the significance level set at $\alpha = 0.05$ [20], [21].

III. RESULTS

A. Strain Screening

The EPS yields of different LAB strains are presented in Table 1, and their statistical comparisons are shown in Table 2. According to the mean values, the highest EPS production was recorded in *Lactococcus lactis cremoris* (652.00 ± 44.00 mg/L), followed by *Lactobacillus plantarum* (520.00 ± 20.60 mg/L) and *Weissella confusa* (482.00 ± 25.40 mg/L). The lowest yield was observed in *Enterococcus faecium* (264.00 ± 5.20 mg/L). One-way ANOVA indicated that the differences among strains were statistically significant ($F = 83.21$; $p < 0.0001$). According to Tukey's HSD test, *L. lactis cremoris* produced significantly higher amounts of EPS than all other strains, while the difference between *L. plantarum* and *W. confusa* was not statistically significant ($p > 0.05$). *E. faecium* exhibited significant differences in all pairwise comparisons with *L. garvieae*, *L. lactis*, *L. lactis cremoris*, *L. plantarum*, *L. sakei*, and *W. confusa* (Table 2).

Table 1. EPS production amounts of different LAB strains

Bacteria	EPS (mg/L)			
	Replicate 1	Replicate 2	Replicate 3	Mean $\pm$ SD
<i>L. sakei</i>	376,0	382,0	374,0	$377,40 \pm 4,20$
<i>L. garvieae</i>	406,0	446,0	398,0	$416,60 \pm 24,80$
<i>L. lactis cremoris</i>	696,0	608,0	652,0	$652,00 \pm 44,00$
<i>E. faecium</i>	266,0	258,0	268,0	$264,00 \pm 5,20$
<i>W. confusa</i>	486,0	504,0	456,0	$482,00 \pm 25,40$
<i>L. lactis</i>	392,0	378,0	402,0	$390,60 \pm 12,20$
<i>L. plantarum</i>	536,0	496,0	528,0	$520,00 \pm 20,60$

Table 2. Tukey HSD multiple comparison test for EPS production amounts of different LAB strains

Group 1	Group 2	Mean Difference	p-value	Lower Limit	Upper Limit
<i>E. faecium</i>	<i>L. garvieae</i>	152.67	0.0000	87.50	217.83
<i>E. faecium</i>	<i>L. lactis</i>	126.67	0.0002	61.50	191.83
<i>E. faecium</i>	<i>L. lactis cremoris</i>	388.00	0.0000	322.84	453.16
<i>E. faecium</i>	<i>L. plantarum</i>	256.00	0.0000	190.84	321.16
<i>E. faecium</i>	<i>L. sakei</i>	113.33	0.0006	48.17	178.50
<i>E. faecium</i>	<i>W. confusa</i>	218.00	0.0000	152.84	283.16
<i>L. garvieae</i>	<i>L. lactis</i>	-26.00	0.8120	-91.16	39.16
<i>L. garvieae</i>	<i>L. lactis cremoris</i>	235.33	0.0000	170.17	300.50
<i>L. garvieae</i>	<i>L. plantarum</i>	103.33	0.0014	38.17	168.50
<i>L. garvieae</i>	<i>L. sakei</i>	-39.33	0.4227	-104.50	25.83
<i>L. garvieae</i>	<i>W. confusa</i>	65.33	0.0492	0.17	130.50
<i>L. lactis</i>	<i>L. lactis cremoris</i>	261.33	0.0000	196.17	326.50
<i>L. lactis</i>	<i>L. plantarum</i>	129.33	0.0001	64.17	194.50
<i>L. lactis</i>	<i>L. sakei</i>	-13.33	0.9905	-78.50	51.83
<i>L. lactis</i>	<i>W. confusa</i>	91.33	0.0042	26.17	156.50
<i>L. lactis cremoris</i>	<i>L. plantarum</i>	-132.00	0.0001	-197.16	-66.84
<i>L. lactis cremoris</i>	<i>L. sakei</i>	-274.67	0.0000	-339.83	-209.50
<i>L. lactis cremoris</i>	<i>W. confusa</i>	-170.00	0.0000	-235.16	-104.84

B. Effect of Carbon Source on EPS Production

Comparisons of fructose, glucose, and sucrose at a concentration of 5% (w/v) are presented in Table 3, while the Tukey HSD test results are shown in Table 4. The mean EPS yields were 777.67 ± 77.97 mg/L

for sucrose, 447.33 ± 94.38 mg/L for fructose, and 327.67 ± 36.51 mg/L for glucose. ANOVA analysis indicated that the differences among the carbon sources were statistically significant ($F = 29.35$; $p = 0.0008$). According to the Tukey HSD test, sucrose resulted in significantly higher EPS production than both fructose ($p = 0.0010$) and glucose ($p = 0.0002$), whereas the difference between fructose and glucose was not statistically significant ($p = 0.1192$).

Table 3. The effect of carbon source on EPS production

Carbon Source	EPS (mg/L)			
	Replicate 1	Replicate 2	Replicate 3	Mean $\pm$ SD
Fruktoz	552	363	427	447.33 ± 94.38
Glikoz	364	291	328	327.67 ± 36.51
Sükroz	788	695	850	777.67 ± 77.97

Table 4. Tukey HSD multiple comparison test for the effect of carbon source on EPS production amount

Group 1	Group 2	Mean Difference	p-value	Lower Limit	Upper Limit
Fruktoz	Glikoz	119,67	0,1192	-25,53	264,87
Fruktoz	Sükroz	-330,33	0,0010	-475,53	-185,13
Glikoz	Sükroz	-450,00	0,0002	-595,20	-304,80

C. Effect of Sucrose Concentration on EPS Production

The results for sucrose concentrations of 5%, 10%, and 15% (w/v) are presented in Table 5, and the multiple comparison results are shown in Table 6. The mean EPS yields were 777.67 ± 77.97 mg/L at 5% sucrose, 937.67 ± 124.65 mg/L at 10%, and 1134.67 ± 55.66 mg/L at 15%. ANOVA confirmed that the differences among sucrose concentrations were statistically significant ($F = 11.87$; $p = 0.0082$). According to the Tukey HSD test, the difference between 5% and 15% sucrose concentrations was significant ($p = 0.0063$), while the differences between 5%–10% and 10%–15% were marginal or statistically insignificant ($p = 0.1644$ and $p = 0.0915$, respectively).

Table 5. Effect of sucrose ratio on EPS production amount

Sucrose Ratio	EPS (mg/L)			
	Replicate 1	Replicate 2	Replicate 3	Mean $\pm$ SD
%5	788	695	850	777.67 ± 77.97
%10	898	840	1075	937.67 ± 124.65
%15	1090	1116	1198	1134.67 ± 55.66

Table 6. Tukey HSD multiple comparison test for the effect of sucrose ratio on EPS production amount

Group 1	Group 2	Mean Difference	p-value	Lower Limit	Upper Limit
%5	%10	-160,00	0,1644	-377,55	57,55
%5	%15	-357,00	0,0063	-574,55	-139,45
%10	%15	-197,00	0,0915	-414,55	20,55

D. Effect of Nitrogen Source Type on EPS Production

The results for 2% meat extract, 2% yeast extract, and 2% peptone are presented in Table 7, while the statistical evaluation is shown in Table 8. The mean EPS yields were 2342.00 ± 104.56 mg/L for yeast extract, 1603.67 ± 288.45 mg/L for meat extract, and 1512.67 ± 174.81 mg/L for peptone. ANOVA revealed that the differences among nitrogen sources were statistically significant ($F = 14.93$; $p = 0.0047$). According to Tukey's HSD test, yeast extract produced significantly higher EPS yields than both meat

extract ($p = 0.0067$) and peptone ($p = 0.0040$), whereas the difference between meat extract and peptone was not significant ($p = 0.8991$).

Table 7. Effect of nitrogen source on EPS production amount

Nitrogen Source	EPS (mg/L)			
	Replicate 1	Replicate 2	Replicate 3	Mean $\pm$ SD
Meat Ekstrakt	1842	1686	1283	1603,67 $\pm$ 288,45
Yeast Ekstrakt	2371	2429	2226	2342,00 $\pm$ 104,56
Pepton	1621	1311	1606	1512,67 $\pm$ 174,81

Table 8. Tukey HSD multiple comparison test for the effect of nitrogen source on EPS production amount

Group 1	Group 2	Mean Difference	p-value	Lower Limit	Upper Limit
Meat Ekstrakt	Yeast Ekstrakt	-738,33	0,0067	-1219,1	-257,6
Meat Ekstrakt	Pepton	91,00	0,8991	-389,8	571,8
Yeast Ekstrakt	Pepton	829,33	0,0040	348,6	1310,1

E. Effect of Yeast Extract Concentration on EPS Production

The results for yeast extract concentrations of 1%, 2%, 3%, and 5% (w/v) are presented in Table 9, and the multiple comparison results are shown in Table 10. The mean EPS yields were measured as 1201.00 $\pm$ 178.21 mg/L at 1%, 2917.33 $\pm$ 103.59 mg/L at 2%, 4976.33 $\pm$ 572.05 mg/L at 3%, and 8415.67 $\pm$ 444.83 mg/L at 5%. ANOVA indicated a highly significant difference among the groups ($F(3,8) = 203.58$; $p < 0.001$). According to the Tukey HSD test, all pairwise comparisons were statistically significant (all $p = 0.001$).

Table 9. Effect of yeast extract ratio on EPS production amount

Yeast Extract Ratio	EPS (mg/L)			
	Replicate 1	Replicate 2	Replicate 3	Mean $\pm$ SD
%1	1336	999	1268	1201,00 $\pm$ 178,21
%2	2845	3036	2871	2917,33 $\pm$ 103,59
%3	4328	5191	5410	4976,33 $\pm$ 572,05
%5	7992	8879	8376	8415,67 $\pm$ 444,83

Table 10. Tukey HSD multiple comparison test for the effect of yeast extract ratio on EPS production amount

Group 1	Group 2	Mean Difference	p-value	Lower Limit	Upper Limit
%1	%2	-1716,33	0,001	-2252,7	-1180,0
%1	%3	-3775,33	0,001	-4311,7	-3239,0
%1	%5	-7214,67	0,001	-7751,0	-6678,3
%2	%3	-2059,00	0,001	-2595,3	-1522,7
%2	%5	-5498,33	0,001	-6034,7	-4962,0
%3	%5	-3439,33	0,001	-3975,7	-2903,0

F. Effect of pH on EPS Production

The mean EPS yields obtained at pH values of 5.5, 6.0, 7.0, and 8.0 are presented in Table 11, with the statistical evaluation given in Table 12. The average yields were 8276.00 $\pm$ 1094.60 mg/L at pH 5.5, 7404.67 $\pm$ 741.51 mg/L at pH 6.0, 8415.67 $\pm$ 444.83 mg/L at pH 7.0, and 7170.67 $\pm$ 592.41 mg/L at pH 8.0. ANOVA indicated no statistically significant difference among pH levels ($F(3,8) = 2.01$; $p = 0.191$). Similarly, Tukey's HSD test revealed that all pairwise comparisons were statistically insignificant (all $p > 0.05$).

Table 11. Effect of pH on EPS production amount

pH	EPS (mg/L)			
	Replicate 1	Replicate 2	Replicate 3	Mean $\pm$ SD
5.5	7018	9011	8799	8276,00 $\pm$ 1094,60
6	6607	8073	7534	7404,67 $\pm$ 741,51
7	7992	8879	8376	8415,67 $\pm$ 444,83
8	7750	6566	7196	7170,67 $\pm$ 592,41

Table 12. Tukey HSD multiple comparison test for the effect of pH on EPS production amount

Group 1	Group 2	Mean Difference	p-value	Lower Limit	Upper Limit
pH 5.5	pH 6	-871,33	0,528	-2852,66	1109,99
pH 5.5	pH 7	139,67	0,996	-1841,66	2120,99
pH 5.5	pH 8	-1105,33	0,345	-3086,66	875,99
pH 6	pH 7	1011,00	0,414	-970,33	2992,33
pH 6	pH 8	-234,00	0,980	-2215,33	1747,33
pH 7	pH 8	-1245,00	0,260	-3226,33	736,33

G. Effect of Temperature on EPS Production

The results for incubation temperatures of 30, 37, 40, and 45 °C are presented in Table 13, while the multiple comparison results are shown in Table 14. The mean EPS yields were 5637.33 $\pm$ 149.47 mg/L at 30 °C, 8415.67 $\pm$ 444.83 mg/L at 37 °C, 7835.00 $\pm$ 256.12 mg/L at 40 °C, and 3596.33 $\pm$ 95.55 mg/L at 45 °C. ANOVA demonstrated a highly significant difference among temperature groups ($F(3,8) = 197.48$; $p < 0.001$). According to Tukey's HSD test, the difference between 37 °C and 40 °C was not significant ($p = 0.114$), whereas both 30 °C and 45 °C resulted in significantly lower EPS yields compared to 37 °C and 40 °C (all $p < 0.001$).

Table 13. Effect of temperature on EPS production amount

Temperature	EPS (mg/L)			
	Replicate 1	Replicate 2	Replicate 3	Mean $\pm$ SD
30°C	5657	5776	5479	5637,33 $\pm$ 149,47
37°C	7992	8879	8376	8415,67 $\pm$ 444,83
40°C	7605	7789	8111	7835,00 $\pm$ 256,12
45°C	3552	3706	3531	3596,33 $\pm$ 95,55

Table 14. Tukey HSD multiple comparison test for the effect of temperature on EPS production amount

Group 1	Group 2	Mean Difference	p-value	Lower Limit	Upper Limit
30°C	37°C	-2778,33	<0,001	-3488,34	-2068,33
30°C	40°C	-2197,67	<0,001	-2907,67	-1487,66
30°C	45°C	2041,00	<0,001	1331,00	2751,00
37°C	40°C	580,67	0,114	-1290,67	129,34
37°C	45°C	4819,33	<0,001	4109,33	5529,34
40°C	45°C	4238,67	<0,001	3528,66	4948,67

H. Effect of Incubation Time on EPS Production

The results for incubation durations of 24, 48, 72, and 96 hours are presented in Table 15, and the multiple comparison results are provided in Table 16. The mean EPS yields were 8415.67 $\pm$ 444.83 mg/L at 24 h, 8285.33 $\pm$ 79.41 mg/L at 48 h, 8809.33 $\pm$ 530.35 mg/L at 72 h, and 10031.00 $\pm$ 432.39 mg/L at 96 h. ANOVA revealed a statistically significant difference among incubation times ($F(3,8) = 11.30$; $p = 0.003$). According to Tukey's HSD test, the differences among 24, 48, and 72 hours were not significant,

while 96 hours resulted in a significantly higher EPS yield compared to all other incubation periods ($p < 0.05$).

Table 15. Effect of incubation time on EPS production amount

Incubation time (hours)	EPS (mg/L)			
	Replicate 1	Replicate 2	Replicate 3	Mean $\pm$ SD
24	7992	8879	8376	8415,67 $\pm$ 444,83
48	8211	8369	8276	8285,33 $\pm$ 79,41
72	8591	8423	9414	8809,33 $\pm$ 530,35
96	9767	10530	9796	10031,00 $\pm$ 432,39

Table 16. Tukey HSD multiple comparison test for the effect of incubation time on EPS production amount

Group 1	Group 2	Mean Difference	p-value	Lower Limit	Upper Limit
24h	48h	-130,33	0,979	-1202,37	941,71
24h	72h	393,67	0,657	-678,37	1465,71
24h	96h	1615,33	0,0057	543,29	2687,37
48h	72h	524,00	0,447	-548,04	1596,04
48h	96h	1745,67	0,0036	673,63	2817,71
72h	96h	1221,67	0,0268	149,63	2293,71

IV. DISCUSSION

The yield differences observed among strains are consistent with the genotypic and metabolic diversity reported in the literature. The superior EPS productivity of *Lactococcus lactis cremoris* aligns with previous findings indicating production levels within the 25–600 mg/L range, with the potential to reach the upper limit under optimized conditions [22], [23]. The several hundred mg/L yield obtained from *Lactobacillus plantarum* is also consistent with studies showing that optimization can elevate production to approximately 600 mg/L [24]. Reports demonstrating that *Weissella confusa* can achieve gram-per-liter levels under suitable carbon regimes suggest a higher potential for this strain in the presence of sucrose [25], [26]. The low productivity of *Enterococcus faecium* supports the notion that yield is species- and medium-dependent and can be improved through targeted optimization [27]. The relatively low yields of *Lactobacillus sakei* and *Lactococcus garvieae* are consistent with previous studies emphasizing their sensitivity to pH and carbon source variations [22], [28], [29].

The carbon source results correspond with the biochemical model in which sucrose accelerates the direct synthesis of homopolysaccharides via glucansucrase/levansucrase activity. Therefore, sucrose yielded higher EPS production than fructose or glucose [30], [31], [32]. The observed increase in yield with higher sucrose concentrations may be attributed to both substrate abundance and the hypothesis that osmotic stress triggers EPS synthesis as an adaptive response [23], [33]. This pattern is consistent with production spectra ranging from milligram to gram per liter under optimized conditions [4], [21], [33].

The findings related to nitrogen sources confirm the critical role of complex nitrogen compounds such as yeast extract in EPS biosynthesis. The presence of free amino acids, peptides, vitamins, and growth factors in yeast extract is reported to enhance EPS production by supporting sugar-nucleotide precursors and glycosyltransferase activity [1], [34], [35], [36], [37]. The strong dose–response relationship observed with increasing yeast extract concentration is in agreement with studies suggesting that the C/N ratio affects not only yield but also quality parameters such as molecular weight distribution of the polymer [34].

The pH results demonstrate a broad tolerance window between 5.5 and 8.0, with maximum yields occurring around pH 7. This agrees with reports highlighting strain-specific pH responses and the preference for near-neutral conditions in certain LAB species [21], [38], [39]. Regarding temperature, the optimal range of 37–40 °C aligns with studies showing that EPS synthesis in mesophilic LAB increases concurrently with growth but rapidly declines at higher temperatures [38], [40].

The significant increase observed at 96 hours in the incubation time analysis suggests that EPS production remains stable during the logarithmic and late-log phases, while longer incubation may enhance secondary production due to differences in nutrient availability and regulatory mechanisms [38], [40], [41], [42]. This interpretation is supported by the absence of significant differences between 24–72 hours and the marked increase observed at 96 hours.

In conclusion, the selection of *L. lactis cremoris* as the base strain, combined with a sucrose- and yeast extract-rich nutrient regime, incubation at 37–40 °C, a broad pH tolerance range, and 96-hour cultivation, defines a process window that enhances yield and scalability. This framework, when integrated with fine-tuned optimizations aimed at improving EPS quality for film or coating applications, will enable the rational design of functional performance in bioplastic matrices.

V. CONCLUSION

This study revealed that among the tested LAB strains, *Lactococcus lactis cremoris* exhibited the highest exopolysaccharide (EPS) production capacity. Optimization of carbon and nitrogen sources showed that the use of 15% (w/v) sucrose and 5% (w/v) yeast extract significantly enhanced EPS yield. Temperature and pH experiments demonstrated that the strain possessed a broad tolerance range, with optimal production occurring at 37–40 °C and near-neutral pH values. In the incubation time experiments, the highest EPS yield was obtained at 96 hours.

Overall, these results identify the key culture conditions enabling high-yield EPS production by *L. lactis cremoris* and indicate that this strain is a strong candidate for sustainable microbial polymer synthesis. The EPS obtained in this study is anticipated to serve as a functional additive in bioplastic matrices in future applications.

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Deep Learning-Based Ensemble Model for Snake Species Classification

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Abstract – Accurate identification of snake species is vital for ecological research, biodiversity conservation, and effective treatment of venomous bites. In this study, a deep learning-based system was employed for the classification of four types of snakes—Common Indian Krait, Indian Cobra, Python, and Russell's Viper—from a large-scale visual dataset comprising 9,733 images. Three convolutional neural network (CNN) structures, VGG16, ResNet50, and EfficientNetB4, were separately trained and tested, then combined with a weighted ensemble fusion strategy to enhance classification accuracy. Experimental results verified that EfficientNetB4 achieved the best single accuracy of 98.05%, while the proposed ensemble model in this paper performed better than all individual architectures at an end outcome accuracy of 98.77%. The ensemble performs well managed to trade recall and accuracy for every class, reducing inter-class vagueness and improving overall generalizability. The experiments demonstrate that the ensemble of different CNN architectures dramatically enhances model robustness and reliability in biological species classification. Moreover, the developed system is adaptable for real-time public health and ecological monitoring applications on mobile or embedded systems. This research provides a potential foundation for AI-assisted identification of venomous snake species and represents a step towards automated biodiversity examination.

Keywords – Snake Classification, Ensemble Method, Deep Learning, Artificial Intelligence.

I. INTRODUCTION

Snakes play a fundamental role in maintaining ecosystem balance and preserving biodiversity. Snake species, classified according to their morphological, genetic, and behavioral characteristics, provide important information about biodiversity, ecological adaptation, venom mechanisms, evolutionary relationships, habitats, and geographic distributions. Therefore, accurate snake species identification is crucial for determining appropriate treatment methods, maintaining ecological balance, reducing public health risks, and advancing scientific knowledge [1].

Snake bites are a largely neglected public health problem, particularly seen in Africa, Asia, and Latin America. Approximately 2 million cases require medical attention each year in Asia and 435,000–580,000 in Africa. Women, children, and rural farmers are the most at-risk groups. Venomous bites can lead to serious consequences such as respiratory paralysis, fatal bleeding disorders, kidney failure, and tissue damage. However, the availability of high-quality antivenoms makes it possible to largely prevent deaths and permanent disabilities [2].

There is a direct and critical relationship between snake species and antivenom selection. Because the venom composition of each snake species differs, antivenoms are developed against these specific venom antigens. In this context, monovalent antivenoms developed specifically for a particular species are effective only against envenomation caused by that species, while polyvalent antivenoms developed against multiple venomous species commonly found in the same region provide broader-spectrum protection. However, the effectiveness of polyvalent antivenoms is often limited compared to monovalent antivenoms due to the variation in venoms of the target species. Furthermore, even snakes of the same

species can exhibit variations in venom composition across different geographic regions, necessitating the use of venoms derived from regional populations in antivenom production. Therefore, accurate snake species identification and consideration of regional differences are crucial for effective, reliable, and rapid treatment [3]. In this study, a deep learning-based classification system was developed using a large-scale visual dataset containing four different snake species. VGG16, ResNet50, and EfficientNetB4 architectures were trained independently, and then the outputs of these models were integrated using a weighted fusion method. This achieved classification performance with high accuracy and generalizability. The developed system's integration with mobile devices enables field experts and healthcare personnel to quickly and reliably identify snake species. In this respect, the study provides an innovative and sustainable example demonstrating the applicability of AI-based approaches in areas such as public health, environmental protection, and education.

II. MATERIALS AND METHOD

A. Materials

This research utilized a custom-created visual dataset for snake species classification [4]. The dataset contains a total of 9733 images and is divided into four classes. The classes are comprised of 1969 examples of the Common Indian Krait, 2628 examples of the Indian Cobra, 2694 examples of Python, and 2442 examples of Russell's Viper. All images are of size 640 (height) x 640 (width) pixels, which were also rescaled to fit the model input size for classification. Although there were differences in the number of examples across classes, the overall distribution is considered balanced.

The diversity of this dataset is an important factor contributing to the model's generalization capacity. The images were taken from different angles, on different grounds, and under different lighting conditions. Additionally, the dataset contains representations of a snake positions: coiled, lying flat, and lateral views. This diversity allows the model to learn not only conditions-specific patterns, but also the general features that will classify the species accurately.

The dataset was separated into two portions for confronting the training and evaluation stages in the model. Eighty percent of the total dataset, or 7,787 images, was used for training, and 20 percent, or 1,946 images, was used for validation/testing. This split ratio is a common practice in deep learning studies because it allows for adequate training of the model on enough data for the learning process while reliably assessing the models performance on other data.



(a)



(b)



(c)



(d)

Fig. 1 Sample images of each snake species (a) Common Indian Krait, (b) Indian Cobra, (c) Python, (d) Russell's Viper

B. Method

Three different deep learning architectures were used in this research for species identification of snakes from a visual dataset. VGG16 [5], ResNet50 [6], and EfficientNetB4 [7] are all of different structure types and learning styles and enable representation of the data from multiple perspectives. After training the individual models, the outputs were blended together with the weighted fusion method [8] to arrive at the final classification system. The approach is meant to offer a more reliable, robust, and highly accurate artificial intelligence system by combining the strengths of the different models. Moreover, the architectural diversity of the models used allowed for holistic learning of low-level edge and texture knowledge and high-level semantic patterns. This rendered the model more resilient to complex visual nuances.

VGG16 is a convolution neural network with a regular and low design by the Visual Geometry Group at Oxford University. Such a design, thirteen convolutional and three fully connected layers, works successful results in deep-level pattern extraction because of small filter sizes and maximum pooling layers. It was selected in this research because it can efficiently represent low-level universal features and has layer architecture that is ideal for transfer learning. Nonetheless, owing to its around 138 million parameters, it comes with high memory and computational requirements. In spite of this limitation, the regular layer architecture of VGG16 ensures stable learning by preventing overfitting, particularly on small datasets [9].

ResNet50 is a convolutional neural network architecture that boosts the trainability of deep networks using the application of a specific structure known as residual connections. The structure, comprising fifty layers, overcomes the issue of gradient loss by providing a more stable learning process in multilayered networks. In every residual block, the input information is added to the output directly, allowing the model to learn only the differences needed. This mechanism relieves error accumulation and prevents performance deterioration due to network depth. ResNet50 was one of the key factors in the success of this study by demonstrating high accuracy and parametric efficiency. Furthermore, residual connections of ResNet50 enabled learning fine morphological differences among classes more effectively and enhanced model convergence speed [10].

EfficientNetB4 is a modern convolutional neural network structure developed by Google on a compound scaling principle. It possesses great accuracy in addition to low computational cost by scaling depth, width, and resolution equally at the same time. blocks are optimized using compression and expansion mechanisms and the Swish activation function. Although it possesses an approximate nineteen million parameters, it offers great classification performance and can execute well even in systems with hardware constraint. Because of such capabilities, EfficientNetB4 has an execution edge over other models because it is designed to be deployable on mobiles or portables with low hardware. The compound scaling method of the model also minimizes information loss due to higher resolution by virtue and enables more potent representation learning at high detail levels [11].

The ensemble method used here achieved higher and more balanced classification accuracy by combining the results produced by different deep learning models. The outputs produced by the three models were averaged together considering their accuracy levels, thus improving the overall accuracy rate. The ensemble process maximized the system's overall generalizability and reliability by reducing the impact of individual model mistakes. Also, this group structure developed with the hybrid approach kept the error variance to a minimum by offsetting the faults of a single model and significantly reduced misclassification rates, particularly when there were low light or complex backgrounds. This provided an additional advantage that improved the system's usability in actual situations [12].

Precision, Recall, and F1-Score metrics based on accuracy, macro- and weighted average values were used for measuring model performance [13]. Accuracy refers to well-classified examples divided by all examples, whereas Precision is positive examples predicted by the model out of all positive examples. Recall defines how well the model can identify true positive examples, whereas F1-Score provides a balanced performance metric by taking the harmonic mean of these two metrics. Macro-average values implies that each class has equal priority.

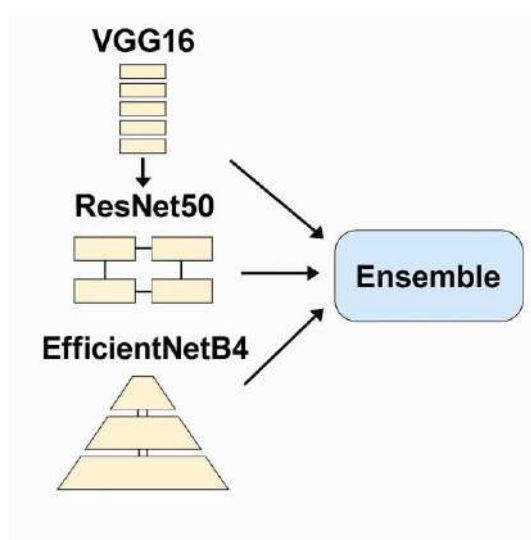


Fig. 2 Ensemble Method

III. RESULTS

The VGG16 model was trained for 50 epochs, and examination of the accuracy and loss graphs during the training process indicated that the model learned quickly in the early stages. The plateauing of the validation accuracy around the tenth epoch indicates that the model's learning capacity has reached a certain level of saturation. The training accuracy remained at 81 percent, while the validation accuracy increased to 88 percent, indicating that the model generalized better on the validation data than on the training data. The similar trends in the training and validation losses suggest that the model does not suffer from overfitting. However, slight fluctuations observed in the validation loss suggest that the decision boundaries between some classes are not fully defined, and the model occasionally experiences uncertainty in distinguishing species with similar visual characteristics. This suggests that, despite VGG16's robust capture of low-level features, it may have limited representational power in distinguishing complex morphological differences. Therefore, although this model provides high accuracy on its own, it is considered a valuable component when combined with other deep architectures to achieve more balanced and consistent classification success. The accuracy and loss curves for the training and validation processes are presented in Figure 3.

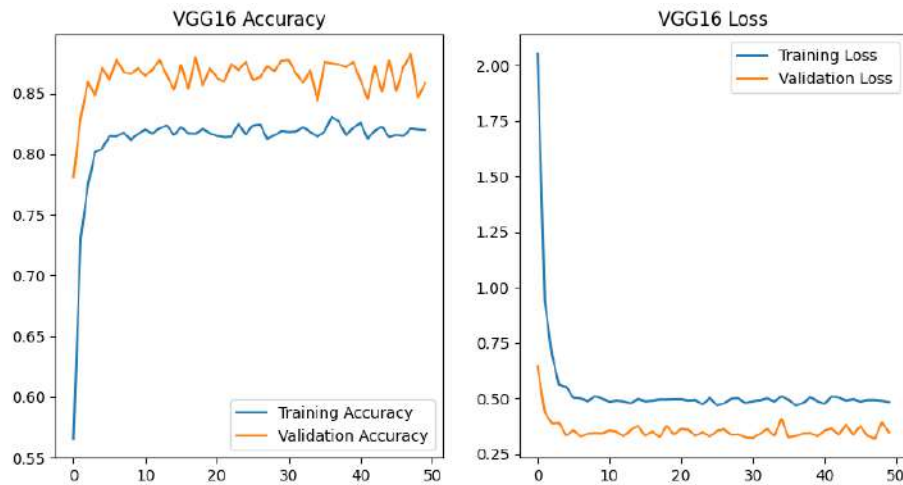


Fig. 3 VGG16 Training and Validation Curves

An examination of the confusion matrix, from Figure 4, reveals that the VGG16 model has predominantly even classification accuracy in four snake classes. There exists confusion among some classes, which shows that the model occasionally fails to grasp class boundaries. This is particularly because separation of species having high visual similarity is challenging. The morphological aspects common to the Common Indian Krait and the Indian Cobra are thought to make it difficult for the model to classify the two classes separately. However, the higher correct classification rates among the species of Python and Russell's Viper suggest that the model fares better in classifying snakes with evident texture and color patterns. The general form of the confusion matrix shows the model's ability to learn patterns between classes and the model's power of generalization. These outcomes suggest that the model must possess more deeper representations for species with the same pattern or color hue, and that adding more higher feature extraction architectures might improve the performance in classification.

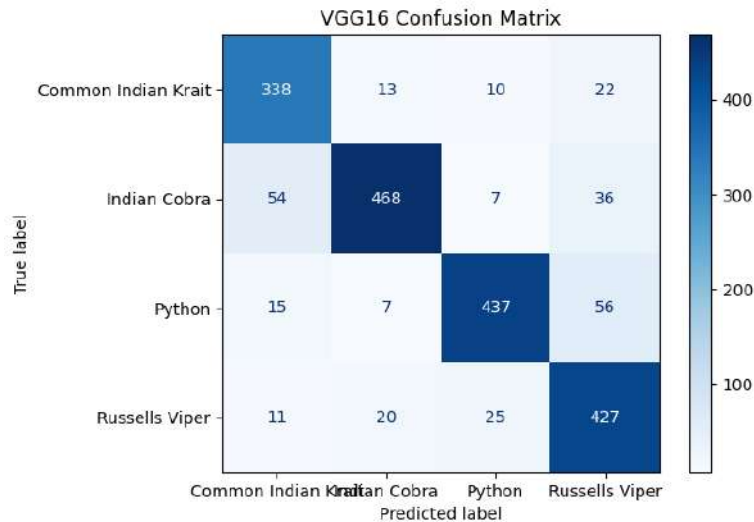


Fig. 4 VGG16 Confusion Matrix

The ResNet50 model was trained for fifty epochs and achieved a high accuracy rate of ninety-five percent on the validation set. Upon examination of the plots of accuracy and loss during training, there was a fairly balanced learning curve. The training accuracy increased steadily, going up to a high of ninety-four percent, while the validation accuracy frequently was higher than this value. The slow diminishing trend of validation loss and training loss indicates that there is no overfitting occurring in the model and the learning process is consistent. The only slight fluctuation observed in the validation loss is noteworthy. This indicates that the ResNet50 model consistently delivers steady and stable learning performance. Due to the residual connection effect, the model is supposed to be able to capture good features at deep layers while avoiding gradient loss, enabling it to maintain a high validation performance. Moreover, the higher validation accuracy than training accuracy confirms the model's strong generalization ability and provides optimal representations rather than overfitting. This balanced learning structure of ResNet50 demonstrates that deep networks may be successfully trained on datasets with complex visual patterns and shows that the model can potentially provide stability to the ensemble structure when used in combination with other structures. Figure 5 illustrates the accuracy and loss curves of training and validation processes.

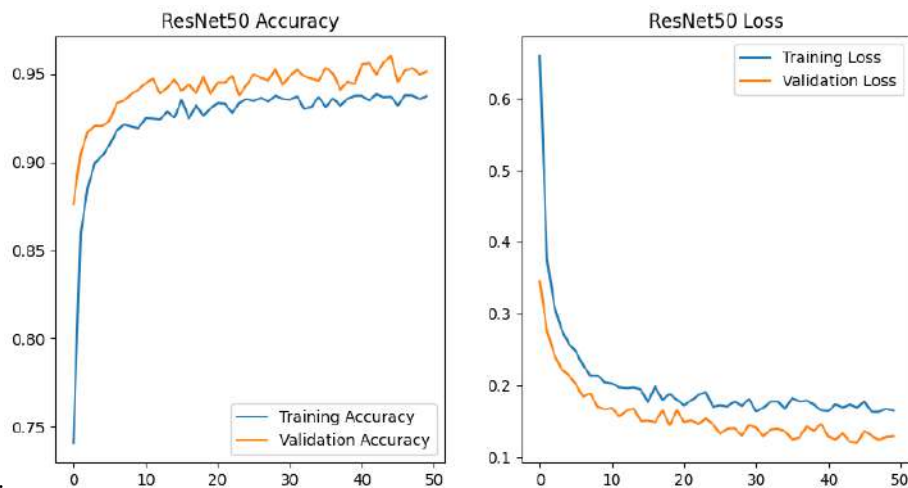


Fig. 5 ResNet50 Training and Validation Curves

From the confusion matrix in Figure 6, it can be seen that the model usually achieved a highly precise and well-balanced classification between four classes. It is apparently clear that cross-class errors were significantly reduced compared to the VGG16 model. This enabled the deepened structure of ResNet50 with residual connections to learn complex visual patterns more effectively and to define boundaries of difference between classes with more accuracy. Lossless transmission of information flow to deeper

layers owing to the residual blocks of the model allowed for the representation of even nuances of morphological differences. There was, however, minimal confusion in a few classes with high visual similarity. Such confusion, particularly in those species with color tone and pattern similarity, implies that the model was unable to clearly distinguish contextual features in some examples. However, ResNet50's successful learning of inter-class discriminative features maximized overall accuracy and reduced misclassification rates. The above results indicate that the model can work stably on visually challenging datasets, and that deep representations contribute directly to classification accuracy.

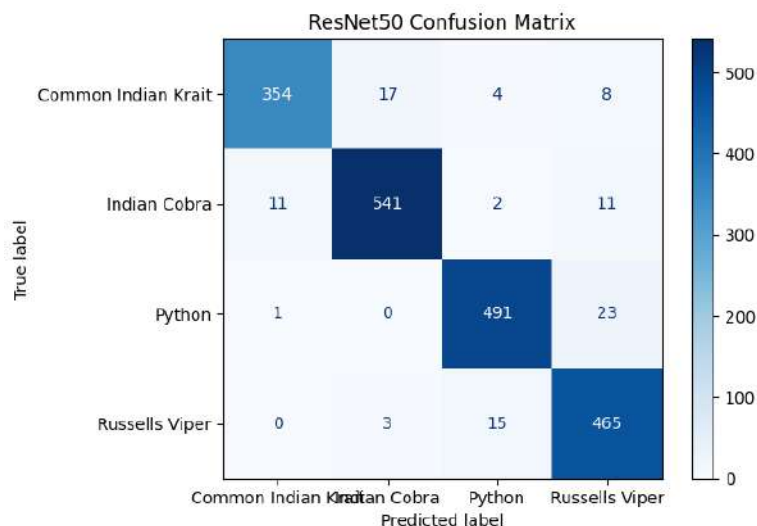


Fig 6: ResNet50 Confusion Matrix

The EfficientNetB4 model was trained for 50 epochs with a very high accuracy rate of ninety-eight percent on the validation set. Upon analyzing the accuracy and loss curves of the model, as demonstrated in Figure 7, the resulting curve was found to be well-balanced and stable. Both training and validation accuracies were seen to be ninety-five percent in initial stages and continued to improve further as the training process went on. The significant decrease in validation and training losses, which were given a low value, indicates that the model is not overfitting and can learn generalized patterns within the data effectively. These findings indicate that the EfficientNetB4 architecture's depth, width, and resolution parameter balancing ability stabilizes learning as well as enhances generalization. The parametric nature of the model provides high accuracy at the expense of low computation, which is indicative of its success even on hardware-constrained systems. Moreover, because of the Swish activation function of the model as well as the structure of the MBConv block, visual details could be captured without losing them, leading to morphological differences being accurately represented in subtle ways. Therefore, the EfficientNetB4 model was experimented with as being the best-performing structure in this study, with maximum accuracy and regular learning behavior.

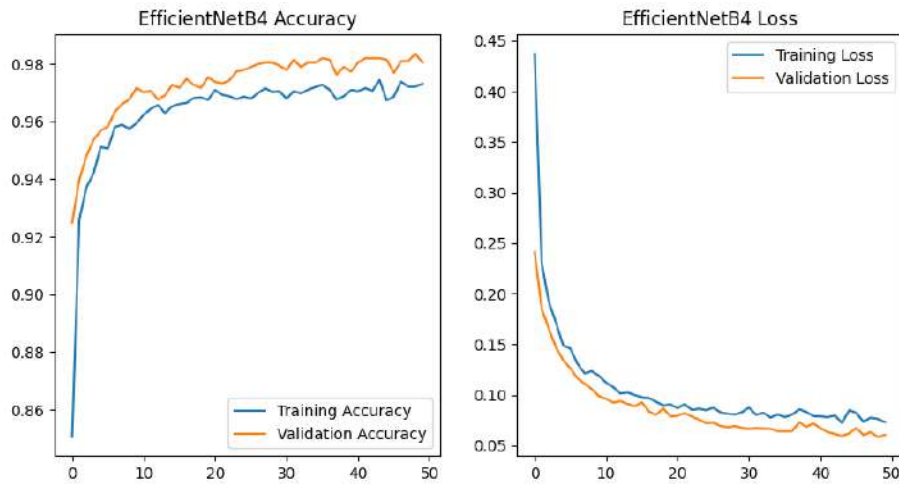


Fig. 7 EfficientNetB4 Training and Validation Curves

The confusion matrix is depicted in Figure 8, which evidently displays the EfficientNetB4 model's prediction accuracy of four classes. The model was found to classify with maximum precision in general, with very few cases in the Python class being confused with Russell's Viper. These handful of cross-classification errors did not successfully reduce the overall accuracy of the model but instead show its robust ability to capture visual patterns between classes. EfficientNetB4's balanced depth, width, and resolution scaling control enabled it to identify even subtle visual variations between classes. This demonstrates the strong capacity of the model to acquire higher-level pattern, color, and texture features, resulting in improved performance regarding generalization and accuracy. Further, the parametric efficiency of the model allows for high accuracy with very little computational cost, making EfficientNetB4 an extremely suitable option for mobile and embedded systems use. In total, EfficientNetB4 is among the most efficient and reliable models in the study, both in terms of predictive accuracy and hardware efficiency.

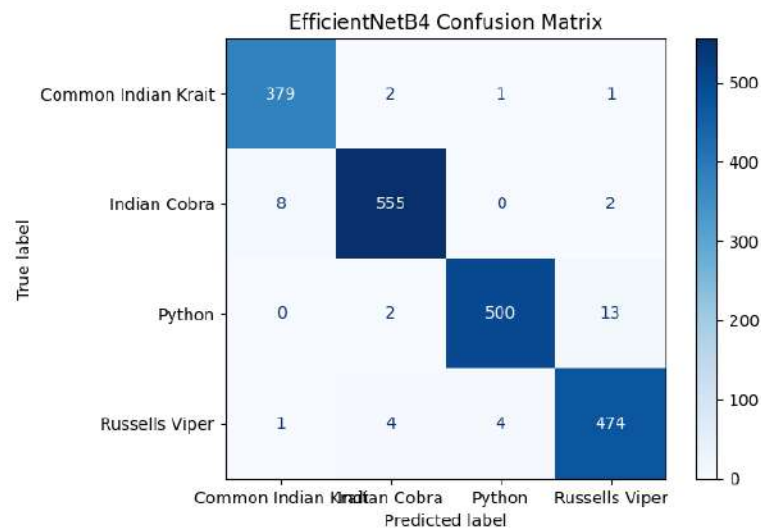


Fig. 8 EfficientNetB4 Confusion Matrix

The ensemble model was created by stacking the VGG16, ResNet50, and EfficientNetB4 model outputs in some proportions. As shown in Figure 9, monitoring the accuracy and loss graphs of the training process, it was observed that the model showed stable and balanced learning performance throughout 50 epochs. For validation accuracy, it increased steadily from the early stages and remained constant at 95% for most of the process. The concurrent decrease and stabilization of validation loss demonstrate that the model is not overfitting and has good generalization ability. This validates that the ensemble system effectively integrates the strengths of different architectures, and errors of single models are largely complemented. The combination of VGG16's low-level feature capturing success, ResNet50's stable

learning capability on deep representations, and EfficientNetB4's parametric efficiency results in a more robust and well-rounded classification system. Furthermore, the consistent duration of the model's validation success over a prolonged period demonstrates that the ensemble approach not only improves accuracy but also the stability of predictions. Consequently, the ensemble model has a good synergy between different deep learning architectures, significantly improving overall accuracy and generalization compared to the individual models.

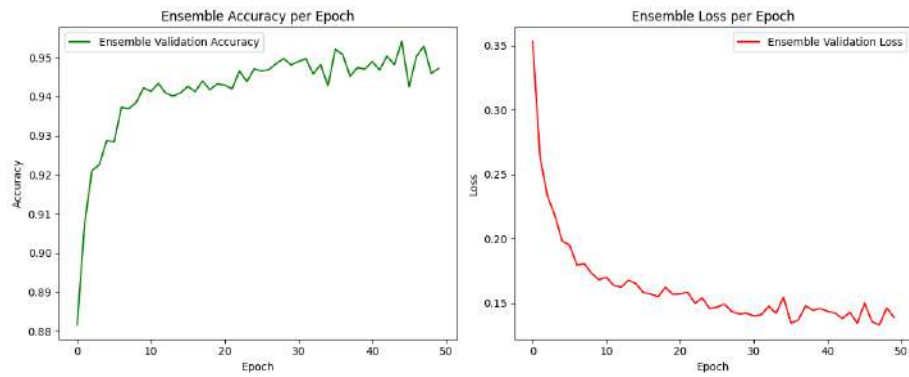


Fig. 9 Ensemble Model Validation Curves

The confusion matrix is plotted in Figure 10, which evidently shows that the ensemble model achieved high correct classification rates for all four classes. It was observed that intra-class confusion present in the individual models was significantly reduced with the ensemble approach. The reduced misclassifications indicate that the model is more capable of distinguishing between-class visual similarities. This result confirms that the ensemble method successfully integrates the strengths of multiple models, creating a more robust decision-making process. In particular, the combination of VGG16's low-level edge and texture features, ResNet50's abstract representations in deep layers, and EfficientNetB4's scaled feature extraction capability greatly enhanced inter-class discrimination. This not only enhanced overall accuracy, but also allowed the model to demonstrate more even recognition success within each class. Consequently, the ensemble system bolstered between-class discrimination, minimizing the likelihood of misclassification and maximizing the system's overall classification success.

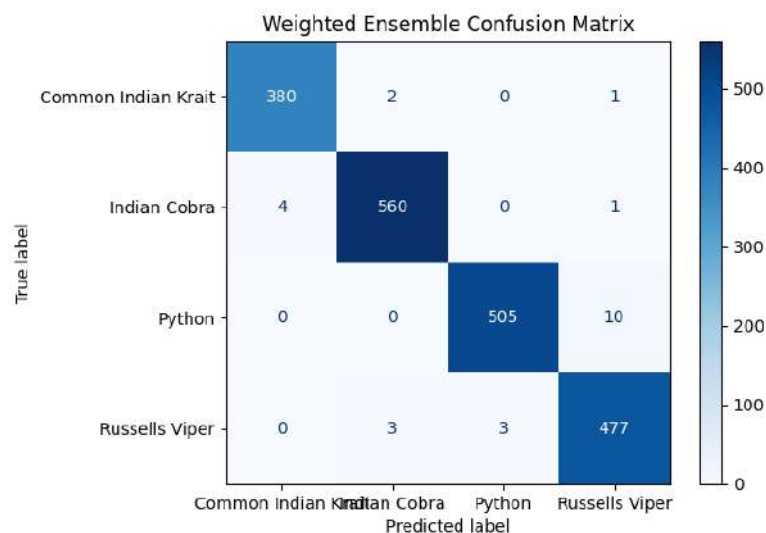


Fig. 10 Ensemble Confusion Matrix

IV. DISCUSSION

The classification performance of four different models used in this study was evaluated using key metrics such as accuracy, sensitivity, precision, and F1 score. The findings indicate that each model has high overall accuracy, but differs in terms of discriminatory power and balance between classes.

Table 1. Results of VGG16, ResNet50, EfficientNetB4 and Ensemble Models

Model	Accuracy	Macro Precision	Macro Average Recall	Macro Average F1-Score	Weighted Average Precision	Weighted Average Recall	Weighted Average F1-Score
VGG16	0.8582	0.8579	0.8609	0.8574	0.8640	0.8582	0.8591
ResNet50	0.9512	0.9519	0.9495	0.9504	0.9518	0.9512	0.9512
EfficientNetB4	0.9805	0.9800	0.9810	0.9805	0.9806	0.9805	0.9805
Ensemble	0.9877	0.9876	0.9879	0.9877	0.9877	0.9877	0.9877

The ensemble model, which integrated the outputs of VGG16, ResNet50, and EfficientNetB4 through a weighted fusion strategy, outperformed all individual networks. This improvement stems from the complementary nature of the architectures: VGG16's fine-grained feature extraction, ResNet50's deep abstract representation, and EfficientNetB4's parametric efficiency collectively provided a robust hybrid system. The ensemble approach successfully reduced intra-class confusion and improved both macro and weighted F1-scores, proving the effectiveness of model fusion in biological image classification.

Compared to previous studies on reptile or animal species identification, which often relied on single CNN architectures, the proposed ensemble framework demonstrates higher accuracy, better robustness against noise, and greater adaptability to real-world visual diversity. Moreover, the system's potential integration with mobile devices or embedded AI systems offers a practical solution for rapid, on-site snake recognition—crucial for timely medical response in venomous bite incidents.

Nevertheless, the study has several limitations. The dataset, though diverse, includes only four snake species, limiting its representational scope. In addition, environmental variations such as occlusions, motion blur, or partial visibility were not fully modeled. Future work should focus on expanding the dataset with more species from different regions, integrating attention-based or transformer-driven modules to enhance feature interpretability, and evaluating real-time performance under field conditions. Despite these limitations, the findings provide a strong foundation for the deployment of AI-assisted species identification systems in ecological monitoring, wildlife management, and healthcare applications.

V. CONCLUSION

In this study, a deep learning-based system was developed for the visual classification of snake species, addressing the challenges of accurate and rapid identification in the field. Using a dataset of 9,733 images from four snake species, three convolutional neural network architectures—VGG16, ResNet50, and EfficientNetB4—were trained, evaluated, and integrated using a weighted ensemble approach. The experimental findings demonstrated that the ensemble model achieved the highest classification accuracy (98.77%), outperforming all individual models while maintaining high stability and generalization capability.

The results confirm that combining architectures with different depths, connectivity structures, and scaling strategies significantly enhances the overall performance of snake species classification. While VGG16 provided robust low-level feature extraction, ResNet50 improved representational depth through residual learning, and EfficientNetB4 offered superior accuracy with remarkable parameter efficiency. The ensemble fusion of these complementary models led to more consistent and balanced recognition across all classes.

Beyond the technical achievements, this research highlights the potential of artificial intelligence and ensemble deep learning models in biodiversity monitoring and public health applications. The developed system can be integrated into portable or mobile platforms to support field experts and healthcare professionals in identifying venomous species in real time, thereby reducing treatment delays and improving safety outcomes.

Future studies will focus on expanding the dataset with additional snake species, incorporating attention and transformer-based hybrid networks, and testing the system under real-world environmental

conditions. Such advancements are expected to further enhance classification precision, interpretability, and real-time applicability in ecological and medical domains.

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Comparative Study on the Applicability of Sulfur Polymer Concrete and Portland Cement Concrete in Structural Systems

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Abstract –In recent years, studies on sulfur polymer concrete (SPC) have become increasingly popular. This study investigates the applicability of SPC in building construction and evaluates its engineering performance in comparison with conventional Portland cement concrete (PCC). Although the literature reports that SPC exhibits high compressive strength, low permeability, and superior chemical resistance, the influence of these properties on structural system behavior and stiffness characteristics in real building applications has not been sufficiently explored. Within this scope, instead of experimental methods, structural analysis software was employed to comparatively evaluate SPC and PCC materials in a standard building type. The analyses included displacements under static loads, as well as natural frequencies, periods, and mode shapes within the scope of modal analyses. The findings revealed that the use of SPC in place of PCC had adverse effects on structural stiffness and demonstrated that it is not suitable for direct substitution of PCC. The results indicate that although SPC possesses certain engineering advantages, more comprehensive research, experimental validation, and the development of design criteria are required before it can replace standard concrete classes, other words PCC in structural applications.

Keywords –Sulfur Polymer Concrete (SPC), Portland Cement Concrete (PCC), Modal analysis, Stiffness, RC structures

I. INTRODUCTION

Concrete is the most widely used building material in the modern construction industry, and Portland cement is used as the primary binder in its production. Portland cement began being produced on an industrial scale in the mid-19th century, and today, annual global production has exceeded 4 billion tons [1]. Portland cement concretes (PCC) have a wide range of applications, from infrastructure to superstructure, due to their high compressive strength, ease of production, and affordability. However, the major disadvantages of PCC include the length of the hydration process, limited early-age strength gain, poor resistance to chemical attack due to high porosity, and a high carbon footprint [2-3]. PCC performance can be inadequate, particularly in aggressive environments such as sulfate-containing soils, acidic environments, and industrial waste sites [4]. These limitations have accelerated research into the development of alternative binder systems. In this context, sulfur polymer concretes (SPC) have emerged as an alternative to traditional PCC in recent years [5]. SPC is produced by using modified sulfur as a binder instead of Portland cement and hardens by dissolving and cooling the sulfur rather than by a hydration reaction [6]. This feature allows SPC to reach high compressive strength within a few hours, offering a significant advantage, especially in infrastructure applications requiring urgent repairs [7]. In terms of mechanical properties, the compressive strength of SPC varies between 40–90 MPa, and these values are often comparable to those of PCC [5]. However, the modulus of elasticity was found to be lower (15–25 GPa) than that of PCC with similar compressive strength [7]. This indicates that despite its

high strength, SPC exhibits a more brittle behavior. Its flexural strength is between 6–12 MPa, and it exhibits a relatively more resistant structure to crack propagation due to the effect of the polymer binder [6]. In terms of durability, SPC performs much better than PCC against acids, salts, and industrial chemicals thanks to its low porosity and impermeability [8-9]. In fact, in the experimental studies, when the PCC and SPC samples with equivalent 28-day compressive strength were compared, the water penetration depth in PCC was measured as 27.7 mm, while this value was found to be zero in SPC [9]. However, the majority of studies on SPC in the literature have focused on compressive strength and chemical resistance, while research on deformation properties such as modulus of elasticity, Poisson's ratio, creep, and shrinkage behavior is limited. Furthermore, current international standards [10-11] lack specific relations for SPC; only those specific to PCC are used. This creates uncertainties in the engineering design of SPC and necessitates the development of new analytical models.

Global energy consumption is increasing rapidly, and a significant portion of this energy demand is met by the petroleum industry. Consequently, the amount of sulfur released as a byproduct of the petroleum industry is increasing. Increasing sulfur reserves, storage space constraints, and the need to find new alternative applications for sulfur use have become essential. In recent years, sulfur has been recognized as a viable alternative building material for certain applications, particularly within construction technologies [12-14]. Sulfur-binded concretes are high-performance thermoplastic composite materials prepared by using sulfur instead of water and cement used as binders in traditional Portland cement concretes. The first studies on the use of sulfur as a building material in the construction industry were conducted on concretes prepared using pure sulfur [15]. The aim of the studies conducted between 1920 and 1960 was to demonstrate that sulfur could be used in construction technologies as an alternative to traditional PCBs. It was determined that sulfur concretes prepared using pure sulfur quickly suffered from fragmentation and collapse due to the phase transformation that took place in the microstructure upon cooling of sulfur, and that they had very low durability performance. In order to prevent this phase transformation, which leads to loss of strength and durability, pure sulfur was modified by controlling sulfur crystallization chemically or physically [16, 17]. The most commonly used chemicals for chemical control are dicyclopentadiene (DCPD) [18] and combinations of DCPD, cyclopentadiene, and dipentene [19]. In physical control sulfur modification, pure sulfur is combined with olefin hydrocarbon polymers and physical stabilizers such as fly ash. The most commonly used olefin hydrocarbon polymers in this method are RP220, RP020, Escopol, and bitumen [19].

Although traditional Portland cement-based concrete (PCC) is one of the most widely used binding systems in the construction industry, it suffers from several drawbacks, including long setting times, limited chemical resistance, and high porosity. Sulfur polymer concrete (SPC), an alternative, offers notable features, particularly in terms of rapid setting, low water absorption, high chemical resistance, and environmental sustainability [20]. Sulfur polymer concrete (SPC), with its binder sulfur and organic/permitted additives, offers a wide range of specialized applications compared to traditional concrete. Its high resistance to chemical and biological agents makes it a preferred choice in industrial facilities, wastewater treatment and sewage systems, and sectors such as fertilizer, petrochemical, and acid production. For example, the study "Sulphur Concrete – Corrosion-Resistant Material for Middle East Construction" notes that SPC exhibits exceptional resistance to salt, acid, and corrosive environments, making it suitable for applications such as sewage systems, marine structures, cast blocks, bridge foundations, and waste containers. Furthermore, the article "A Critical Review on the Properties and Applications of Sulfur-Based Concrete" emphasizes the widespread use of PCC in building components such as road curbs, pavements, drainage/sewer pipes, railway sleepers, bridge decks, and acid tanks [21].

The primary objective of this study is to evaluate the applicability of sulfur polymer concretes (SPC) in structural construction and to demonstrate their engineering performance compared to conventional Portland cement concrete (PCC). While the literature reports the high compressive strength, low permeability, and superior chemical resistance of CPC, the impact of these properties on structural system behavior, stiffness properties, and deformation capacity in real-world applications has not yet been adequately investigated. In this context, this study will conduct a comparative analysis of SPC and PCC

on a standard building type using structural analysis software rather than experimental methods. Within the scope of the analysis, static analyses will evaluate displacements under vertical loads for both materials, while modal analyses will evaluate natural frequencies, periods, and mode shapes. Thus, the effects of using both materials on structural stiffness and vibration behavior will be revealed and discussed. Consequently, this study aims to examine the applicability of SPC in real-world building types and provide scientific data that will contribute to future design standards.

II. MATERIALS AND METHOD

The Finite Element Method (FEM) is a numerical analysis method widely used in solving various engineering problems. This method divides the solution domain of the structure or object to be analyzed into subregions (elements), and each subregion is solved separately to obtain the behavior of the entire structure [22]. In this study, the finite element method was used in the modeling and analysis stages. SAP2000 software [23] was preferred for the implementation of FEM. Two different finite element models were created for comparison purposes within the scope of the study: a PCC model and an SPC model. Reinforced concrete was selected as the load-bearing system in both models. The reinforcement type and ratio were selected as S420 [24]. Two different models (PCC and SPC) were created by keeping the reinforcement ratio constant and changing only the concrete material type. The models were developed as fictitious, identical, symmetric, and geometrically simple structures. This approach was adopted to minimize potential variables that could influence the results, thereby enabling a more objective and clear evaluation of both static and modal parameters.

A. Model Using Portland Cement Concrete (PCC)

The model was designed as a reinforced concrete load-bearing system building. The model geometry is designed symmetrically. The aim of this design is to prevent the stiffness differences in the X and Y directions from affecting the results of the study. It is thought that the results to be obtained will be more clearly presented in this way. The model consists of 6 openings in the X and Y directions. The opening widths are equal and 5 meters. The number of floors is 12 and the floor heights are equal on each floor and are 3 meters. Columns dimensions are selected as 45x45 cm reinforced Portland cement concrete. Beam dimensions are selected as 50 (depth) x 30 (width) cm reinforced Portland cement concrete. The thickness of all floors is selected as 15 cm reinforced Portland cement concrete. Portland cement concrete class C25/30 was selected. According to industry reports and statistics from the Turkish Ready-Mixed Concrete Association (THBB), C25/30 is by far the most widely used concrete grade in reinforced concrete buildings. According to THBB [25], C25/30 usage is reported to be 62% of all other concrete grades in 2023. Information about the model (PCC) is given in Table 1.

Table 1. Model information

Name	Dimensions	Piece	Material	Connection Type
X Spanning	5 m	6	-	Fixed
Total Length in X Direction	30 m	1	-	Fixed
Y Spanning	5 m	6	-	Fixed
Total Length in Y Direction	30 m	1	-	Fixed
Story Height	3 m	12	-	Fixed
Building Height	36 m	1	-	Fixed
Columns	0.45x0.45 m	588	PCC (C25/30)	Fixed
Column Section Area	0.2025 m ²	588	PCC (C25/30)	Fixed
Column Moment of Inertia (I _x =I _y)	341718.80 cm ⁴	588	PCC (C25/30)	Fixed
Beams	0.50x0.30 m	1008	PCC (C25/30)	Fixed
Beam Section Area	0.15 m ²	1008	PCC (C25/30)	Fixed
Beam Moment of Inertia (I _z)	312500 cm ⁴	1008	PCC (C25/30)	Fixed
Floors Thickness	0.15 m	432	PCC (C25/30)	Fixed
Floor Areas	900 m ²	12	PCC (C25/30)	Fixed

Floor Moment of Inertia (I_z)	3645.83 cm ⁴	48	PCC (C25/30)	Fixed
Support Type	-	49	-	Fixed

The important mechanical properties of the used Portland cement concrete class C25/30 [24-25] in this study;

- Density: 2400 kg/m³
- Modulus of elasticity: 30 GPa
- Poisson's ratio: 0.2
- Compressive strength: 25 Mpa

In this study, reinforcement of grade S420 was used, and the reinforcement ratio in the section was assumed to be 2%.

The important mechanical properties of the used rebar S420 [24-25] in this study;

- Density: 7850 kg/m³
- Modulus of elasticity: 200 GPa
- Poisson's ratio: 0.3

The connection of the model to the ground is fully fixed. All nodes are assumed to be rigid. Automatic meshing process has been applied to all system elements. The system was designed simply due to the numerical study and not many architectural details were added.

The 3D finite element model constructed with Portland cement concrete (PCC) is presented in Figure 1.

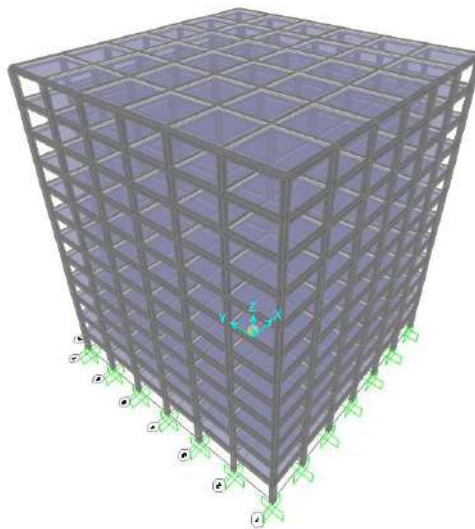


Fig. 1 The 3D finite element model constructed with PCC

B. Model Using Sulfur Polymer Concrete (SPC)

The SPC model was generated by maintaining the geometry and configuration of the PCC-based reinforced concrete model, with the material type substituted accordingly.

Previous experimental investigations [5,7,14,20,21,27,28,29] have demonstrated that the fundamental mechanical and physical properties of sulfur polymer concretes, including density, elastic modulus, Poisson's ratio, and compressive strength, are not constant but rather vary within certain ranges depending on factors such as mixture composition, curing conditions, and testing methodologies. These variations reported in the literature highlight the sensitivity of sulfur polymer concrete to both material constituents and experimental procedures, which makes it essential to adopt representative values when conducting numerical modeling or comparative analyses.

In order to establish consistent and reliable input parameters for the present study, the mean values derived from the referenced experimental works were taken into account. Accordingly, the density of the sulfur polymer concrete was considered as 2300 kg/m^3 , which reflects a typical value within the reported range and ensures compatibility with structural modeling assumptions. Similarly, the elastic modulus was adopted as 20 GPa , representing an average stiffness value that aligns with the mechanical response observed in prior studies. The Poisson's ratio, which characterizes the lateral deformation behavior of the material, was taken as 0.22 , again corresponding to the mean of the reported intervals. Finally, the compressive strength of the sulfur polymer concrete used in this research was assumed to be 65 MPa , a value that not only reflects the average of the cited studies but also provides a realistic representation of the material's load-bearing capacity.

By adopting these averaged parameters, the material model employed in this study achieves a balanced characterization of sulfur polymer concrete as documented in the literature. This approach ensures that the numerical simulations are grounded in experimentally validated data, while at the same time avoiding the potential bias that could arise from relying on extreme values reported in individual studies. Consequently, the selected material properties provide a robust basis for the structural analyses carried out in the scope of this research.

The 3D finite element model constructed with sulfur polymer concrete (PCC) is presented in Figure 2.

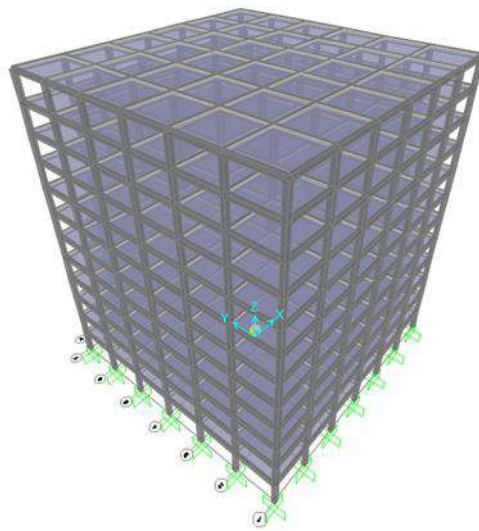


Fig. 2 The 3D finite element model constructed with SPC

III. RESULTS AND DISCUSSION

A. Model Using Portland Cement Concrete (PCC)

The modal analysis of the model composed of Portland Cement Concrete (PCC) was conducted using the finite element method. The cumulative dynamic mass participation ratio was found to be 99.99% in both the X and Y directions. The mode shapes corresponding to the first five modes, obtained from the analysis, are presented in Figures 3–7, respectively.

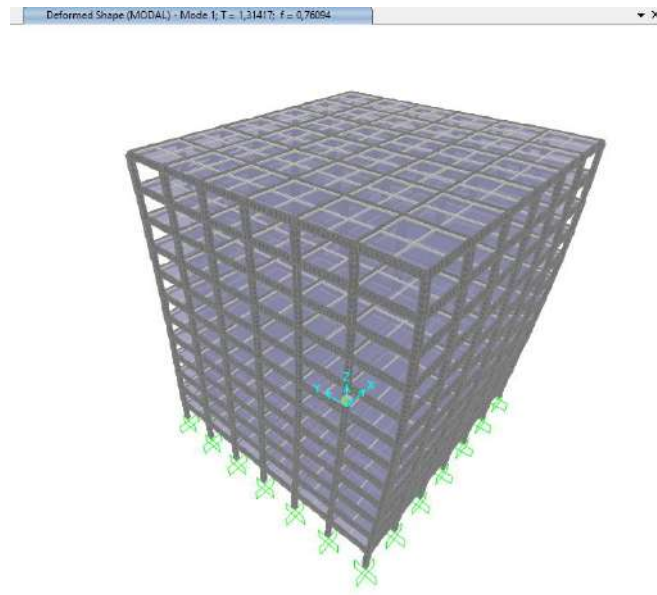


Fig. 3 The 3D view of mode 1 (Translation mode)

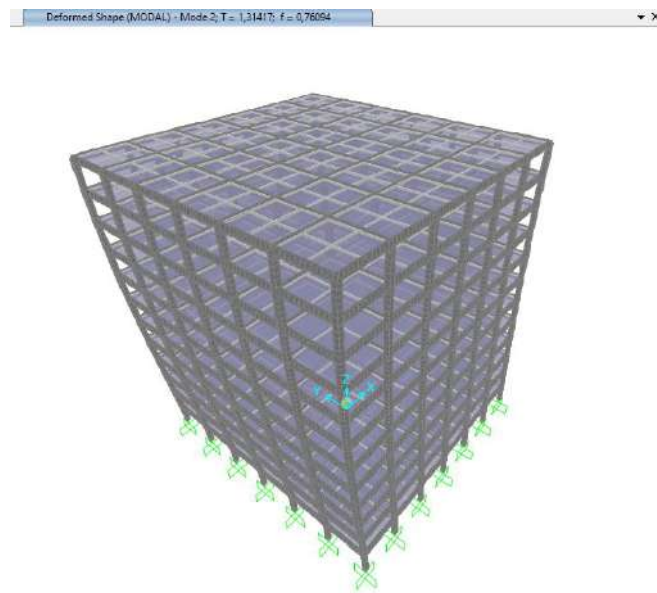


Fig. 4 The 3D view of mode 2 (Translation mode)

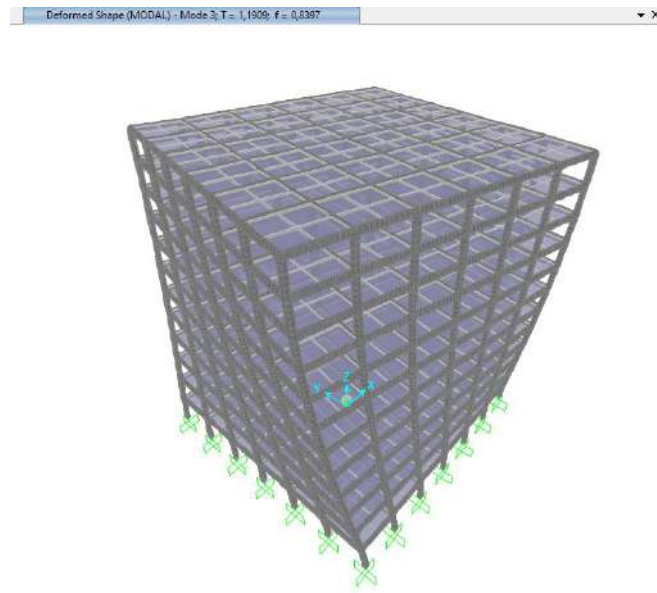


Fig. 5 The 3D view of mode 3 (Torsion mode)

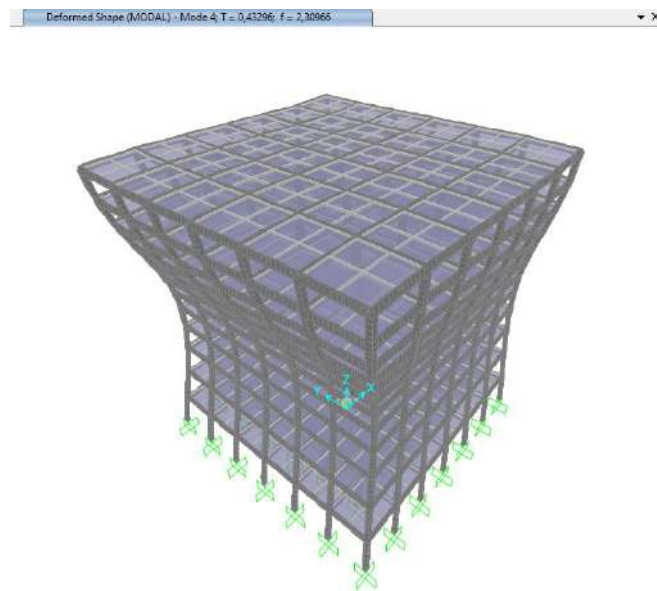


Fig. 6 The 3D view of mode 4 (Translation mode)

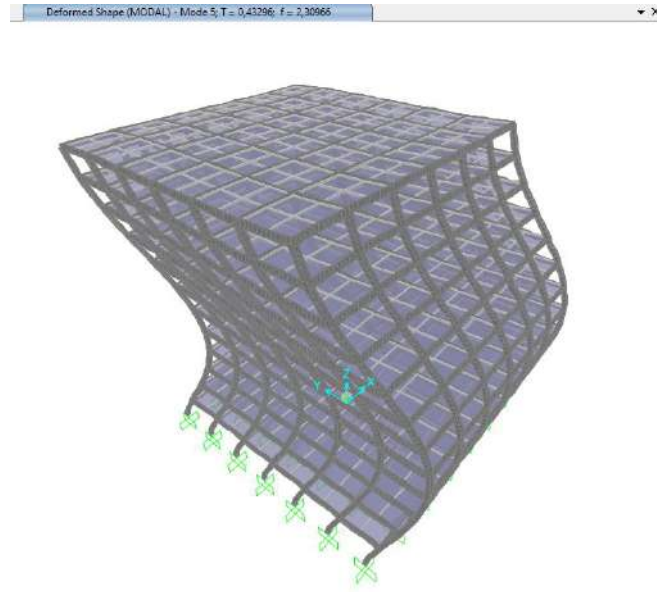


Fig. 7 The 3D view of mode 5 (Translation mode)

Period values and modal participating mass ratios of the first 5 modes are given in Table 2.

Table 2. Period values and modal participating mass of the first 5 modes PPC model

Mode	Period (sec)	UX	UY	UZ	RX	RY	RZ
1	1.314167	0.00627	0.8083	0	0.10795	0.00084	0
2	1.314167	0.8083	0.00627	7.588E-19	0.00084	0.10795	0
3	1.190901	0	0	2.47E-20	2.668E-20	8.387E-20	0.81746
4	0.432963	0.0691	0.02863	1.238E-17	0.09898	0.23887	9.892E-17
5	0.432963	0.02863	0.0691	1.522E-17	0.23887	0.09898	4.214E-16

During the evaluation of the static analysis results, the analysis process was carried out by taking into account the displacements occurring especially in the Z axis direction and the findings were interpreted within this scope. In this analysis phase, the dead load of the structure was taken into account. These loads determine the initial conditions for accurately assessing the safety and strength of the structure and provide a basic reference point against which the effects of other variable loads can be examined. The distribution and magnitudes of vertical (Uz) displacements are shown in detail in Figure 8.

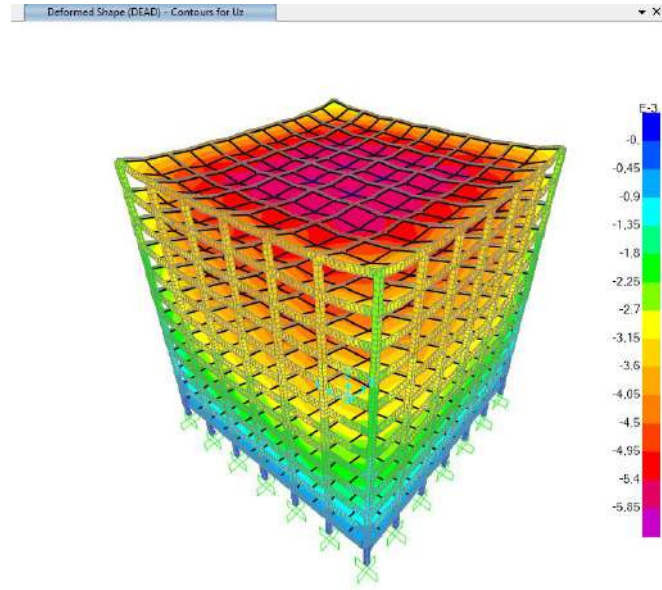


Fig. 8 The distribution and magnitudes of vertical (U_z) displacements

B. Model Using Sulfur Polymer Concrete (SPC)

The modal analysis of the model composed of Sulfur Polymer Concrete (SPC) was conducted using the finite element method. The total dynamic mass participation rate is 99.99 percent in the X and Y directions. The mode shapes of the first 5 modes obtained as a result of the modal analysis are given in Figures 9 - 13 respectively.

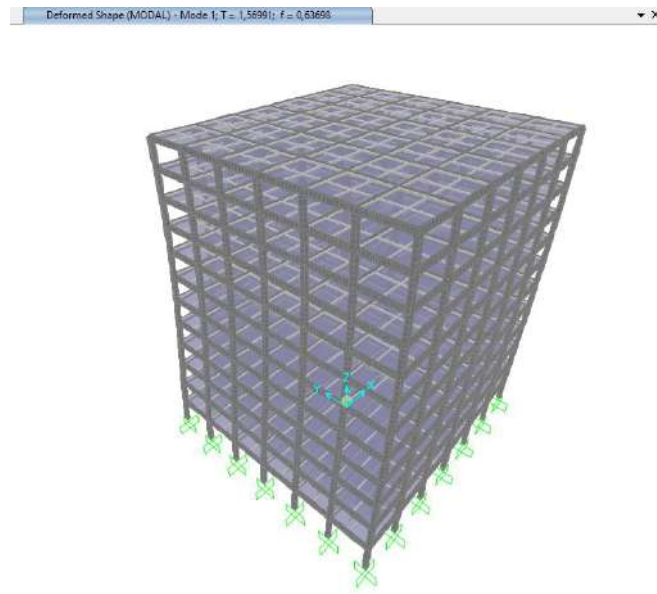


Fig. 9 The 3D view of mode 1 (Translation mode)

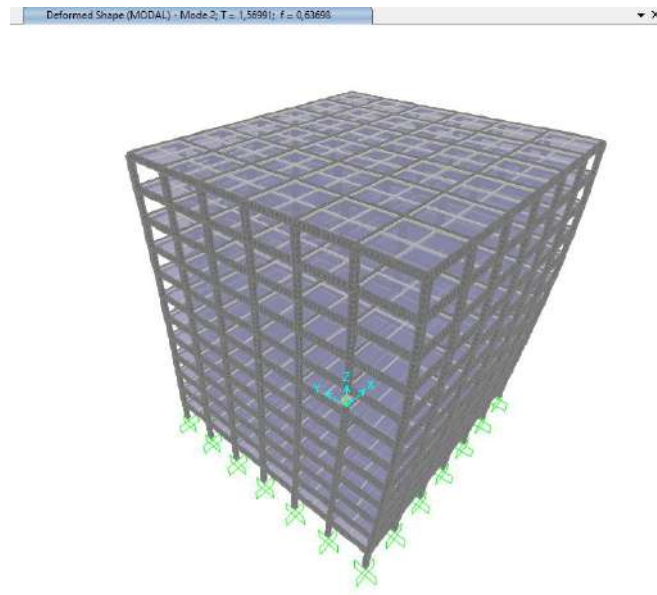


Fig. 10 The 3D view of mode 2 (Translation mode)

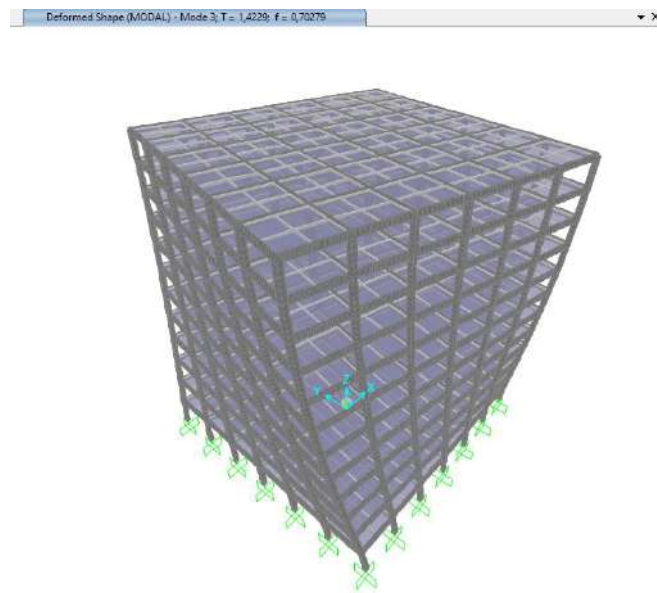


Fig. 11 The 3D view of mode 3 (Torsion mode)

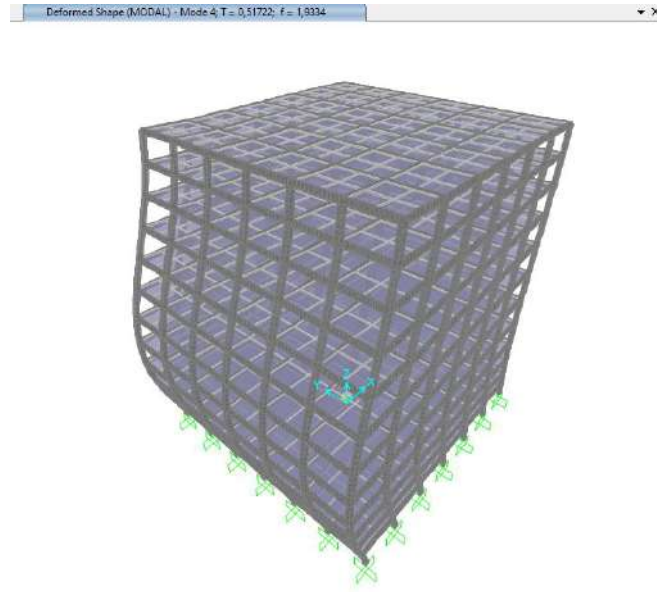


Fig. 12 The 3D view of mode 4 (Translation mode)

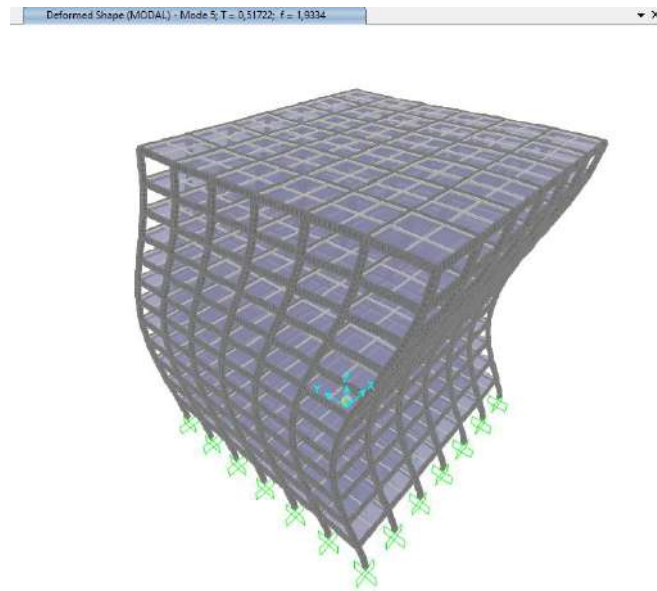


Fig. 13 The 3D view of mode 5 (Translation mode)

Period values and modal participating mass ratios of the first 5 modes are given in Table 3.

Table 3. Period values and modal participating mass ratios of the first 5 modes SPC model

Mode	Period (sec)	UX	UY	UZ	RX	RY	RZ
1	1.569911	0.79829	0.01628	7.475E-19	0.00217	0.10661	0
2	1.569911	0.01628	0.79829	1.287E-20	0.10661	0.00217	0
3	1.422896	0	0	2.453E-20	2.715E-20	8.24E-20	0.81746
4	0.517223	0.09346	0.00428	2.158E-17	0.01478	0.32307	4.195E-18
5	0.517223	0.00428	0.09346	5.814E-18	0.32307	0.01478	5.181E-16

The distribution and magnitudes of vertical (Uz) displacements are shown in detail in Figure 14.

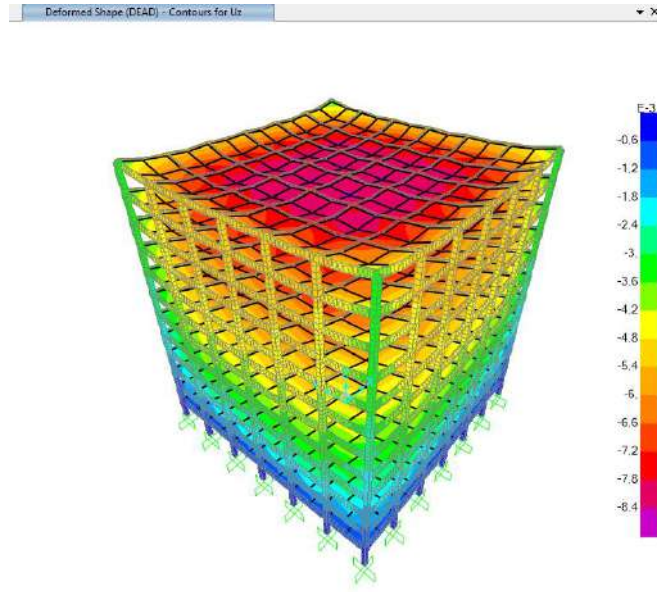


Fig. 14 The distribution and magnitudes of vertical (U_z) displacements

C. Comparison of Results

The comparison of period of the PCC and SPC model is given in Table 4.

Table 4. Comparison of period values

Mode	1	2	3	4	5
PCC model (sec)	1.314167	1.314167	1.190901	0.432963	0.432963
SPC model (sec)	1.569911	1.569911	1.422896	0.517223	0.517223
Difference (sec)	0.255744	0.255744	0.231995	0.08426	0.08426
Difference (%)	19.46	19.46	19.48	19.46	19.46

The comparison of mode shapes of the PCC and SPC model is given in Table 5.

Table 5. Comparison of mode shapes

Mode	1	2	3	4	5
PCC model	Translation	Translation	Torsion	Translation	Translation
SPC model	Translation	Translation	Torsion	Translation	Translation

The comparison of maximum vertical (U_z) displacement of the PCC and SPC model is given in Table 6.

Table 6. Comparison of maximum vertical displacement

	Maximum vertical displacement
PCC model (m)	0.006
SPC model (m)	0.009
Difference (m)	0.003
Difference (%)	50.00

In Mode 1 and 2 the difference in the fundamental period between the PPC and the SPC models was calculated as 0.255744 seconds. An increase of approximately 19.46% in the period value was observed after using SPC instead of PCC. The observation of an increase in the period value, while a decrease is expected due to the lower density of SPC, is thought to be evidence of the decrease in the structural rigidity. Examination of the corresponding mode shape showed no change in the primary deformation directions. Nevertheless, the mass contribution ratio decreases in the direction of the mode shape.

However, the mass contribution ratio increases in the torsional direction. This situation is generally thought to increase unwanted torsions in the structural system.

In Mode 3 the difference in the fundamental period between the PPC and the SPC models was calculated as 0.231995 seconds. An increase of approximately 19.48% in the period value was observed after using SPC instead of PCC. The observation of an increase in the period value, while a decrease is expected due to the lower density of SPC, is thought to be evidence of the decrease in the structural rigidity. Examination of the corresponding mode shape showed no change in the primary deformation directions. It was also observed that the mass participation ratio in the dominant direction (torsional) did not change.

In Mode 4 and 5 the difference in the fundamental period between the PPC and the SPC models was calculated as 0.08426 seconds. An increase of approximately 19.46% in the period value was observed after using SPC instead of PCC. The observation of an increase in the period value, while a decrease is expected due to the lower density of SPC, is thought to be evidence of the decrease in the structural rigidity. Examination of the corresponding mode shape showed no change in the primary deformation directions. However, in both modes, the mass participation ratios increased in the translational direction. This increase is thought to cause undesirable horizontal displacements. Although the mass participation ratio in the torsional direction decreases with the use of SPC, an increase in torsional forces in the RX and RY directions is observed. These findings indicate that the use of SPC instead of PPC results in two unfavorable conditions (increased translational and torsional forces) occurring simultaneously in modes 4 and 5.

When the analysis performed under vertical displacements compared the maximum displacements, it was observed that the maximum vertical displacement increased by 0.003 m and 50% when SPC was used instead of PPC. It is understood that the overall vertical displacements support this increase. In this case, it is thought that the use of SPC instead of PPC causes a decrease in the vertical rigidity of the structural system. It is known that SPC has higher compressive strength than PPC. Normally, there is a positive relationship between concrete's compressive strength and modulus of elasticity: as strength increases, stiffness generally increases. However, in some special cases, compressive strength may increase while modulus of elasticity decreases. This is because in sulfur polymer concretes, the binder phase is very dense and strong. However, the elastic behavior of the polymer matrix is lower than that of the cementitious matrix. This can be understood by examining the modulus of elasticity of both materials.

In the findings and discussion section the reference studies [30-38] were used to compare and verify the results obtained with the literature.

IV. CONCLUSION

The comparative analysis between PPC and SPC models revealed consistent increases in the fundamental period across all examined modes, with values rising by approximately 19–20% when SPC was used instead of PPC. This outcome, contrary to the expectation of reduced periods due to the lower density of SPC, indicates a significant reduction in the overall structural rigidity. While the primary deformation directions of the mode shapes remained unchanged, notable shifts in mass participation ratios were observed. Specifically, Modes 1 and 2 exhibited increased torsional contributions, suggesting a heightened susceptibility to unwanted torsional effects. In Mode 3, although the torsional mass participation ratio remained stable, the extended period again confirmed reduced stiffness. Modes 4 and 5 demonstrated simultaneous increases in translational and torsional effects, a combination that may amplify both horizontal displacements and torsional demands, thereby creating unfavorable structural conditions.

Vertical displacement analyses further supported these findings, with maximum displacements increasing by 50% under SPC. This indicates a reduction in vertical rigidity, despite SPC's higher compressive strength compared to PPC. The apparent contradiction can be explained by the material characteristics of sulfur polymer concretes: while the dense binder phase enhances compressive strength, the polymer matrix exhibits lower elastic behavior than cementitious matrices, resulting in a reduced modulus of elasticity and, consequently, diminished stiffness.

According to the results, despite SPC's high compressive strength, its use in structural systems instead of C25/30 PPC, commonly used in Turkey, is deemed unsuitable due to its loss of rigidity. SPC's reducing structural rigidity can negatively impact structural system safety, particularly by increasing horizontal and vertical displacements. Therefore, SPC is more suitable for applications where rigidity is not critical and only high compressive strength is required (infill elements, compressive blocks, or special non-structural components where strength is a priority rather than rigidity).

In order to use SPC in reinforced concrete structure carrier systems instead of PPC in the future, more research and development studies should be carried out, especially on the modulus of elasticity.

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Performance Evaluation of Event-Based and RGB Cameras in Dynamic Scenes

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Abstract – Event-based vision systems have emerged as a transformative alternative to conventional frame-based cameras by capturing visual information in an asynchronous, pixel-level manner. Unlike traditional RGB sensors that record full images at fixed frame rates, event-based cameras—such as Dynamic Vision Sensor (DVS), DAVIS, and ATIS—detect only brightness changes, resulting in microsecond-level temporal resolution and ultra-low latency. This unique sensing paradigm enables efficient data processing, low power consumption, and high dynamic range (HDR) imaging, particularly under challenging conditions such as high-speed motion and low illumination. Recent studies highlight that integrating deep learning architectures, including Spiking Neural Networks (SNNs) and event-driven Convolutional Neural Networks (Event-CNNs), significantly enhances event data interpretation and enables frameless object detection. Applications span across autonomous navigation, robotic control, industrial inspection, and real-time tracking. Despite their advantages, challenges remain in spatial resolution, sensor noise, and the need for specialized algorithms. The reviewed literature demonstrates a growing trend toward hybrid frameworks combining event-based sensors and traditional RGB modalities to achieve both temporal and spatial precision. Overall, event-based vision represents a paradigm shift toward bio-inspired, energy-efficient, and temporally precise perception systems, with promising implications for future intelligent machines and autonomous systems.

Keywords – Event-Based Vision; Dynamic Vision Sensor (DVS); Asynchronous Imaging; High Dynamic Range; Low-Power Perception; Real-Time Object Detection.

I. INTRODUCTION

In recent years, the field of computer vision has witnessed a paradigm shift from traditional frame-based image acquisition toward event-driven perception systems. Conventional RGB cameras operate by capturing full intensity images at fixed frame rates, which inherently limits their temporal resolution and leads to motion blur, latency, and redundant data under dynamic conditions [1,2]. In contrast, event-based cameras, such as the Dynamic Vision Sensor (DVS), DAVIS, and ATIS, record only the changes in logarithmic brightness asynchronously at the pixel level. Each pixel operates independently, generating an event whenever the intensity change exceeds a threshold. This enables microsecond-level temporal precision, high dynamic range (HDR) imaging, and low power consumption, making these sensors exceptionally suitable for real-time and high-speed applications [3].

The bio-inspired operating principle of event-based cameras mimics the human retina's mechanism of detecting temporal contrast rather than absolute brightness. As a result, event-based systems have gained increasing attention in autonomous driving, robotic control, industrial inspection, and gesture recognition. Moreover, the integration of neuromorphic computing and spiking neural networks (SNNs) has enabled the direct processing of asynchronous data streams, further enhancing recognition accuracy and processing efficiency [4]. Recent studies demonstrate that hybrid architectures combining event-based and RGB modalities can leverage the complementary strengths of both—temporal responsiveness from

event data and rich spatial information from intensity images. Despite these advantages, event-based sensors face several challenges, including limited spatial resolution, sensor noise, and the absence of standardized datasets for benchmarking. Nevertheless, with rapid advancements in sensor design, noise filtering algorithms, and event-based deep learning frameworks, these systems are increasingly moving from laboratory research toward real-world deployment. This study presents a comprehensive analysis of recent developments in event-based and RGB vision technologies, focusing on their operational principles, advantages, limitations, and application potentials in modern intelligent systems [5-7].

II. LITERATURE REVIEW

Event-based cameras are sensors developed on neuromorphic principles as an alternative to the conventional frame-based imaging paradigm. The fundamental difference of these sensors lies in their ability to capture scene changes with high temporal resolution and energy efficiency. Rebecq et al. [8] proposed a deep learning-based reconstruction network for high-speed and high-dynamic-range dense image/video reconstruction from event streams. Trained with perceptual loss functions, the model achieved up to 20% structural and perceptual improvement compared to existing methods and was able to generate thousands of frames per second nearly in real time. This study was pioneering in demonstrating that event data can serve as an intermediate representation, enabling subsequent tasks such as classification or odometry to be performed on reconstructed frames. However, sensitivity to sensor statistics and the lack of events in textureless regions were identified as major limitations.

Matsuda et al. [9] introduced the Motion Contrast 3D Scanning (MC3D) technique to overcome the bandwidth and light power constraints in structured-light-based 3D scanning. This approach employed motion-contrast cameras that asynchronously capture temporal gradients at each pixel, thereby reducing redundant sampling and achieving reliable depth measurements even under strong ambient illumination. Nonetheless, the requirement for specialized hardware and the need for calibration on complex surfaces increased the practical cost of implementation.

Delbrück [10] presented a comprehensive review summarizing the evolution of neuromorphic vision sensors between 2002 and 2016. The study described the advantages of DVS and DAVIS architectures in terms of power consumption and latency; however, it focused primarily on conceptual discussions and included limited quantitative comparisons. Nguyen et al. [11] proposed a method that estimates the six degrees of freedom (6DoF) camera pose using only event data. In this study, an “event image” representation was constructed from event streams, and a CNN-based feature extractor was combined with a Stacked Spatial LSTM (SP-LSTM) architecture. The results demonstrated that spatial dependencies within event data could be effectively learned. However, partial loss of temporal information during the conversion of raw events into image form limited the overall estimation accuracy.

Lee et al. [12] developed a real-time hand gesture recognition interface using event data from stereo silicon retina-based dynamic vision sensors. Motion trajectories were extracted using leaky integrate-and-fire (LIF) neurons, and gesture start–end points were detected through a stereoscopic spatio-temporal correlation method. Classification based on Hidden Markov Models (HMMs) and Gaussian Mixture Models (GMMs) achieved over 90% accuracy. Nevertheless, the limited number of gesture categories and the controlled experimental setup reduced the method’s generalizability to complex real-world scenarios. Amir et al. [13] presented a fully event-driven, low-power, end-to-end hardware system for gesture recognition. Dynamic Vision Sensor (DVS) outputs were fed into a CNN operating on IBM’s TrueNorth neuromorphic processor, transmitting data only when an event occurred. The system achieved 96.5% accuracy on the DvsGesture dataset, with 105 ms latency and power consumption below 200 mW. This work represented the first real-time gesture recognition system running entirely on event-based sensing and neuromorphic hardware.

Benosman et al. [14] proposed a novel differential framework for dense optical flow estimation using event timing information. This method achieved microsecond-level direction and magnitude estimation while maintaining low computational and bandwidth costs. However, event scarcity in low-texture regions remained a challenge for system stability. Liu et al. [15] analyzed the integration of event-driven vision and auditory sensors, explaining the reasons behind their power and latency advantages in a

systematic manner. The study emphasized the significance of matching event-based representations with algorithmic design to achieve real-time performance, though its contribution remained largely conceptual. Delbrück and Lang [16] demonstrated ultra-low-latency robotic response systems using event-based vision sensors, achieving approximately 3 ms reaction time, 4% CPU utilization, and 550 Hz update rates in a “robot goalkeeper” experiment. The study clearly highlighted the latency advantage of event-based perception; however, its task-specific nature limited generalization potential. Taverni et al. [17] compared front-side illuminated (FSI) and back-side illuminated (BSI) designs of DAVIS sensors, showing that BSI sensors offered higher light sensitivity with a 93% quantum efficiency but also produced more leakage events. This finding underscored the need for hardware-level optimization depending on application requirements. Orchard et al. [18] developed a hierarchical spiking model (HFirst) for object recognition using the temporal information from address-event representation (AER) sensors. The temporal winner-take-all mechanism allowed the system to operate without synchronized clock pulses, achieving approximately 97.5% accuracy. These results demonstrated that temporal information alone can serve as a discriminative feature in object recognition. However, the model was not evaluated on large-scale datasets, limiting its comparability to modern deep learning approaches. Overall, the reviewed literature indicates that event-based systems offer clear advantages over RGB cameras in terms of high speed, low power consumption, and wide dynamic range. Nevertheless, challenges such as event sparsity, reconstruction complexity, and limited datasets still need to be addressed for broader adoption in practical applications.

Table 1. Comparative Overview of Event-Based Sensing Approaches

Study	Problem	Core Idea	Main Metric / Result	Strength	Potential Weakness
Rebecq et al.	Event → high HDR / very high fps video	Deep re-synthesis + perceptual loss, synthetic training	>20% better than SOTA, near real-time	HDR & very high fps; usable for downstream tasks	Sensitive to sensor / scene statistics
MC3D	Event-like sensing for 3D scanning	Asynchronous motion-contrast measurement; single shot	Robust depth under sunlight / glare	Good balance of speed-resolution-light efficiency	Hardware / calibration requirements
Delbrück (review)	Field panoramas	DVS/DAVIS principles, energy-latency analysis	Conceptual framework	Roadmap, design insights	Limited quantitative comparison
Nguyen et al.	Event-based 6DoF relocalization	CNN + SP-LSTM	SOTA-level accuracy, real-time	Good use of spatial dependencies	Partial loss of raw temporal information
Lee et al.	Stereo-event gesture interface	LIF + HMM/GMM, stereo correlation	>90% accuracy, 60 dB illumination tolerance	Low power, real-time	Scalability in complex scenes

III. PRINCIPLES OF EVENT-BASED VISION

Event-based vision represents a paradigm shift in image acquisition, departing from conventional frame-based methods by recording visual information asynchronously at the pixel level. Unlike traditional RGB cameras, which capture full intensity frames at fixed time intervals, event-based sensors such as the Dynamic Vision Sensor (DVS), DAVIS, and ATIS generate events only when a change in logarithmic brightness exceeds a predefined threshold. Each pixel operates independently, producing an event characterized by its coordinates, timestamp, and polarity (indicating an increase or decrease in intensity). This mechanism allows for microsecond-level temporal resolution, ultra-low latency, and high dynamic range imaging, particularly advantageous in fast-moving or poorly lit environments.

The fundamental operating principle is illustrated in Figure 1, which depicts how an individual pixel triggers an event whenever the intensity change crosses the threshold. Unlike frame-based imaging, which continuously captures redundant data, event-based vision focuses only on dynamic regions of the scene, optimizing data efficiency and reducing power consumption. This asynchronous data stream enables immediate response to changes in the visual field, making it ideal for real-time perception tasks such as motion detection, optical flow estimation, and high-speed tracking.

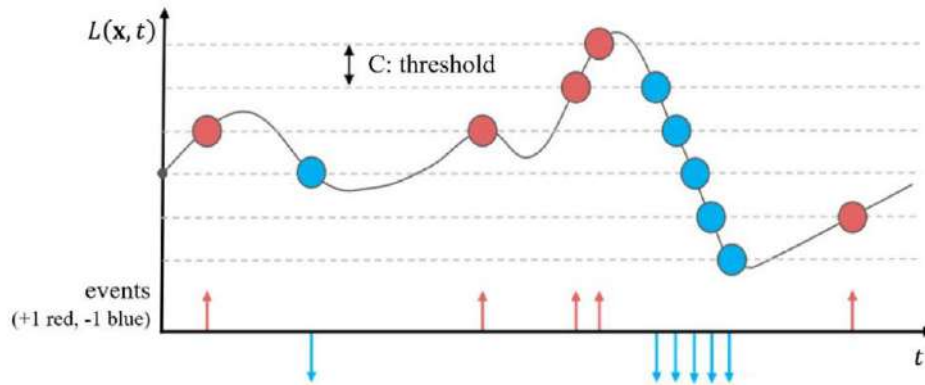


Fig. 1 Pixel-level event generation schematic. Show a pixel detecting brightness changes and producing an event with coordinates, timestamp, and polarity [19].

Another key advantage of event-based vision is its capability to handle extreme lighting conditions. Event cameras maintain performance in both very low-light and high dynamic range (HDR) scenarios, as they respond to temporal contrast rather than absolute intensity values. Figure 2 compares the outputs of a standard RGB camera and an event-based sensor observing the same dynamic scene. The RGB image shows motion blur and limited exposure adaptability, whereas the event-based representation captures fast-moving objects with precise temporal localization and minimal latency. In summary, event-based vision leverages asynchronous, pixel-level data acquisition to overcome the limitations of conventional cameras. Its temporal precision, low power consumption, and HDR capabilities provide a robust foundation for advanced vision algorithms, real-time robotic perception, and hybrid sensor systems that combine the complementary strengths of RGB and event-based modalities.

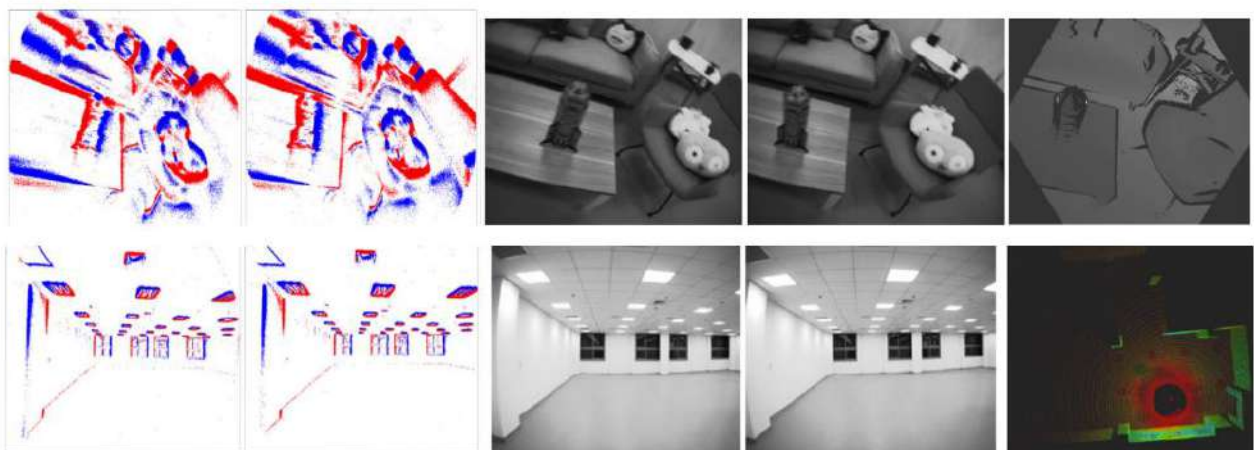


Fig. 2 Side-by-side comparison of RGB frame vs event-based representation in a dynamic scene (e.g., fast-moving car or hand gesture) [20].

IV. FUTURE DIRECTIONS

The key findings and insights from the comparative analysis of event-based and RGB cameras can be summarized in the following five points:

1. Bio-inspired sensing and temporal advantages: Event-based cameras, such as DVS, DAVIS, and ATIS, capture only changes in scene brightness asynchronously at the pixel level. This mechanism mimics the human retina, enabling microsecond-level temporal resolution, ultra-low latency, and high dynamic range (HDR) imaging. These properties make event-based vision highly effective for high-speed, low-light, and dynamic applications where traditional RGB cameras are limited by motion blur and fixed frame rates.
2. Energy efficiency and data reduction: Unlike frame-based systems that capture full images continuously, event-based sensors generate data only when intensity changes occur. This results in significant reductions in redundant information and power consumption, making them particularly suitable for embedded, mobile, and autonomous systems requiring real-time perception.
3. Enhanced performance through computational methods: Deep learning frameworks, including Event-CNNs, spiking neural networks (SNNs), and hybrid architectures, enable effective interpretation of asynchronous event streams. Applications such as dense image reconstruction, optical flow estimation, and six degrees of freedom (6DoF) pose estimation demonstrate that event data can act as an intermediate representation, supporting a wide range of computer vision tasks with high accuracy.
4. Challenges and limitations: Despite their advantages, event-based systems face notable challenges: event sparsity in low-texture regions, sensor noise, limited spatial resolution, algorithmic complexity, hardware calibration requirements, and the lack of standardized, large-scale datasets. These factors constrain broader adoption in practical, real-world applications.
5. Future directions and hybrid approaches: Combining event-based sensors with traditional RGB modalities offers a promising solution to current limitations, leveraging both temporal precision and rich spatial information. Continued research in sensor design, neuromorphic hardware, deep learning algorithms, and benchmarking standards will be critical for realizing the full potential of event-based vision in autonomous systems, robotics, industrial monitoring, and intelligent machine perception.

V. CONCLUSION

Event-based vision represents a fundamental shift in the field of computer vision, offering a bio-inspired alternative to conventional frame-based cameras. By capturing only changes in scene brightness at the pixel level, these sensors provide microsecond-level temporal resolution, ultra-low latency, and high dynamic range imaging, which are particularly advantageous under challenging conditions such as high-speed motion or low illumination. Compared to traditional RGB cameras, event-based systems significantly reduce redundant data acquisition and power consumption, enabling real-time processing for applications in autonomous navigation, robotics, industrial inspection, and gesture recognition. The integration of deep learning frameworks, including event-driven convolutional networks (Event-CNNs), spiking neural networks (SNNs), and hybrid architectures, has further enhanced the utility of event-based data. Techniques such as event image reconstruction, optical flow estimation, and six degrees of freedom (6DoF) pose estimation demonstrate that event streams can serve as an effective intermediate representation for downstream vision tasks. Moreover, neuromorphic hardware implementations, exemplified by low-power gesture recognition systems, highlight the potential for fully asynchronous and energy-efficient processing pipelines. Despite these advantages, several challenges remain. Event sparsity in low-texture regions, noise, limited spatial resolution, and the lack of standardized large-scale datasets constrain the broader adoption of event-based systems. Hardware costs, calibration requirements, and algorithmic complexity further limit their practical deployment. Recent studies suggest that hybrid approaches combining event-based and RGB modalities can mitigate some of these limitations, leveraging the temporal precision of events and the rich spatial information of intensity frames. Overall, event-based vision systems offer compelling benefits for high-speed, low-power, and temporally precise perception, signaling a paradigm shift toward intelligent, energy-efficient, and real-time sensing. Continued research in sensor design, algorithm development, and standardization will be critical to

overcoming current limitations and realizing the full potential of these systems in real-world autonomous and intelligent applications.

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Performance Analysis of Multiple Object Tracking Algorithms for Maritime Environments

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Abstract – Robust Multi-Object Tracking (MOT) is critical for maritime navigation, surveillance, and autonomous operations. This paper presents a comparative analysis of state-of-the-art MOT algorithms - SORT, DeepSORT, ByteTrack, BoT-SORT, OC-SORT, and StrongSORT- evaluated within challenging maritime contexts. Using the Singapore Maritime Dataset (SMD), known for its diverse weather, lighting, and vessel density, we assess algorithms based on tracking accuracy (MOTA) and speed (FPS). Our empirical results indicate that ByteTrack provides the most balanced performance, achieving approximately 80% MOTA at a high frame rate, making it ideal for real-time applications. BoT-SORT also demonstrates high accuracy with robust camera motion compensation. While SORT offers a compelling speed-accuracy trade-off for resource-constrained systems, StrongSORT and OC-SORT provide strong alternatives in scenarios requiring high identity preservation, albeit at a higher computational cost. DeepSORT, in our tests, yielded limited performance. This analysis offers a guideline for selecting optimal MOT algorithms tailored to specific maritime operational requirements.

Keywords – Multiple Object Tracking, Maritime Computer Vision, Performance Evaluation, SORT, DeepSORT, ByteTrack, BoT-SORT, OC-SORT, StrongSORT, Singapore Maritime Dataset.

I. INTRODUCTION

In modern technologies, object tracking, a fundamental component of computer vision systems, refers to the ability to continuously monitor the positions and identities of objects of interest within video sequences over time [1]. This critical capability plays a vital role in ensuring reliability and efficiency across a wide range of applications, including autonomous vehicles, intelligent surveillance systems, robotics, and human-computer interaction. Initially, classical methods such as the Kalman filter and particle filter dominated the field, achieving successful results in static and low-complexity scenes [2]. However, in modern scenarios characterized by crowded, dynamic, and complex environments, particularly in Multiple Object Tracking (MOT) tasks—the limitations of these traditional approaches have become evident. Challenges such as object occlusion, abrupt motion changes, and long-term tracking losses make it difficult for conventional algorithms to maintain identity consistency, motivating researchers to redesign tracking solutions [3].

Recently, the integration of deep learning into computer vision has led to a significant paradigm shift in object tracking. The track-by-detection approach has gained prominence, giving rise to advanced algorithms such as DeepSORT, FairMOT, ByteTrack, and BoT-SORT. These next-generation models leverage high-accuracy outputs from object detection networks to jointly analyze both visual and motion features of objects, thus achieving superior identity preservation [4,5]. This study aims to experimentally evaluate the reliability and performance of modern multiple object tracking algorithms in challenging maritime environments. Prominent algorithms from the literature—including SORT, DeepSORT,

ByteTrack, BoT-SORT, OC-SORT, and StrongSORT—were tested on the Singapore Maritime Dataset (SMD), which includes realistic and variable conditions. The analysis focuses on the critical balance between tracking accuracy (MOTA) and speed (FPS) to identify the optimal tracking solution that best satisfies the system’s real-time and high-accuracy requirements [6].

II. LITERATURE REVIEW

The use of camera-based systems in maritime environments presents unique challenges compared to terrestrial applications, including wave motion, wake turbulence, fog, low illumination, and platform oscillation. Various studies in the literature have proposed different methods to address these issues. Prasad et al. [7] provided a comprehensive survey of maritime object detection and tracking approaches based on electro-optical (EO) sensor video data. Their study emphasized that core modules of autonomous ship systems—such as horizon detection and background subtraction—must be redesigned due to the unique dynamics of the maritime domain. In a subsequent study, Prasad et al. [8] evaluated the performance of 23 different background subtraction (BS) algorithms on the Singapore Maritime Dataset (SMD). Their results demonstrated that traditional BS methods perform inadequately in maritime environments due to the false dynamics of water surfaces and the effects of wake turbulence. This finding justifies the necessity of deep learning-based object detection methods adopted in this thesis. Hoehner et al. [9] reviewed research focused on person-overboard (POB) scenarios, which are critical for search and rescue operations. They highlighted the importance of ensuring reliable detection under challenging environmental conditions.

The limitations of conventional approaches have directed recent research toward Artificial Intelligence (AI) and Computer Vision (CV)-based solutions. Hong et al. [10] proposed an enhanced YOLOv4 architecture with simplified design to simultaneously meet the speed and accuracy requirements of multi-ship detection and tracking. Their work demonstrated that YOLO-based one-stage detectors are essential for real-time maritime applications. Similarly, Vasilopoulos et al. [11] conducted a comparative performance analysis of different autonomous object detection algorithms for maritime surveillance using Unmanned Aerial Vehicle (UAV) platforms. They emphasized the significance of hardware–algorithm compatibility in autonomous systems. Following object detection, maintaining target identity and tracking motion are fundamental requirements for precise operations such as autonomous docking or robotic charging.

In this context, Niu et al. [12] developed a real-time algorithm named MOMT (Maritime Object Motion Tracker) based on ByteTrack for visual tracking in Unmanned Surface Vehicle (USV) applications. The authors adapted the core principle of ByteTrack—utilizing low-confidence detections—to maritime scenarios and integrated an Augmented Observation Kalman Filter to mitigate the effects of nonlinear target motion. Moreover, a new “Fuse-distance” metric combining IoU, object category, and size information was introduced for improved data association. Liu and Yang [13] proposed a novel maritime radar multi-object tracking algorithm based on an improved Spatio-Temporal Memory Network (STMN) to achieve high accuracy and stability in complex maritime environments. This study supports the thesis in terms of both tracking performance and sensor data integration (data fusion). Finally, Krüger and Orlov developed a robust multi-layer, multi-algorithm architecture with motion stabilization for tracking small and distant vessels using thermal imagery. Their approach improved detection performance under low-contrast and long-range conditions.

III. MATERIALS AND METHOD

Object tracking is defined as the process of monitoring the positions of objects within a scene over time. While classical approaches such as the Kalman filter and particle filter are adequate for simple or static scenes, they often fall short in complex and dynamic tasks such as Multiple Object Tracking (MOT). In recent years, the integration of deep learning has shifted the field toward the track-by-detection paradigm, where detection and tracking are jointly utilized. These models maintain the continuity and consistency of

object identities by leveraging outputs from modern object detection networks. The following sections provide a detailed examination of the prominent representatives of this emerging paradigm.

A. Prominent Tracking Algorithms

DeepSORT is an advanced MOT (Multiple Object Tracking) algorithm widely used in real-time video analysis that extends the capabilities of the classical SORT method. It employs a Kalman filter to predict future object positions, but its key improvement lies in the appearance-based matching mechanism. Instead of relying solely on spatial proximity, DeepSORT extracts appearance feature vectors using a CNN, which are then evaluated together with Mahalanobis distance to associate detections with existing tracks. This integration enables more accurate distinction between closely located or similarly moving objects, significantly reducing ID switches and improving tracking accuracy over purely geometric methods [14].

FairMOT stands out in MOT by performing both object detection and re-identification (Re-ID) tasks within a unified architecture. Unlike traditional two-step approaches, FairMOT employs a CenterNet-based anchor-free representation, allowing it to jointly and efficiently learn both tasks. The network outputs a heatmap and bounding box dimensions for detection, while simultaneously generating fixed-size embedding vectors for Re-ID. By sharing feature maps between detection and Re-ID branches, FairMOT improves computational efficiency and provides robust visual representations for consistent identity tracking [15].

ByteTrack introduces an innovative approach to MOT by maximizing the contribution of low-confidence detections. Its core principle is to retain nearly all detection boxes and divide them into high-score and low-score groups. In the first association stage, tracks are matched only with high-confidence detections. In the second stage, unmatched tracks are re-associated with low-confidence detections. This two-stage association mechanism recovers missed or partially occluded objects that conventional algorithms would discard, resulting in a significant improvement in overall tracking robustness and accuracy [16].

StrongSORT enhances the original DeepSORT framework by incorporating a more powerful detector and a refined Re-ID module, along with two auxiliary components: Gaussian-Smoothed Interpolation and Appearance-Free Link. The former predicts object positions during temporary detection losses to fill trajectory gaps, while the latter globally associates short tracklets using only spatial-temporal information, without relying on appearance features. These enhancements reduce ID switches and improve positional stability, offering higher identity preservation with minimal computational overhead [17].

BoT-SORT is a robust tracking algorithm that effectively combines motion-based matching with visual Re-ID features within a track-by-detection framework. One of its major innovations is the Camera Motion Compensation (CMC) module, which increases stability in moving-camera scenarios by correcting positional discrepancies between detections and predictions. Additionally, improvements to the Kalman filter allow more accurate updates of bounding box dimensions over time. Through these integrations, BoT-SORT achieves high performance in MOTA and IDF1 metrics, providing stable long-term identity tracking [18].

OC-SORT was developed to address the error accumulation problem that classical SORT faces in non-linear motion and long-term occlusion scenarios. Unlike prediction-centric approaches, OC-SORT adopts an observation-centric framework through its Observation-Centric Re-Update (ORU) mechanism. When an object is re-detected after being lost, ORU retrospectively corrects previous tracking inaccuracies, thus improving tracking precision. Furthermore, a directional consistency-based matching strategy is employed to reduce false associations. As a result, OC-SORT delivers more stable and reliable tracking performance in dense scenes and situations involving object disappearance and reappearance [19].

B. Singapore maritime dataset (SMD)

We utilized the Singapore Maritime Dataset (SMD) for evaluation. SMD is a well-known benchmark containing video sequences captured from a maritime environment, encompassing a wide variety of conditions: different weather patterns (sunny, rainy, foggy), varying illumination (day, night, dusk), and diverse object densities. This realism and complexity make it an ideal testbed for assessing the reliability of MOT algorithms under challenging, real-world scenarios. SMD is an open-access maritime dataset

widely used for multiple object tracking (MOT) applications [20]. The dataset contains high-resolution images designed to support computer vision-based maritime applications such as unmanned surface vehicles (USVs), ship tracking systems, and autonomous navigation algorithms. These images include scenes recorded with fixed and mobile cameras under different weather conditions and at various times of the day (Figure 1). Each scene contains class labels and location information for multiple vessels, and the images are labeled appropriately for training and evaluation of multiple object detection and tracking algorithms.



Figure 1. Example scenes containing different vessel types from the SMD dataset.

In this study, the SMD dataset was used to examine the performance of tracking algorithms in ship-approaching scenarios. Vessels such as barges, cargo ships, speedboats, sailboats, tugboats, and buoys were labeled with bounding boxes. Tracking algorithms were evaluated using metrics such as ID consistency, tracking accuracy, and frame continuity across scenes consisting of consecutive frames. The environmental diversity of SMD provided a suitable environment to test the temporal robustness of the algorithms in real-world scenarios.

IV. PERFORMANCE ANALYSIS

This section presents the performance results of the object tracking algorithms that form the core component of the developed system. In this study, several widely recognized Multiple Object Tracking (MOT) algorithms with distinct architectures—namely SORT, DeepSORT, ByteTrack, BoT-SORT, OC-SORT, and StrongSORT—were experimentally evaluated. The primary objectives were to measure the overall performance of these algorithms in terms of object detection and identity tracking (ID consistency) and to analyze their reliability under challenging and complex maritime scenarios.

A. Experimental Setup and Evaluation Metrics

The algorithms were tested on the challenging Singapore Maritime Dataset (SMD), which includes various weather conditions, illumination levels, and object densities typical of maritime environments. This dataset was selected as a reliable benchmark for assessing algorithm performance under realistic conditions. Two key metrics were used for evaluation: Multiple Object Tracking Accuracy (MOTA),

representing overall tracking precision, and Frames Per Second (FPS), indicating real-time performance. Figure 2 presents the comparative distribution of the algorithms based on their speed–accuracy balance.

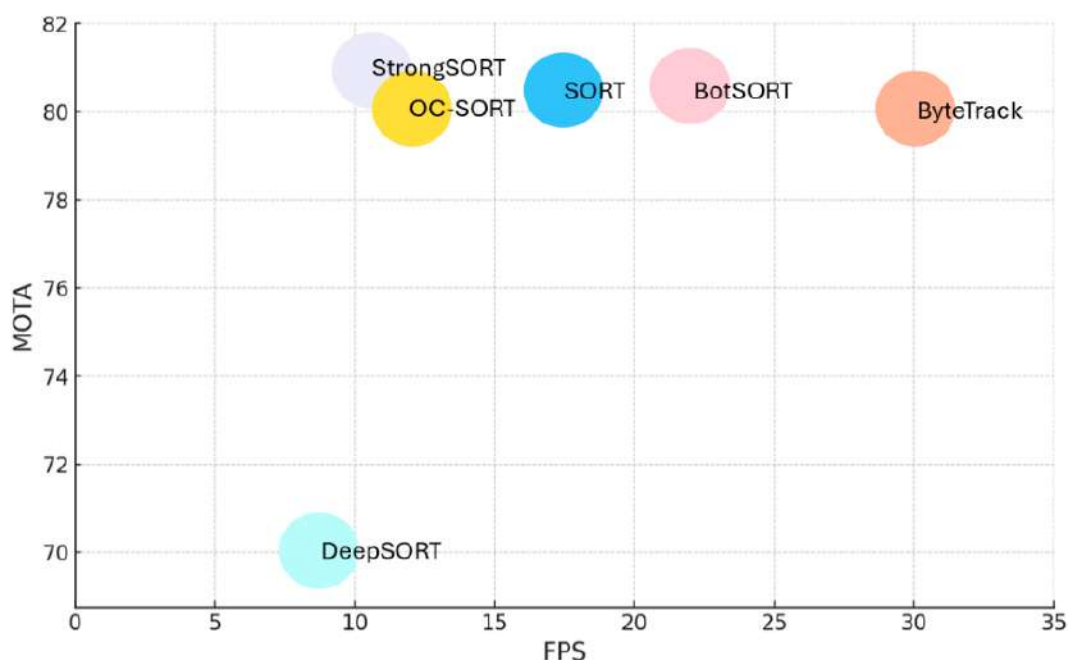


Figure 2. Comparison of multiple object tracking algorithms based on FPS and MOTA values.

B. Evaluation of Performance Results

The obtained results revealed distinct trade-offs between tracking accuracy and processing speed across the evaluated algorithms:

Superior Balance of ByteTrack: The ByteTrack algorithm achieved a balanced performance, offering approximately 80% MOTA alongside one of the highest FPS values among all methods. Its real-time capability and robust tracking mechanism—enabled by leveraging low-confidence detections—make it one of the most suitable algorithms for the proposed system.

High-Accuracy Alternatives: The BoT-SORT algorithm demonstrated similarly high accuracy with moderate speed. Its advanced features, such as camera motion compensation, enhanced tracking precision while maintaining real-time feasibility. The SORT algorithm achieved about 81% MOTA at roughly 18 FPS, proving to be an efficient option for low-computation scenarios, though its long-term tracking performance was limited.

Lower-Speed Solutions: OC-SORT and StrongSORT operated at 11–13 FPS, yet achieved MOTA values above 80%, making them viable options for accuracy-focused maritime applications. In contrast, DeepSORT was among the slowest (around 10 FPS) and reached only 70% MOTA, indicating limited overall performance compared to more recent algorithms.

In summary, ByteTrack and BoT-SORT emerged as the most effective algorithms for achieving real-time and high-accuracy tracking, aligning with the system’s operational objectives. For resource-constrained conditions, SORT and StrongSORT can serve as suitable alternatives.

V. CONCLUSION

This study evaluated six multiple object tracking algorithms—SORT, DeepSORT, ByteTrack, BoT-SORT, OC-SORT, and StrongSORT—on the Singapore Maritime Dataset to assess their performance under maritime conditions. Challenges such as reflections, waves, and illumination changes were key factors in performance variation. Among the tested methods, ByteTrack achieved the best overall balance with around 80% MOTA and high real-time capability, while BoT-SORT offered strong accuracy thanks to its camera motion compensation. SORT remained the fastest but less reliable for long-term tracking, whereas OC-SORT and StrongSORT provided higher accuracy at the cost of slower speeds. In

conclusion, ByteTrack and BoT-SORT stand out as effective solutions for real-time maritime applications. Future work will focus on improving robustness through sensor fusion, weather adaptation, and lightweight models for embedded platforms.

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Süreksizlik Noktası İçeren Sturm-Liouville Problemi İçin Green Fonksiyonunun Özfonksiyon Açılımı

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Özet – Sturm-Liouville problemlerinin spektral yöntemler açısından önemi, kısmi diferansiyel denklemler için başlangıç ve/veya sınır değer problemlerinin analitik biçimde veya seri biçiminde verilen çözümlerinin, genellikle uygun Sturm-Liouville problemlerinin özfonksiyonlarının sonlu veya seri biçiminde bir açılımı olarak görülmesinden kaynaklanmaktadır. Genelleştirilmiş özfonksiyonlarda açılım problemi, en azından Fourier dönemine kadar uzanan klasik bir problemidir. Bu problemin yeni bir gelişimi, rastgele ortamlarda dalga yayılımının incelenmesiyle ilgilidir. Schrödinger operatörü için elde edilen önemli sonuçlar, bu uygulamaların gerekçesini oluşturmuştur. Ancak, klasik dalgalarla ilişkili operatörlerin incelenmesi, özfonksiyon açılımları hakkında daha genel sonuçlar elde etme ihtiyacını doğurmuştur. Son yıllarda, atmosferik dalgalar, Dünya'nın sismik davranışı, sicim titreşimleri ve kuantum mekaniksel bir osilatörün enerji özfonksiyonları gibi salınımlı süreçlerin modellenmesi gibi çeşitli problem türleri için periyodik sınır koşulları ortaya çıkmıştır. Bu durumda, özdeğerler enerji seviyelerinin salınımlarının rezonans frekanslarına karşılık gelir. Bu çalışmada, yeni ve özgün yöntemler kullanılarak, iç süreksizliğe sahip çok aralıklı Sturm-Liouville problemleri için Green fonksiyonu elde edilmiş ve daha sonra bu Green fonksiyonu için bir açılım formülü bulunmuştur. Problemdeki süreksizlikleri gidermek için, süreksizlik noktalarında iletim koşulları ilave edilmiştir. Bu tür problemler genellikle çeşitli fiziksel iletim problemlerinde ortaya çıkmaktadır. Örneğin, iletim koşulları kullanılarak çözülebilen bazı problemler, ince katmanlı bir levhadaki (yani, farklı özelliklere ve değişken kalınlığa sahip malzemelerin üst üste istiflenmesiyle oluşturulan bir levha) ısı iletimi problemlerinde de ortaya çıkar.

Anahtar Kelimeler – Sturm-Liouville Problemi, İletim Koşulları, Green Fonksiyonu İçin Özfonksiyon Açılımı.

I. GİRİŞ

19. yüzyıl ve 20. yüzyılın ilk yarısı boyunca Sturm-Liouville problemlerini araştırmak için bir dizi analitik yöntem ve kapsamlı bir teori geliştirilmiştir [1,10]. Denklemler sabit katsayılarla sahip olduğu veya Bessel ya da hipergeometrik denklem gibi özel bir formda olduğu zaman, problemler kolaylıkla çözülebilirdi; yani özfonksiyonlar özel fonksiyonlar cinsinden ve özdeğerler de karakteristik fonksiyonların sıfırları cinsinden ifade edilebilirdi. Asimptotik açılımlar, seri gösterimleri ve diğer özel yöntemler, ilk birkaç özdeğer ve özfonksiyonların sayısal yaklaşımlarının hesaplanmasına imkan vermektedir. Regüler bir Sturm-Liouville sınır değer problemi için Green fonksiyonu hem homojen olmayan denklemi hem de sınır koşullarını içeren problemin çözüm fonksiyonunun çekirdeğidir. Çözümlerin Green fonksiyonu gösteriminin birçok uygulama alanı vardır. Ayrıca, sınır değer probleminin çözümünün özellikleri genellikle Green fonksiyonun gösteriminden ve Green fonksiyonun tekil noktalarındaki davranışından kaynaklanır. Klasik Sturm-Liouville problemleri için özfonksiyon açılım problemleri Green fonksiyonu aracılığı ile de araştırılabilir. Özfonksiyon açılımı problemleri birçok yazar tarafından araştırılmıştır (bkz. [5, 8] ve burada atıfta bulunulan referanslar)

Bu çalışmada

$$\Delta\chi := -\chi''(x) + q(x)\chi(x) = \lambda\chi(x), \quad x \in [-1,0) \cup (0,1) \cup (1,2] \quad (1)$$

diferensiyel denkleminde

$$\Delta_1\chi := \chi(-1) = 0 \quad (2)$$

$$\Delta_2\chi := \chi'(2) = 0 \quad (3)$$

sınır şartlarından ve de $x = \Gamma_1$ ve $x = \Gamma_2$ süreksizlik noktalarında verilen

$$\Delta_3\chi := \chi(0-0) - \chi(0+0) = 0 \quad (4)$$

$$\Delta_4\chi := \chi'(0-0) - \chi'(0+0) = 0 \quad (5)$$

$$\Delta_5\chi := \chi(1-0) - \delta\chi(1+0) = 0 \quad (6)$$

$$\Delta_6\chi := \chi'(1-0) - \frac{1}{\delta}\chi'(1+0) = 0 \quad (7)$$

geçiş şartlarından oluşan üç-aralıklı bir Sturm-Liouville özdeğer problemi araştırılmıştır. Bu çalışma boyunca $q(x)$ fonksiyonu $[-1,0)$, $(0,1)$ ve $(1,2]$ aralıklarının her birinde sürekli ve sonlu $q(0 \pm 0)$, $q(1 \pm 0)$ limit değerleri mevcuttur (burada $q(c \pm 0) := \lim_{\varepsilon \rightarrow 0} q(c \pm \varepsilon)$) gösteriminden yararlanılmıştır. Bu tür problemler genellikle çeşitli fiziksel iletim problemlerinde ortaya çıkar. Ayrıca, ince lamine bir plaka için termal iletim problemlerinde iletim koşullarıyla ilgili bazı problemler ortaya çıkar. Noktasal etkileşimli problemlerin bazı spektral özellikleri [6, 7, 11] de incelenmiştir.

Bu çalışmada, kendi yaklaşımımızı uygulayarak, iç tekilliklere sahip Sturm-Liouville problemleri için yeni bir ortogonal genişleme formülü ve Green özfonksiyon açılımı için bazı eşitlikler elde edilmiştir. Problemin süreksizliği ile araştırma yapabilmek için, süreksiz noktalarda iletim koşulları verilmiştir. Bu iletim koşulları için etkileşim koşulları, geçiş şartları, arayüz koşulu vb. gibi başka terminolojiler de vardır. Birçok yazar süreksiz problemlerin incelenmesine katkıda bulunmuştur [2, 3, 4, 8, 9]. Tek süreksiz nokta içeren Sturm-Liouville problemleri farklı özelliklerini içeren araştırmalar farklı yazarlar tarafından kapsamlı şekilde incelenmiştir. Bu makalede, iki noktada süreksizlik içeren ve bu noktalarda iletim koşulları içeren bir Sturm-Liouville probleminin Green özfonksiyon açılımı araştırılmıştır.

II. MATERYAL VE YÖNTEM

Bu çalışmada, çözümlerin sol ve sağ uç noktalarındaki değerler arasındaki bağlantıyı belirleyen iletim koşullarını içeren çok aralıklı Sturm-Liouville problemi incelenmiştir. Bu probleme uygun başlangıç değer problemleri tanımlanarak bu başlangıç değer problemleri aracılığıyla probleme uygun bir yöntem geliştirilerek Green fonksiyonu bulunmuştur.

III. BULGULAR

A. Başlangıç Değer Problemleri

İlk olarak (1) denklemi için

$$u(x; \lambda) = \begin{cases} u_1(x, \lambda), & [-1, 0) \\ u_2(x, \lambda), & (0, 1) \\ u_3(x, \lambda), & (1, 2] \end{cases}$$

ve

$$v(x; \lambda) = \begin{cases} v_1(x, \lambda), & [-1, 0) \\ v_2(x, \lambda), & (0, 1) \\ v_3(x, \lambda), & (1, 2] \end{cases}$$

çözümlerini aşağıdaki şekilde tanımlayalım. (1) denkleminin $[-1, 0)$ sol aralığında tanımlı olan ve

$$u(-1) = 1, \quad u'(-1) = 0 \quad (8)$$

başlangıç şartlarını sağlayan çözümünü $u_1(x, \lambda)$ ile

$$u(-1) = 0, \quad u'(-1) = 1 \quad (9)$$

başlangıç şartlarını sağlayan çözümünü ise $v_1(x, \lambda)$ ile gösterelim. Aynı diferensiyel denklemin $(0, 1)$ aralığında tanımlı olan ve

$$u(0+0) = u_1(0-0), \quad u'(0+0) = u_1'(0-0, \lambda) \quad (10)$$

şartlarını sağlayan çözümünü $u_2(x, \lambda)$ ile,

$$u(0+0) = v_1(0-0, \lambda), \quad u'(0+0) = v_1'(0-0, \lambda) \quad (11)$$

şartlarını sağlayan çözümünü ise $v_2(x, \lambda)$ ile gösterelim. Bu çözümün varlığı ve tekliği klasik yöntemler ile ispatlanabilir.

Aynı diferensiyel denklemin $(1, 2]$ sağ aralığında tanımlı olan ve

$$u(1+0) = \frac{1}{\delta} u_2(1-0, \lambda), \quad u'(1+0) = \delta u_2'(1-0, \lambda) \quad (12)$$

şartlarını sağlayan çözümünü $u_3(x, \lambda)$ ile,

$$u(1+0) = \frac{1}{\delta} v_2(1-0, \lambda), \quad u'(1+0) = \delta v_2'(1-0, \lambda) \quad (13)$$

şartlarını sağlayan çözümünü ise $v_3(x, \lambda)$ ile gösterelim.

$u_i(x, \lambda)$ ve $v_i(x, \lambda)$ ($i = 1, 2, 3$) çözümlerinin her biri, herhangi bir sabit x için kompleks λ parametresine göre tam fonksiyondur.

$u(x; \lambda)$ fonksiyonu λ özdeğerine karşılık gelen herhangi bir özfonksiyon olsun. Bu durumda

$$u(x; \lambda) = \begin{cases} au_1(x, \lambda) + bu_2(x, \lambda), & [-1, 0) \cup (0, 1) \cup (1, 2] \\ cv_1(x, \lambda) + dv_2(x, \lambda), & [-1, 0) \cup (0, 1) \cup (1, 2] \\ eu_3(x, \lambda) + fv_3(x, \lambda), & [-1, 0) \cup (0, 1) \cup (1, 2] \end{cases}$$

olacak şekilde a, b, c, d, e, f sabitleri vardır. Bu çözüme sırasıyla (4)-(7) geçiş şartlarını ve daha sonra (2)-(3) sınır şartları uygulanırsa a, b, c, d, e, f değişkenlerine göre lineer olan homojen cebirsel denklem sistemi elde edilir. Bu sistemin determinantının $Q(\lambda)$ olmak üzere, $Q(\lambda)$ sıfır yerleri (1)-(7) probleminin özdeğerleri çakışıktır. Bu $Q(\lambda)$ fonksiyonu (1)-(3) probleminin karakteristik fonksiyonu olarak adlandırılmaktadır.

Homojen olmayan

$$-u'' + (\lambda - q(x))u = f(x), \quad x \in [-1, 0) \cup (0, 1) \cup (1, 2] \quad (14)$$

denklemleri ile birlikte (2)-(7) sınır-geçiş şartlarından oluşmuş probleme karşılık gelen homojen olmayan sınır değer probleminin Green fonksiyonu

$$\mathfrak{H}(y, t; \lambda) = \frac{1}{\mathcal{F}(\lambda)} \begin{cases} u(t, \lambda)v(y, \lambda), & -1 < t \leq y < 2, & t, y \neq 0, 1 \\ u(t, \lambda)v(y, \lambda), & -1 < y \leq t < 2, & t, y \neq 0, 1 \end{cases}$$

şeklindedir. Böylece çözüm

$$u(x, \lambda) = \int_{-1}^{0-0} \mathfrak{H}(y, t; \lambda) f(t) dt + \int_{0+0}^{1-0} \mathfrak{H}(y, t; \lambda) f(t) dt + \int_{1+0}^2 \mathfrak{H}(y, t; \lambda) f(t) dt$$

biçimindedir.

B. Green Fonksiyonunun Özfonksiyon Açılımı

Kabul edelim ki $\lambda = 0$ özdeğer olmasın. Bu kabulümüz genelliği bozmamaktadır. O halde

$$\mathfrak{H}(y, t; \lambda) = \mathfrak{H}(y, t; 0)$$

alınırsa

$$u(x, \lambda) = \int_{-1}^{0-0} \mathfrak{H}(y, t) \vartheta(t) dt + \int_{0+0}^{1-0} \mathfrak{H}(y, t) \vartheta(t) dt + \int_{1+0}^2 \mathfrak{H}(y, t) \vartheta(t) dt \quad (15)$$

fonksiyonu

$$-u'' + q(x)u = \vartheta(x)$$

denkleminin bir çözümüdür ve bu çözüm (2)-(7) sınır geçiş şartlarını sağlar. (14) eşitliği

$$\tilde{\vartheta}(x) = \vartheta(x) - \lambda u \text{ için}$$

$$u'' - q(x)u = \tilde{\vartheta}(x) \quad (16)$$

şeklinde yazılırsa (2)-(7), (14) problemi

$$\begin{aligned} u(x, \lambda) + \lambda \left\{ \int_{-1}^{0-0} \mathfrak{H}(y, t) u(t) dt + \int_{0+0}^{1-0} \mathfrak{H}(y, t) u(t) dt + \int_{1+0}^2 \mathfrak{H}(y, t) u(t) dt \right\} \\ = \int_{-1}^{0-0} \mathfrak{H}(y, t) \vartheta(t) dt + \int_{0+0}^{1-0} \mathfrak{H}(y, t) \vartheta(t) dt + \int_{1+0}^2 \mathfrak{H}(y, t) \vartheta(t) dt \end{aligned}$$

şeklinde yazılabilir. Sonuç olarak $\vartheta(x) \equiv 0$ için karşılık gelen homojen problem

$$u(x, \lambda) + \lambda \left\{ \int_{-1}^{0-0} \mathfrak{H}(y, t) u(t) dt + \int_{0+0}^{1-0} \mathfrak{H}(y, t) u(t) dt + \int_{1+0}^2 \mathfrak{H}(y, t) u(t) dt \right\} = 0$$

integral denklemine eşdeğerdir. $f_1, f_2, \dots, f_n, \dots$ (1)-(7) probleminin $\lambda_1, \lambda_2, \dots, \lambda_n, \dots$ özdeğerlerine karşılık gelen normalleştirilmiş özfonksiyonları olsun. Yani

$$\int_{-1}^{0-0} f_n(y) f_m(y) dy + \int_{0+0}^{1-0} f_n(y) f_m(y) dy + \int_{1+0}^2 f_n(y) f_m(y) dy = \begin{cases} 1, & m = n \\ 0, & m \neq n \end{cases}$$

olsun. Bu eşitliği ve önceki çalışmamızdaki özdeğer ve özfonksiyonlar için elde edilen asimptotik formülleri kullanılarak gerekli işlemler yapılırsa Green fonksiyonu için

$$\mathfrak{H}(y, \xi) = - \sum_{n=0}^{\infty} \frac{1}{\lambda_n} f_n(y) f_m(\xi)$$

açılımı elde edilmiştir.

IV. SONUÇLAR

Bu araştırmada (2)-(3) sınır koşullarını içeren ve iki noktada süreksizliğe sahip olan üç-aralıklı bir sınır-değer geçiş problemi üzerine bazı spektral özellikler elde edilmiştir. Bu problemde araştırılan diferansiyel denklem üç ayrı alt aralıkta tanımlanmıştır. Bu problem sadece aralığın uç noktalarındaki sınır şartlarını değil ayrıca süreksizlik noktasında verilen (4)-(7) geçiş şartlarını da içermektedir. Burada (1)-(7) probleminin özfonksiyonları ile bağlantılı olan altı tane başlangıç değer problemi tanımlanmış, Green fonksiyonu elde edilmiş ve daha sonra bu

Green fonksiyonu için

$$\mathfrak{H}(y, \xi) = - \sum_{n=0}^{\infty} \frac{1}{\lambda_n} f_n(y) f_m(\xi)$$

açılımı bulunmuştur. Ele alınan problem, klasik Sturm-Liouville özdeğer problemini genelleştirdiği için elde edilen sonuçlar, klasik Green Fonksiyonu teorisinden elde edilen ilgili sonuçları genişletmekte ve genelleştirmektedir.

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Kuzeydoğu Türkiye’de Avliyana (Gümüşhane) Sahası Topraklarındaki İz Elementlerin Jeokimyasal Zenginleşmesi/Kirlilik Düzeylerinin Tespiti

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Özet – Avliyana (Gümüşhane, KD Türkiye) sahası, Doğu Pontid Orojeni’nin Güney Zonu’nda yer almakta olup, bölgesel metalojeni üzerinde etkili olan yoğun magmatik ve hidrotermal faaliyetlerle karakterizedir. Bu çalışmada, Avliyana sahasında gelişmiş topraklardan alınan on altı örnek, seçilmiş iz elementlerin konsantrasyonlarını, zenginleşme düzeylerini ve kirlenme derecelerini belirlemek amacıyla ICP–AES yöntemiyle analiz edilmiştir. Üst Kıtasal Kabuk (UCC) değerlerine göre element zenginleşmesini değerlendirmek üzere zenginleşme indeksi (PI) ve jeobirikim indeksi (Igeo) parametreleri hesaplanmıştır. Sonuçlar, topraklarda özellikle As, Cd ve Pb açısından orta ila yüksek düzeyde zenginleşme olduğunu; Cr, Mn, Ni, Cu, Zn, Co ve Fe gibi elementlerin ise yerel ölçekte artış gösterdiğini ortaya koymaktadır. Igeo değerleri, özellikle As için belirgin zenginleşmeyi işaret etmekte olup, bu durum hem litolojik arka plan hem de granitoyidden kaynaklanan olası hidrotermal katkılarla ilişkilendirilmektedir. Bu da bölgeye özgü yerel arka plan ve eşik değerlerin yüksek olduğunu düşündürmektedir. Elde edilen bulgular, doğal jeokimyasal zenginleşme süreçlerinin cevherleşme süreçleriyle yakından ilişkili olduğunu göstermektedir. Yerel eşik değerlerin belirlenmesi, gelecekteki jeokimyasal prospeksiyon çalışmalarında jeojenik ve antropojenik anomalilerin ayırt edilmesi açısından büyük önem taşımaktadır. Ayrıca sonuçlar, Gümüşhane metalojenik bölgesinde çevresel izleme ve maden potansiyeli değerlendirmeleri için değerli bir temel veri sunmaktadır.

Anahtar Kelimeler – Doğu Pontidler, Toprak Jeokimyası, Zenginleşme Faktörü, Igeo, Yerel Eşik Değeri, İz Elementler, Gümüşhane.

I. GİRİŞ

Avliyana (Gümüşhane) sahası Doğu Pontid Orojenik Kuşağı’nın Kuzey-Güney Zon geçişinde Güney Zonu içinde yer almaktadır [1], [2], [3], [4], [5], [6], [7], [8], [9], [10]. Saha, ilk madencilik faaliyetleri antik döneme kadar uzanan Gümüşhane il sınırları içindedir [11], [12]. Gümüşhane içerdiği kurşun, çinko, bakır yanında gümüş içerikli maden yatakları zenginliğinden dolayı geçmişte Argyropolis olarak isimlendirilmiştir [13]. Günümüzde de Gümüşhane yöresinin keşfedilmeye bekleyen pek çok maden yatağına sahip olduğu düşünülmektedir. Bu yüzden de bölgede pek çok maden arama faaliyeti yürütülmüş/yürütülmektedir [14], [15], [16], [17], [18], [19], [20] [3], [4], [8], [11], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33] [27], [34], [35], [36] [17], [37], [38], [39], [40], [41], [42], [43], [44]. Madencilik faaliyetleri, ülkelerin ekonomik kalkınmasında önemli bir rol oynamakla birlikte, özellikle 20. yüzyılın ikinci yarısından sonra - ve 1980’lerden itibaren artan çevre bilincinin duyarlılığı - bu tür faaliyetlere yönelik çeşitli toplumsal muhalefet de giderek yükselmeye başlamıştır [45], [46], [47], [48], [49]. Bu konudaki uzlaşma noktası son yıllarda madencilik ve çevre duyarlılığının dengede tutulduğu yaklaşımlar olmuştur. Maden sahası demek, ortalama değerlere göre bazı elementlerin yatak

olarak kabul edilen bölgede zenginleşmesi demektir. Bu ise bölgenin antropojenik etki dışında, doğal olarak bazı elementlerce zenginleşmesi anlamına gelir. Dolayısıyla bir bölgede element zenginleşmesi ile element toksitesi yakın ilişki içindedir [30], [50], [51], [52], [53], [54], [55] [21], [26], [53], [56], [57], [58], [59].

Bu çalışmanın amacı, Gümüşhane ili sınırları içinde yer alan Avliyana sahasındaki toprakların belli başlı iz elementler için ortalama değerlerinin belirlenerek yerel zenginleşme eşik değeri ve kirlenmesinin araştırılmasıdır.

II. MATERYAL VE YÖNTEM

A. Bölgesel jeoloji

Çalışma sahası Doğu Karadeniz Tektonik Birliği (DKTB) (Pontid Tektonik Birlikleri) içinde yer alır [60]. Doğu Karadeniz Tektonik Birliği içindeki kayaçlar Geç Kretase döneminde kuzey ve güney bölgelerde farklılıklar gösterdiği için Kuzey Bölge (zon) ve Güney Bölge (zon) olarak iki farklı bölgeye (zona) ayrılmışlardır [61]. Bektaş [62] ve Bektaş ve Güven [63] ise Doğu Karadeniz Magmatik Yayını, farklı magmatizma, tektonizma ve sedimantolojik özellikleri de dikkate alarak kuzeyden güneye Kuzey Zon, Güney Zon ve Eksen Zonu olarak başlıca üç alt sınıfa ayırmışlardır.

DKTB kayaçların temeli Erken Karbonifer yaşlı metamorfik kayaçlar [64] ve Erken-Geç Karbonifer yaşlı plütonik kayaçlar oluşturur [65], [66], [67], [68], [69], [70], [71], [72], [73]. Bu temel kayaçlar uyumsuz olarak Erken-Orta Jura yaşlı volkano-sedimanter kayaçlarca üzerlenirler [74], [75], ve Orta-Geç Jura yaşlı plütonik kayaçlarca kesilirler [76], [77]. Bölge, Geç Jura-Erken Kretase dönemi ise maruz kaldığı magmatik ve tektonik sakinliğin etkisiyle yaygın bir karbonat çökelişiyle temsil edilmekte olup [78], Geç Kretase dönemi plütonik, volkanik ve sedimanter kayaçlarla temsil edilmektedir [6], [79], [80], [81], [82], [83], [84], [85]. Bölgenin Senozoyik dönemi ise volkanik, plütonik ve sedimanter kayaçlarca temsil edilmektedir [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101]. Bölgenin en genç birimler ise yamaç moluzu, taraça, traverten, ve alüvyonlardır [102], [103], [104], [105], [106]

Çalışma sahası Kuzey-Güney Zon geçişinde bulunmakta olup, ağırlıklı Güney Zon içindedir. Bölgede Paleozoyik'ten Tersiyer sonuna kadar farklı yaş ve litolojilerde birimler yüzeylenmektedir [5], [107], [108]. Sahanın en yaşlı birimleri Premo-Karbonifer yaşlı plütonik kayaçlardan oluşur (Artabel Granitoyidi) [67], [109], [110]. Bu kayaçlar Erken-Orta Jura volkano-tortul birimlerce (Zimonköy Formasyonu), ve iki birim arasındaki erozyonal bir uyumsuzlukla üzerlenir [107], [111], [112]. Geç Jura-Erken Kretase yaşlı Berdiga Formasyonu ise uyumlu olarak bu birimleri örter [78]. Berdiga Formasyonu Geç Kretase Kermutdere Formasyonu tarafından üzerlenmektedir. Bu formasyon tabanda kumlu kireçtaşları ile başlamakta, mor renkli kireçtaşları ile devam etmekte ve volkano-tortul birimler ile sonlanır. Formasyon aynı zamanda Geç Kretase yaşlı andezit ve basaltlar tarafından da üstlenmektedir [5], [6], [113]. Andezit, bazalt ve bunlara ait piroklastlardan oluşan ve yer yer sedimanter kayaçlarla ardalamalı karakterdeki Eosen Alibaba Formasyonu ise uyumsuz olarak Kermutdere Formasyonu üstüne gelmektedir. Tüm bu birimler ise Lütesiyen yaşlı Avliyana Granitoyidi tarafından kesilmektedirler [2], [5], [99] (Şekil 1). Sahadaki en geç birimler ise Kuvaterner yaşlı alüvyon, yamaç moluzu ve travertenlerdir [110].

B. Örnek Alımı ve Analitik Süreçler

Jeokimyasal amaçlı olarak Avliyana sahanından 16 adet toprak örneği toprak profilinin üst kısmından (B horizonu; 10–25 cm derinlikten) plastik spatula kullanılarak alınmış ve olası tüm kontaminasyon kaynaklarından kaçınılarak temiz plastik torbalara konulmuştur. Örnekler önce oda sıcaklığında kurutulmuş, ardından nem içeriğini gidermek amacıyla 70-80 °C'de 2 saat boyunca etüvde kurutulmuştur. Daha sonra 2 mm elekten geçirilmiş, akabinde öğütülmüş numuneler Rose ve diğ. [50] tarafından ideal tane boyutu olarak önerilen 80 mesh ($\approx 177 \mu\text{m}$) elekten geçirilmiştir.

Analize hazır hale getirilen örnekler Gümüşhane Üniversitesi Merkezi Laboratuvarında ICP-AES yöntemi ile belli başlı iz elementler için analiz edilmiştir. İz element içeriklerinin belirlenmesinden önce örnekler, berrak çözeltiler elde etmek amacıyla kapalı sistem mikrodalga cihazında çözündürülmüştür. Bu süreçte her bir toprak örneğinden 1 g alınarak 2 ml HNO₃ çözeltisinde 1 saat bekletilmiştir. Daha sonra örnekler 2:2:2 oranında HCl-HNO₃-H₂O karışımından 6 ml eklenmiş, 95 °C'de 1 saat süreyle çözündürülmüş ve ICP-AES cihazında analiz edilmiştir. Örnek hazırlama ve analiz detayları Vural [114], [115], Vural vd. [116], Vural ve Erdoğan [117], Vural ve Şahin [118] ve Bulut vd. [119]'de mevcuttur.

Sahadaki element zenginleşmesi (bir yönüyle de kirliliği), jeobirikim indeksi (Igeo), Zenginleşme oranı (PI) kullanılarak değerlendirilmiştir. Igeo sınıflandırması Müller [120] tarafından önerilmiş olup, elementlerin güncel konsantrasyonları ile zenginleşmeye uğramamış içeriklerinin karşılaştırılması yoluyla zenginleşme düzeyinin değerlendirilmesine olanak tanır.

Bu parametre şu eşitlik ile hesaplanmaktadır:

$$Igeo = \log_2(Cn/1.5Bn)$$

Burada Cn, incelenen örneklerdeki elementin konsantrasyonunu, Bn ise kıtasal üst kabukta ilgili elementin ortalama konsantrasyonunu [121] ifade eder. 1.5 katsayısı, litojenik etkilerden kaynaklanabilecek olası değişimleri dikkate almak amacıyla Stoffers vd. [122] tarafından önerilmiş bir katsayıdır. Jeobirikim indeksi için 4 tanımlayıcı sınıf önerilebilir (Tablo 1).

Zenginleşme indeksi PI ise, incelenen örnekteki element konsantrasyonunun kıtasal üst kabuğun ortalamasına oranı olarak tanımlanmaktadır. Avliyana sahası element zenginleşmelerinin tespitine yönelik PI değeri hesaplanmış ve şu şekilde sınıflandırılmıştır: Zenginleşme yok: $PI \leq 1,5$; Zenginleşmiş: $PI > 1,5$

Tablo 1. Jeobirikim indeksi zenginleşme sınıfları

Sınıf	Değer	Zenginleşme derecesi
0	$Igeo \leq 1$	Zenginleşme yok
1	$1 < Igeo < 2$	Az zenginleşme
2	$2 < Igeo < 3$	Orta zenginleşme
3	$3 < Igeo$	Yüksek zenginleşme

III. BULGULAR

Avliya topraklarının element içeriklerinin tanımlayıcı istatistikleri hesaplanmış ve Tablo 2'de sunulmuştur. Sahadaki toprakların PI değerleri hesap edilmiş (Tablo 3) ve zenginleşme dereceleri gösterilmiştir. PI değerlerine göre sahanın As, Cd ve Pb elementlerince dikkat çekici oranda zenginleştiği, Cr, Mn, Ni, Cu, Zn, Co ve Fe elementlerince ise yer yer zenginleşme gösterdiği tespit edilmiştir. Sahanın PI değerlerine ait tanımlayıcı istatistikleri ise Tablo 4'te verilmiştir.

Sahanın Igeo değerleri ise Tablo 5'te, tanımlayıcı istatistik parametreleri ise Tablo 6'da sunulmuştur. Igeo verilerine göre Avliyana sahası As elementince dikkat çekici bir zenginleşme göstermektedir. Diğer elementlere ait Igeo değerleri ise kısmen bir zenginleşmeye işaret etmektedir. Elde edilen veriler birlikte değerlendirildiğinde sahanın belli başlı elementlerce kısmen ve/veya dikkat çekici oranda zenginleşmeye diğer bir yönüyle ise bahse konu bu elementlerce bir kirliliğe sahip olduğuna işaret etmekte olup, bu veriler hidrotermal süreçlerle ilişkili maden yataklarının aranması (prospeksiyonunda) ve sahanın kirlilik riskinin araştırılmasında öncelikli olarak kullanılacak elementler olarak önerilmiştir.

Tablo 2. Avliyana sahası topraklarının elementlerine ait tanımlayıcı istatistik parametreleri (ppm)

	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Pb
Ortalama	121,30	1313,80	6,48	25,15	72,10	54,39	98,88	82,74	0,27	37,38
Medyan	75,69	1085,25	5,91	23,13	56,68	49,35	85,91	23,30	0,21	26,39
Standart Sapma	112,74	1025,68	3,71	12,45	42,44	42,68	42,98	164,61	0,18	23,02
Basıklık	5,83	4,42	0,52	3,29	2,91	7,00	0,49	4,98	3,31	-0,28
Çarpıklık	2,21	2,15	0,87	1,64	1,57	2,32	1,07	2,50	1,85	0,99
#	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00
En Büyük	471,20	4245,86	15,17	60,19	190,63	190,76	196,44	533,04	0,75	87,19
En Küçük	19,30	381,28	1,96	11,00	24,80	12,68	50,90	6,61	0,10	9,79

Tablo 3. Avliyana sahası topraklarının elementlerine ait PI değerleri. PI>1.5 değerleri açık pembe renkte gösterilmiştir.

	PI Cr	PI Mn	PI Fe	PI Co	PI Ni	PI Cu	PI Zn	PI As	PI Cd	PI Pb
TP1-187	5,12	5,48	1,66	3,48	4,06	1,91	2,63	98,07	3,62	3,41
TP1-189	2,52	4,22	1,95	2,33	2,35	1,94	2,93	12,80	3,80	3,80
TP1-191	2,01	1,50	1,36	1,46	2,35	2,08	1,52	5,02	2,22	1,75
TP2-186	1,62	1,66	2,48	1,60	1,57	2,56	1,33	2,83	2,50	1,26
TP2-187	0,78	0,49	3,88	1,35	1,86	6,81	1,58	111,05	1,12	1,17
TP2-188	0,65	2,23	3,10	1,53	1,13	1,99	1,74	4,12	2,82	3,50
TP2-189	0,70	1,21	2,12	1,14	0,89	1,33	0,98	5,85	2,03	1,41
TP2-190	1,48	1,21	2,15	1,32	0,91	1,02	0,90	1,38	1,24	0,58
TP2-191	2,16	1,40	1,28	1,44	2,43	1,61	1,24	9,10	2,22	1,39
TP2-192	0,53	1,57	1,87	0,83	1,03	0,59	2,08	6,01	8,34	5,13
TP3-191	0,30	0,84	0,68	0,74	0,53	2,57	1,89	1,56	3,33	1,98
TP1-185	0,87	0,65	0,55	0,86	0,97	0,45	0,83	1,92	2,33	1,25
TP1-186	0,87	1,03	0,96	2,24	1,51	3,28	0,93	4,69	2,22	1,69
TP1-188	0,58	0,78	0,79	1,05	1,29	1,11	0,76	3,94	1,11	1,37
TP1-190	0,71	1,40	1,17	1,25	0,98	1,31	1,09	2,02	1,78	1,21
TP1-192	0,21	1,46	0,50	0,64	0,69	0,50	1,18	5,46	6,67	4,27

Tablo 4. Avliyana sahası topraklarının elementlerine ait PI değerleri ait tanımlayıcı istatistik parametreleri

	PI Cr	PI Mn	PI Fe	PI Co	PI Ni	PI Cu	PI Zn	PI As	PI Cd	PI Pb
Ortalama	1,32	1,70	1,66	1,45	1,53	1,94	1,48	17,24	2,96	2,20
Medyan	0,82	1,40	1,51	1,34	1,21	1,76	1,28	4,85	2,28	1,55
Standart Sapma	1,23	1,32	0,95	0,72	0,90	1,52	0,64	34,29	1,97	1,35
Basıklık	5,83	4,42	0,52	3,29	2,91	7,00	0,49	4,98	3,31	-0,28
Çarpıklık	2,21	2,15	0,87	1,64	1,57	2,32	1,07	2,50	1,85	0,99
Say	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00
En Büyük	5,12	5,48	3,88	3,48	4,06	6,81	2,93	111,05	8,34	5,13
En Küçük	0,21	0,49	0,50	0,64	0,53	0,45	0,76	1,38	1,11	0,58

Tablo 5. Avliyana sahası topraklarının Igeo değerleri

	Igeo_Cr	Igeo Mn	Igeo_Fe	Igeo_Co	Igeo_Ni	Igeo_Cu	Igeo_Zn	Igeo_As	Igeo_Cd	Igeo_Pb
TP1-187	1,77	1,87	0,15	1,21	1,44	0,35	0,81	6,03	1,27	1,19
TP1-189	0,75	1,49	0,38	0,64	0,65	0,37	0,97	3,09	1,34	1,34
TP1-191	0,42	0,00	-0,14	-0,04	0,65	0,47	0,02	1,74	0,57	0,22
TP2-186	0,11	0,15	0,72	0,10	0,07	0,77	-0,18	0,92	0,74	-0,25
TP2-187	-0,94	-1,61	1,37	-0,15	0,31	2,18	0,07	6,21	-0,42	-0,35
TP2-188	-1,22	0,57	1,05	0,03	-0,41	0,41	0,22	1,46	0,91	1,22
TP2-189	-1,10	-0,31	0,50	-0,39	-0,75	-0,17	-0,61	1,96	0,44	-0,08
TP2-190	-0,02	-0,31	0,52	-0,19	-0,73	-0,55	-0,73	-0,12	-0,27	-1,38
TP2-191	0,52	-0,10	-0,23	-0,06	0,69	0,11	-0,28	2,60	0,57	-0,11
TP2-192	-1,49	0,07	0,32	-0,85	-0,54	-1,35	0,47	2,00	2,47	1,77
TP3-191	-2,32	-0,84	-1,15	-1,02	-1,51	0,78	0,34	0,06	1,15	0,40
TP1-185	-0,79	-1,20	-1,43	-0,80	-0,63	-1,73	-0,85	0,35	0,64	-0,26
TP1-186	-0,79	-0,55	-0,65	0,58	0,01	1,13	-0,69	1,64	0,57	0,17
TP1-188	-1,36	-0,94	-0,93	-0,52	-0,22	-0,43	-0,98	1,39	-0,43	-0,13
TP1-190	-1,09	-0,10	-0,36	-0,26	-0,61	-0,20	-0,46	0,43	0,25	-0,31
TP1-192	-2,84	-0,04	-1,58	-1,24	-1,12	-1,59	-0,35	1,86	2,15	1,51

Tablo 6. Avliyana sahası Igeo değerlerinin tanımlayıcı istatistikleri

	IgeoCr	Igeo Mn	IgeoFe	IgeoCo	IgeoNi	IgeoCu	IgeoZn	IgeoAs	IgeoCd	Igeo_Pb
Ortalama	-0,65	-0,11	-0,09	-0,19	-0,17	0,03	-0,14	1,98	0,75	0,31
Medyan	-0,87	-0,10	0,00	-0,17	-0,32	0,23	-0,23	1,69	0,60	0,04
Standart S	1,18	0,89	0,88	0,64	0,77	1,03	0,59	1,84	0,82	0,86
Basıklık	0,05	0,90	-0,83	0,25	-0,20	0,24	-0,73	1,80	0,30	-0,47
Çarpıklık	0,18	0,71	-0,22	0,42	0,35	-0,03	0,42	1,43	0,54	0,17
#	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00
En Büyük	1,77	1,87	1,37	1,21	1,44	2,18	0,97	6,21	2,47	1,77
En Küçük	-2,84	-1,61	-1,58	-1,24	-1,51	-1,73	-0,98	-0,12	-0,43	-1,38

IV. SONUÇLAR

Avliyana sahasında yapılan toprak jeokimyası çalışmaları, bölgedeki element dağılımlarının hem litolojik hem de hidrotermal süreçlerin kontrolünde geliştiğini ortaya koymaktadır. Tanımlayıcı istatistiksel değerlendirmeler, toprakların genel olarak As, Cd ve Pb elementleri açısından belirgin, Cr, Mn, Ni, Cu, Zn, Co ve Fe açısından ise yer yer zenginleşme gösterdiğini ortaya koymuştur. PI ve Igeo indeksleri, özellikle As bakımından dikkat çekici düzeyde bir zenginleşmeye işaret etmekte olup, bu durum bölgedeki granitoidin hidrotermal alterasyon süreçleriyle doğrudan ilişkili olabilir.

Igeo ve PI değerlerinin birlikte değerlendirilmesi, sahanın bazı elementlerce doğal jeokimyasal zenginleşme sınırlarını aşarak çevresel anlamda potansiyel kirlilik riski taşıyabileceğini göstermektedir. Bu nedenle As, Cd ve Pb elementleri hem çevresel izleme hem de jeokimyasal prospeksiyon çalışmalarında öncelikli göstergeler olarak önerilmektedir.

Genel olarak elde edilen bulgular, Avliyana granitoidi üzerinde gelişen toprakların metal zenginleşmesi bakımından bölgesel madenleşme süreçleriyle yakından ilişkili olduğunu ve aynı zamanda bölgenin çevresel risk değerlendirmelerinde dikkate alınması gereken özgün bir jeokimyasal imza sunduğunu ortaya koymaktadır.

TEŞEKKÜR

Bu çalışma verilerin bir kısmı TÜBİTAK tarafından desteklenen 115Y146 numaralı proje verilerinden üretilmiş olup, sağlanan destek için TÜBİTAK'a teşekkür edilir.

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The First Zagreb Index and First Leap Zagreb Index of Fibonacci Cubes

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Abstract – Fibonacci cubes derived from Fibonacci numbers represent chemical structures as well as are used in networks. Chemical graph theory uses topological indices to predict chemical structures' physical, chemical, and biological properties without experimentation. Topological indices are scalar descriptors of the chemical molecule represented by a ϑ graph. In this study, the first Zagreb index which is degree based and first leap Zagreb index which is distance based of Fibonacci cubes are obtained.

Keywords – Graph Theory, Topological Index, Fibonacci Cubes, First Zagreb Index, First Leap Zagreb Index.

I. INTRODUCTION

Graph theory, emerged in 1736 by being used to solve a problem, is a field of Discrete Mathematics. Graph theory has brought solutions to many problems in various science areas. The Boolean cube or hypercube, cosmic cube, n -cube, or binary n -cube are popular interconnection schemes for multicomputer. Fibonacci cubes are introduced as an alternative model to these. Since sub graph of the hypercube and also an upper graph of other structures are Fibonacci cubes, they can find applications in fault-tolerant computing. In addition, the common system communication principles of Fibonacci cubes can be applied efficiently. Although the Fibonacci cubes appear to be structurally disadvantaged compared to the hypercube, information about semi-regular networks has been found to be useful for fault-tolerant applications [1].

Representations of Fibonacci cubes are seen in chemistry. Since a Fibonacci is a chain with three hexagonal, Fibonacci cubes are resonance graph of a Fibonacci with n hexagons. In addition, they are the plane bipartite graphs of resonance graphs [2]. Chemical graph theory is the field of study with the graph theory of chemical structures. It focuses on topological indices. The topological index is the numerical value obtained using various features such as distance and degree of the graph representation of the chemical structure [3]. Topological indices are used to predict the physicochemical and bioactivity properties of chemical structures. The first-known index to have an application is the Wiener index [4]. Among the topological indices, the most studied indices are degree-dependent indices.

Klavzar and Mollard studied the Wiener indices and Hosoya polynomials of Fibonacci cubes [5]. Klavzar and Rho expressed the Wiener index of generalized Fibonacci cubes [6]. Egecioğlu et al. obtained the Mostar indices of Fibonacci cubes [7]. Egecioğlu et al. determined the irregularity polynomials of Fibonacci cubes [8]. Alizadeh et al. studied on the irregularity of Fibonacci cubes [9].

This paper is focused on Fibonacci cubes. The first Zagreb and the first leap Zagreb indices of Fibonacci cubes are obtained.

II. PRELIMINARIES

Let ϑ be a graph with vertex set $V(\vartheta)$ and edge set $E(\vartheta)$. The cardinality of $V(\vartheta)$ (order) is defined as n . The cardinality of $E(\vartheta)$ (size) is defined as m . $N_u(\vartheta)$ is the set of vertices that neighbour to u [10].

Lemma 2.1. [10] If ϑ is graph with size m , then $\sum_{u \in V(\vartheta)} d_u = 2m$.

Definition 2.2. [7] The k -dimensional hypercube has vertex set which is set of all binary strings of length k . Let two vertices $\gamma_1\gamma_2 \dots \gamma_k$ and $\gamma_1'\gamma_2' \dots \gamma_k'$ of the k -dimensional hypercube where $\gamma_i \in \{0,1\}$ for $i = 1, \dots, k$. The vertices $\gamma_1\gamma_2 \dots \gamma_k$ and $\gamma_1'\gamma_2' \dots \gamma_k'$ are adjacent if and only if γ_i and γ_i' differ in exactly one $i = 1, \dots, k$.

Definition 2.3. [1] The k -dimensional Fibonacci cubes, Γ_k are the subgraph of k -dimensional hypercubes. If $\gamma_1\gamma_2 \dots \gamma_k$ is a vertex of Fibonacci cube, then $\gamma_i \cdot \gamma_{i+1} = 0$ for $i = 1, \dots, k-1$ and $\gamma_1 \cdot \gamma_2 = 0$.

The Fibonacci cubes have

$$|V(\Gamma_k)| = F_{k+2} \quad (1)$$

and

$$|E(\Gamma_k)| = \frac{kF_{k+1} + 2(k+1)F_k}{5} \quad (2)$$

where $F_0 = 0, F_1 = 1$ and $F_{k+2} = F_{k+1} + F_k$ for $k \geq 1$ [1, 9].

Eğecioğlu et al. [8] defined symbolically decomposition as

$$\Gamma_k = 0\Gamma_{k-1} + 10\Gamma_{k-2} \quad (3)$$

Alizadeh et al. [9] defined the following subsets of vertices of Γ_k :

$$A_k = \{00\gamma_3\gamma_4 \dots \gamma_k : \gamma_i \in \{0,1\}, i = 3, \dots, k\} \quad (4)$$

$$B_k = \{10\gamma_3\gamma_4 \dots \gamma_k : \gamma_i \in \{0,1\}, i = 3, \dots, k\} \quad (5)$$

$$C_k = \{010\gamma_4\gamma_5 \dots \gamma_k : \gamma_i \in \{0,1\}, i = 4, \dots, k\} \quad (6)$$

$V(\Gamma_k) = A_k \cup B_k \cup C_k$ and the sets A_k, B_k, C_k are disjoint. Moreover, the subgraphs $\langle A_k \rangle, \langle B_k \rangle, \langle C_k \rangle$ are isomorphic to $\Gamma_{k-2}, \Gamma_{k-2}$ and Γ_{k-3} , respectively. Then, the vertices in A_k set are neighbour the vertices in B_k and C_k . The vertices in B_k is not neighbour the vertices in C_k [9].

III. THE FIRST ZAGREB INDEX OF FIBONACCI CUBES

One of the most used degree-based indices is the first Zagreb index. The first Zagreb index introduced by Gutman and Trinajstić [11] as

$$M_1(\vartheta) = \sum_{uv \in E(\vartheta)} (d_u + d_v) \quad (7)$$

They used to find the energy of the molecules [11]. There are many studies related with the first Zagreb index (for more detail, see [12-19]).

Theorem 3.1. Let Γ_k be k -dimensional Fibonacci cubes. Then, for $k \geq 2$,

$$M_1(\Gamma_k) = M_1(\Gamma_{k-1}) + M_1(\Gamma_{k-2}) + 8|E(\Gamma_{k-2})| + 2|V(\Gamma_{k-2})| + 2|V(\Gamma_{k-3})|$$

Proof. By direct computation, $M_1(\Gamma_0) = 0$ and $M_1(\Gamma_1) = 2$. Figure 1 is Γ_5 graph which is equal to $0\Gamma_4 + 10\Gamma_3$.

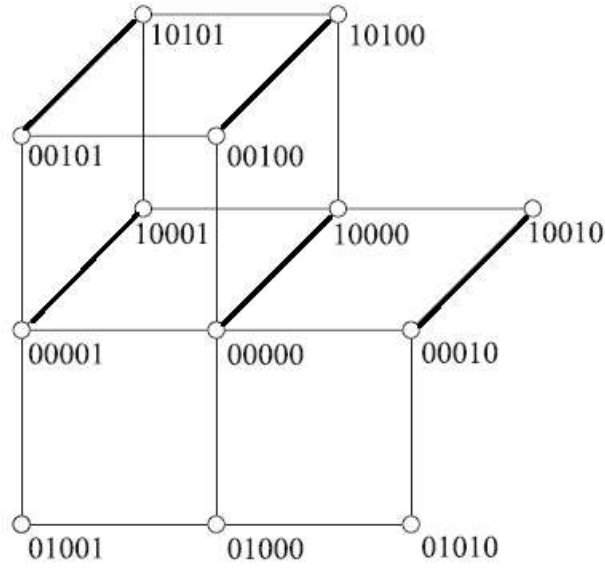


Fig. 1. The Γ_5 graph ($\Gamma_5 = 0\Gamma_4 + 10\Gamma_3$)

Assume that the vertex and edge sets of Γ_k are decomposition as

$$V(\Gamma_k) = V(\Gamma_{k-1}) \cup V(\Gamma_{k-2}) \quad (8)$$

where $V(\Gamma_{k-1}) = A_k \cup C_k$, $V(\Gamma_{k-2}) = B_k$

$$E(\Gamma_k) = E(\Gamma_{k-1}) \cup E(\Gamma_{k-2}) \cup E' \quad (9)$$

where $E(\Gamma_{k-1}) = \{uv \in E(\Gamma_k) | u \in A_k, v \in C_k\} \cup \{uv \in E(\Gamma_k) | u, v \in A_k\} \cup \{uv \in E(\Gamma_k) | u, v \in C_k\}$,
 $E(\Gamma_{k-2}) = \{uv \in E(\Gamma_k) | u, v \in B_k\}$, and $E' = \{uv \in E(\Gamma_k) | u \in A_k, v \in B_k\}$

where A_k, B_k, C_k are given in Equations (4), (5), and (6), respectively.

It is clear that

$$|E(\Gamma_k)| = |E(\Gamma_{k-1})| + |E(\Gamma_{k-2})| + |E'| \text{ where } |E'| = |V(\Gamma_{k-2})| = F_n$$

All vertex of the $\langle B_k \rangle$ subgraph in Γ_k to the vertices of the $\langle A_k \rangle$ subgraph in Γ_k and are connected by edges.

The following equation can be written by Equations (7) and (9):

$$\begin{aligned} M_1(\Gamma_k) = & \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u \in A_k, v \in C_k}} (d_u + 1 + d_v) + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in A_k}} (d_u + 1 + d_v + 1) \\ & + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in C_k}} (d_u + d_v) \\ & + \sum_{\substack{uv \in E(\Gamma_{k-2}) \\ u, v \in B_k}} (d_u + 1 + d_v + 1) + \sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k}} (d_u + 1 + d_v + 1) \end{aligned}$$

or

$$\begin{aligned}
M_1(\Gamma_k) = & \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u \in A_k, v \in C_k}} (d_u + d_v) + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u \in A_k, v \in C_k}} 1 + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in A_k}} (d_u + d_v) + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in A_k}} 2 \\
& + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in C_k}} (d_u + d_v) \\
& + \sum_{\substack{uv \in E(\Gamma_{k-2}) \\ u, v \in B_k}} (d_u + d_v) + \sum_{\substack{uv \in E(\Gamma_{k-2}) \\ u, v \in B_k}} 2 + \sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k}} (d_u + d_v) + \sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k}} 2
\end{aligned} \tag{10}$$

Note 1. Since $\langle A_k \rangle$ and $\langle B_k \rangle$ are isomorphic to Γ_{k-2} ,

i. $\sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in A_k}}$ is equal to $|E(\Gamma_{k-2})|$.

ii. $\sum_{\substack{uv \in E(\Gamma_{k-2}) \\ u, v \in B_k}}$ is equal to $|E(\Gamma_{k-2})|$.

Note 2. Since $\langle C_k \rangle$ is isomorphic to Γ_{k-3} , $\sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u \in A_k, v \in C_k}}$ is equal to $|V(\Gamma_{k-3})| = F_{n-1}$.

From Equations (7) and (10), and Notes 1-2, it can be written

$$\begin{aligned}
M_1(\Gamma_k) = & M_1(\Gamma_{k-1}) + |V(\Gamma_{k-3})| + 2|E(\Gamma_{k-2})| + M_1(\Gamma_{k-2}) + 2|E(\Gamma_{k-2})| + \sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k}} (d_u + d_v) \\
& + 2|V(\Gamma_{k-2})|
\end{aligned} \tag{11}$$

Lemma 3.2. For $uv \in E'$ and $v \in A_k, u \in B_k$ in Γ_k ,

$$\sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k}} (d_{u_{\Gamma_{k-1}}} + d_{v_{\Gamma_{k-2}}}) = 4|E(\Gamma_{k-2})| + |V(\Gamma_{k-3})|.$$

Proof. Let $x \in V(\Gamma_{k-3})$ and $v \in V(\Gamma_{k-2})$ in $xv \in E(\Gamma_{k-1})$. For $v \in A_k, u \in B_k$,

i. If $v \in N(V(\Gamma_{k-3}))$, then

$$d_{v_{\Gamma_{k-1}}} = d_{u_{\Gamma_{k-2}}} + 1 \tag{12}$$

ii. If $v \notin N(V(\Gamma_{k-3}))$, then

$$d_{v_{\Gamma_{k-1}}} = d_{u_{\Gamma_{k-2}}} \tag{13}$$

From Equations (12)-(13), it can be written

$$\begin{aligned}
& \sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k}} (d_{u_{\Gamma_{k-1}}} + d_{v_{\Gamma_{k-2}}}) \\
&= \sum_{\substack{v \in A_k, u \in B_k \\ v \in N(C_k)}} (d_{u_{\Gamma_{k-2}}} + 1 + d_{u_{\Gamma_{k-2}}}) \\
&\quad + \sum_{\substack{v \in A_k, u \in B_k \\ v \notin N(C_k)}} (d_{u_{\Gamma_{k-2}}} + d_{u_{\Gamma_{k-2}}}) \\
&= \sum_{\substack{v \in A_k, u \in B_k \\ v \in N(C_k)}} 1 + \sum_{u \in B_k} 2d_{u_{\Gamma_{k-2}}} \\
&= \sum_{\substack{v \in A_k, u \in B_k \\ v \in N(C_k)}} (d_{u_{\Gamma_{k-2}}} + 1 + d_{u_{\Gamma_{k-2}}}) + \sum_{\substack{v \in A_k, u \in B_k \\ v \notin N(C_k)}} (d_{u_{\Gamma_{k-2}}} + d_{u_{\Gamma_{k-2}}}) \\
&= \sum_{\substack{v \in A_k, u \in B_k \\ v \in N(C_k)}} 1 + \sum_{u \in B_k} 2d_{u_{\Gamma_{k-2}}} \\
&= 2 \sum_{u \in B_k} d_{u_{\Gamma_{k-2}}} + |V(\Gamma_{k-3})|.
\end{aligned}$$

From Lemma 2.1,

$$\sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k}} (d_{u_{\Gamma_{k-1}}} + d_{v_{\Gamma_{k-2}}}) = 4|E(\Gamma_{k-2})| + |V(\Gamma_{k-3})|.$$

From Equation (11), Equation (1), and Lemma 3.2, the proof is completed.

Corollary 3.3. If Γ_k is k -dimensional Fibonacci cubes, then, for $k \geq 2$,

$$M_1(\Gamma_k) = M_1(\Gamma_{k-1}) + M_1(\Gamma_{k-2}) + \frac{(8k - 14)F_{k-1} + 16(k - 1)F_{k-2} + 10F_k}{5}$$

Proof. From Theorem 3.1 and Equations (1) and (2), the proof is completed.

IV. THE FIRST LEAP ZAGREB INDEX OF FIBONACCI CUBES

In 2007, the first leap Zagreb indices of graph ϑ are introduced by Naji et al. as

$$LM_1(\vartheta) = \sum_{uv \in E(\vartheta)} (d'_u + d'_v) \tag{14}$$

where $d'_u = |\{u \in V: d(u, v) = 2\}|$ [20]. The first leap Zagreb index has been found to be a very good predictive index for many properties such as the boiling point of octane isomers [21]. Manjunatha et al. examined the first leap Zagreb index of a Mycielskian graph [22]. Chidambaram et al. studied leap Zagreb indices of bridge and chain graphs and chemical applications [23]. It was studied leap Zagreb indices of some networks [24], of central of a graph [25], of graph operations [26].

Lemma 4.1. ([27, 28]) If ϑ is a graph with k order and m size, then $\sum_{u \in V(\vartheta)} d'_u \leq M_1(\vartheta) - 2m$. ϑ is a $\{C_3, C_4\}$ -free graph if and only if it holds the equality.

Theorem 4.2. Let Γ_k be k -dimensional Fibonacci cubes. Then, for $k \geq 3$,

$$LM_1(\Gamma_k) \leq LM_1(\Gamma_{k-1}) + LM_1(\Gamma_{k-2}) + 3M_1(\Gamma_{k-2}) + 4|E(\Gamma_{k-2})| + 6|E(\Gamma_{k-3})| + |V(\Gamma_{k-4})| \\ + |V(\Gamma_{k-3})| + |V(\Gamma_{k-1})|$$

Proof. Since all the vertices $V(\Gamma_{k-2})$ in $V(\Gamma_k)$ are joined by one edge with the $V(\Gamma_{k-2})$ vertices in $V(\Gamma_{k-1})$, the followings are written:

- i. If $u \in A_k$, then $d'_{u\Gamma_k} = d'_{u\Gamma_{k-1}} + d_{x\Gamma_{k-2}}$, for $x \in B_k$, $xu \in E'$ and $x \in N(A_k)$.
- ii. If $u \in B_k$, then $d'_{u\Gamma_k} = d'_{u\Gamma_{k-2}} + d_{x\Gamma_{k-1}}$, for $x \in A_k$ and $x \in N(B_k)$.
- iii. If $u \in C_k$, then $d'_{u\Gamma_k} = d'_{u\Gamma_{k-1}} + 1$.

From Equations (9) and (14), and also above (i), (ii), and (iii), the following equation is obtained:

$$LM_1(\Gamma_k) = \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in A_k, x, y \in B_k}} (d'_{u\Gamma_{k-1}} + d_{x\Gamma_{k-2}} + d'_{v\Gamma_{k-1}} + d_{y\Gamma_{k-2}}) \\ + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u \in A_k, v \in C_k, x \in B_k}} (d'_{u\Gamma_{k-1}} + d_{x\Gamma_{k-2}} + d'_{v\Gamma_{k-1}} + 1) \\ + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in C_k}} (d'_{u\Gamma_{k-1}} + 1 + d'_{v\Gamma_{k-1}} + 1) \\ + \sum_{\substack{uv \in E(\Gamma_{k-2}) \\ u, v \in B_k, x, y \in A_k \\ xy \in E(\Gamma_{k-1})}} (d'_{u\Gamma_{k-2}} + d_{x\Gamma_{k-1}} + d'_{v\Gamma_{k-2}} + d_{y\Gamma_{k-1}}) \\ + \sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k \\ x \in B_k, x \in N(A_k), y \in A_k}} (d'_{u\Gamma_{k-1}} + d_{x\Gamma_{k-2}} + d'_{v\Gamma_{k-2}} + d_{y\Gamma_{k-1}})$$

or

$$LM_1(\Gamma_k) = \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in A_k}} (d'_{u\Gamma_{k-1}} + d'_{v\Gamma_{k-1}}) + \sum_{\substack{xy \in E(\Gamma_{k-2}) \\ x, y \in B_k}} (d_{x\Gamma_{k-2}} + d_{y\Gamma_{k-2}}) \\ + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u \in A_k, v \in C_k}} (d'_{u\Gamma_{k-1}} + d'_{v\Gamma_{k-1}}) \\ + \sum_{x \in B_k} d_{x\Gamma_{k-2}} + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u \in A_k, v \in C_k}} 1 + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in C_k}} (d'_{u\Gamma_{k-1}} + d'_{v\Gamma_{k-1}}) + \sum_{\substack{uv \in E(\Gamma_{k-1}) \\ u, v \in C_k}} 2$$

$$\begin{aligned}
& + \sum_{\substack{uv \in E(\Gamma_{k-2}) \\ u, v \in B_k}} (d'_{u_{\Gamma_{k-2}}} + d'_{v_{\Gamma_{k-2}}}) + \sum_{\substack{xy \in E(\Gamma_{k-1}) \\ x, y \in A_k}} (d_{x_{\Gamma_{k-1}}} + d_{y_{\Gamma_{k-1}}}) \\
& + \sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k}} (d'_{u_{\Gamma_{k-1}}} + d'_{v_{\Gamma_{k-2}}}) \\
& + \sum_{\substack{uv \in E' \\ v=y \in A_k, x=u \in B_k}} (d_{x_{\Gamma_{k-2}}} + d_{y_{\Gamma_{k-1}}})
\end{aligned}$$

From Note 1, Note 2 and Equations (7) and (9), Lemma 2.1, the following equation is written:

$$\begin{aligned}
LM_1(\Gamma_k) &= LM_1(\Gamma_{k-1}) + LM_1(\Gamma_{k-2}) + M_1(\Gamma_{k-2}) + 2|E(\Gamma_{k-2})| + |V(\Gamma_{k-3})| \\
&+ 2|E(\Gamma_{k-3})| + \\
&+ \sum_{\substack{xy \in E(\Gamma_{k-1}) \\ x, y \in A_k}} (d_{x_{\Gamma_{k-1}}} + d_{y_{\Gamma_{k-1}}}) + \sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k}} (d'_{u_{\Gamma_{k-1}}} + d'_{v_{\Gamma_{k-2}}}) \\
&+ \sum_{\substack{uv \in E' \\ v=y \in A_k, x=u \in B_k}} (d_{x_{\Gamma_{k-2}}} + d_{y_{\Gamma_{k-1}}})
\end{aligned} \tag{15}$$

Lemma 4.3. For $uv \in E'$ and $v \in A_k, u \in B_k$ in Γ_k ,

$$\sum_{\substack{uv \in E' \\ v \in A_k, u \in B_k}} (d'_{u_{\Gamma_{k-1}}} + d'_{v_{\Gamma_{k-2}}}) \leq M_1(\Gamma_{k-2}) - 2|E(\Gamma_{k-2})| + 2|E(\Gamma_{k-3})| + |V(\Gamma_{k-1})| - |V(\Gamma_{k-3})|$$

Proof. Let $u \in A_k$ and $v \in V(\Gamma_{k-2})$ in $uv \in E(\Gamma_{k-1})$,

i. If $u \in N(V(\Gamma_{k-3}))$ and $x \in V(\Gamma_{k-3})$, then

$$d'_{u_{\Gamma_{k-1}}} = d'_{v_{\Gamma_{k-2}}} + d_{x_{\Gamma_{k-3}}} \tag{16}$$

ii. If $u \notin N(V(\Gamma_{k-3}))$, then

$$d'_{u_{\Gamma_{k-1}}} = d'_{v_{\Gamma_{k-2}}} + 1 \tag{17}$$

From Equations (16)-(17), it can be written

$$\begin{aligned}
\sum_{\substack{uv \in E' \\ u \in A_k, v \in B_k}} (d'_{u_{\Gamma_{k-1}}} + d'_{v_{\Gamma_{k-2}}}) &= \sum_{\substack{uv \in E', v \in B_k \\ x \in V(\Gamma_{k-3})}} (d'_{v_{\Gamma_{k-2}}} + d_{x_{\Gamma_{k-3}}} + d'_{v_{\Gamma_{k-2}}}) \\
&\quad + \sum_{\substack{uv \in E', v \in B_k \\ u \notin N(V(\Gamma_{k-3}))}} (d'_{v_{\Gamma_{k-2}}} + 1 + d'_{v_{\Gamma_{k-2}}}) \\
&= \sum_{v \in B_k} 2d'_{u_{\Gamma_{k-2}}} + \sum_{\substack{uv \in E', v \in B_k \\ u \notin N(V(\Gamma_{k-3}))}} 1 + \sum_{\substack{x \in B_k \\ x \in V(\Gamma_{k-3})}} d_{x_{\Gamma_{k-3}}}
\end{aligned}$$

From Lemma 4.1,

$$\sum_{\substack{uv \in E' \\ u \in A_k, v \in B_k}} (d'_{u_{\Gamma_{k-1}}} + d'_{v_{\Gamma_{k-2}}}) \leq M_1(\Gamma_{k-2}) - 2|E(\Gamma_{k-2})| + 2|E(\Gamma_{k-3})| + |V(\Gamma_{k-1})| - |V(\Gamma_{k-3})|$$

Lemma 4.4. For $xy \in E(\Gamma_{k-1})$ and $x, y \in A_k$,

$$\sum_{\substack{xy \in E(\Gamma_{k-1}) \\ x, y \in A_k}} (d_{x_{\Gamma_{k-1}}} + d_{y_{\Gamma_{k-1}}}) = M_1(\Gamma_{k-2}) + 2|E(\Gamma_{k-3})| + |V(\Gamma_{k-4})|$$

Proof. From Equations (12)-(13),

$$\begin{aligned}
\sum_{\substack{xy \in E(\Gamma_{k-1}) \\ x, y \in A_k}} (d_{x_{\Gamma_{k-1}}} + d_{y_{\Gamma_{k-1}}}) &= \sum_{\substack{sl \in B_k \\ x, y \in A_k \\ x, y \in N(C_k)}} (d_{s_{\Gamma_{k-2}}} + d_{l_{\Gamma_{k-2}}} + 2) + \sum_{\substack{s, l \in B_k \\ x, y \in A_k \\ x \in N(C_k)}} (d_{s_{\Gamma_{k-2}}} + d_{l_{\Gamma_{k-2}}} + 1) \\
&\quad + \sum_{\substack{sl \in B_k \\ x, y \in A_k \\ x, y \notin N(C_k)}} (d_{s_{\Gamma_{k-2}}} + d_{l_{\Gamma_{k-2}}}) \\
&= M_1(\Gamma_{k-2}) + 2|E(\Gamma_{k-3})| + |V(\Gamma_{k-4})|
\end{aligned}$$

Using Lemma 3.2, Lemma 4.3, Lemma 4.4 in Equation (15), the following equation is obtained

$$\begin{aligned}
LM_1(\Gamma_k) &\leq LM_1(\Gamma_{k-1}) + LM_1(\Gamma_{k-2}) + 3M_1(\Gamma_{k-2}) + 4|E(\Gamma_{k-2})| + 6|E(\Gamma_{k-3})| + |V(\Gamma_{k-4})| + |V(\Gamma_{k-3})| \\
&\quad + |V(\Gamma_{k-1})|
\end{aligned}$$

Corollary 4.5. If Γ_k is k -dimensional Fibonacci cubes, then, for $k \geq 3$,

$$LM_1(\Gamma_k) \leq LM_1(\Gamma_{k-1}) + LM_1(\Gamma_{k-2}) + 3M_1(\Gamma_{k-2}) \\ + \frac{(14k-21)F_{k-2} + (4k-3)F_{k-1} + 12(k-2)F_{k-3}}{5} + F_{k+1}$$

Proof. From Theorem 4.2 and Equations (1)-(2), the proof is completed.

V. RESULTS AND DISCUSSION

Using the concept of topological indices in chemical graph theory, properties of chemical structures can be predicted without experimentation, saving time and money, and contributing to drug discovery. this, in turn, accelerates computer-aided research with advancing technology. in this study, two topological indices based on both the degree and distance concepts of graphs were studied. the values of the topological indices for fibonacci cube graphs were obtained.

VI. CONCLUSION

Fibonacci cubes, which first emerged as a new network topology in parallel computing, have many advantages over other interconnections in the network topology. In addition, Fibonacci cubes are also used in chemical graph theory. Polycyclic aromatic hydrocarbons and some hydrocarbons in chemistry match exactly with Fibonacci cubes. Topological indices are numerical values of the graph representation of the chemical structure used in QSPR/QSAR studies to predict the properties of a chemical structure. In this study, the first Zagreb and first leap Zagreb indices of Fibonacci cubes are calculated. These results will be used in QSPR/QSAR modelling to predict the properties of chemical structures and will shed light on new drug discoveries.

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Soğuk İş Takım Çeliklerinin Tornalanmasında Kesme Hızı Değişiminin Kesme Kuvveti Üzerindeki Etkisinin İncelenmesi

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Özet – Bu çalışmada soğuk iş takım çeliklerinden biri olan DIN 2379 / AISI D2 malzemesinin tornalanmasında kesme hızı değişiminin kesme kuvvetleri üzerindeki etkisi deneysel olarak incelenmiştir. Yüksek oranda sertliğe ve aşınma direncine sahip olan 2379 çeliği, kalıpların ve kesici takımların üretiminde yaygın olarak kullanılmaktadır. Ancak sahip olduğu bu özellikler, talaşlı imalat süreçlerinde işlenebilirlik açısından çeşitli zorluklara yol açmaktadır. Özellikle kesme kuvvetleri, işleme sırasında takım yükünü, enerji tüketimini ve yüzey kalitesini doğrudan etkileyen önemli bir parametre olmaktadır.

Deneysel çalışmalarda çapı 50 mm ve uzunluğu 100 mm olan 2379 çeliği kullanılmış, kuru işleme koşullarında tornalama işlemi gerçekleştirilmiştir. Kesici takım olarak PVD kaplamalı karbür uçlar kullanılmıştır. İlerleme hızı 0,1 mm/dev ve talaş derinliği 0,2 mm olarak belirlenip sabit tutulmuştur. Deneyler yalnızca kesme hızının değiştirilmesi üzerine karar verilmiş ve hız değerleri 40, 50, 65, 100 ve 135 m/dak olarak seçilmiştir. Deney esnasında kesme kuvvetleri torna tezgahına entegre edilmiş dinamometre yardımıyla ölçülmüştür.

Sonuç olarak, kesme hızındaki artış; kesme kuvvetlerini azalttığını göstermiştir. Düşük hızlarda daha yüksek kuvvetler ölçülmüş, hızın artmasıyla birlikte kuvvetlerde belirgin bir azalma gözlenmiştir. Bu durum ise kesme bölgesindeki sıcaklık artışı ile malzemenin lokal olarak yumuşaması ve talaşın daha kolay ayrılmasıyla açıklanabilir. Bu çalışma DIN 2379 çeliğinin işlenebilirliği konusunda önemli veriler sunarak, uygun kesme parametrelerinin belirlenmesine katkı sağlamaktadır.

Anahtar Kelimeler – 2379 Çeliği, Tornalama, Kesme Kuvveti, PVD Kaplamalı Karbür, Kuru İşleme.

I. GİRİŞ

Talaşlı imalat, modern imalat alanında kritik öneme sahip üretim yöntemlerinden biri olarak kabul edilmektedir. Özellikle yüzey kalitesi ve toleransın önemli olduğu uygulamalarda tornalama, frezeleme, taşlama gibi işlemler artık sadece form vermek değil aynı zamanda verimli ve düzgün üretim sağlamak açısından da kritik hale gelmiştir. Bu durumda kesme kuvvetlerinin belirlenmesi; takım ömrü, enerji tüketimi, tezgah dinamiği ve yüzey kalitesi gibi çok sayıda parametre açısından belirleyicidir.

Kesme kuvvetleri genellikle üç gruba ayrılmaktadır: ana (teğetsel) kuvvet, radyal kuvvet ve ilerleme bileşeni. Bu kuvvetlerin büyüklüğü ise; kesme hızı (V), ilerleme miktarı (f), talaş derinliği (a), takım geometrisi, takım malzemesi ve kaplaması, iş parça malzemesi ve kesme ortamına bağlıdır. Yüksek sertlikte olan malzemelerde özellikle soğuk iş takım çeliklerinde, etkileşim daha karmaşıktır çünkü yüksek sertliğinden dolayı malzeme içinde karbür fazları, mikro yapısal heterojenlikler gibi yapısal zorluklar da meydana gelmektedir.

2379 / D2 çeliği, soğuk iş takım çeliği grubuna ait bir malzemedir ve karbon açısından zengin olup yaklaşık %12 krom içeriğiyle karakterizedir. Bu kompoze malzemeye yüksek sertlik ve iyi bir aşınma direnci kazandırmaktadır. Ancak bu özellikler aynı zamanda işlenebilirliğini zorlaştırmaktadır. Talaşlı imalat sırasında yüksek kesme yüklerine maruz kalınması, artan sıcaklıklara ve takım aşınmalarına yol açmaktadır.

Literatürde 2379/D2 malzemesiyle işlenebilirlik üzerine bazı çalışmalar mevcuttur. Ancak çoğu çalışmada CNC tezgahlar, yağlama koşulları, farklı kesici takımlar kullanılmış olup manuel torna tezgahında ve kuru işleme ortamında yapılan sistematik kesme kuvveti üzerine odaklanan deneysel çalışmalar daha sınırlıdır. Bu sınır, atölye koşullarında deneysel verilerin önemini artırmaktadır.

Mhamdi ve ark. (2013), AISI D2 (2379) çeliğini tornalanması üzerine bir çalışma gerçekleştirilmiştir. Deneyde farklı kesme hızları ve takım türleri ile DIN 2379 çeliği tornalanmış, talaş morfolojisi incelenmiştir. Sonuçlarda kesme hızının artmasıyla birlikte talaş oluşumu değişmekte ve genel olarak kesme kuvvetlerinde azalma olduğu belirtilmiştir [1].

X. M. Anthony (2015), çalışmada kesme kuvvetlerini ve talaş morfolojisini incelemiştir. Deneyinde 55 HRC D2 çeliği, farklı kesme hızı, ilerleme, talaş derinliği kombinasyonlarını incelemiştir. Sonuç olarak kesme hızındaki artış kesme kuvvetlerini azaltmış olup talaş yapısı parametrelere bağlı olarak değişmiştir [2].

Mallick ve ark. (2023), 2379 / D2 çeliğini, minimum miktarda yağlama (MMY) ortamında tornalama işlemi gerçekleştirmiştir. Deneyde farklı kesme hızları, MMY ve kuru ortam koşullarının karşılaştırılması yapılmış, yüzey pürüzlülüğü, sıcaklık değişimi ve takım aşınması incelenmiştir. Sonuç olarak MMY ortamında kesme kuvvetleri ve takım aşınmasında azalma, yüzey kalitesinde iyileşme olduğu bildirilmiştir [3].

Kara ve ark. (2020), çalışmada derin kriyojenik işlem kullanarak D2 çeliğini tornalanmasının işlenebilirliğini incelemiştir. Deney sonucunda kriyojenik işlemin ardından gerçekleştirilen ısıtma işlemi D2 çeliğinin işlenebilirliğini ve mikro yapısal özelliklerini önemli ölçüde arttırdığını, özellikle de kaplamalı seramik kesici takımlar kullanılmasıyla daha iyi bir yüzey kalitesi ve daha düşük takım aşınmasına yol açtığını vurgulamaktadır. Aynı zamanda yüzey pürüzlülüğünün tahmin edilmesinde ANN (Yapay Sinir Ağı) kullanıldığı; kesme hızı, ilerleme, talaş derinliği ve kesici takım gibi parametreleri dikkate alarak işleme sonuçlarını tahmin etmede faydası olduğu belirtilmiştir [4].

Gaitonde ve ark. (2009), çalışmada farklı seramik kesici uçlarla D2 çeliğinde tornalama işlemi gerçekleştirilmiş ve sonucunda CC650WG wiper kesici ucun yüzey pürüzlülüğü ve takım aşınması bakımında daha iyi sonuçlar verdiği, CC650 konvensiyonel ucun ise güç ve kesme kuvvetini azaltmada daha iyi olduğu ortaya konmuştur [5].

Srithar ve ark. (2014), çalışmada D2 çeliğini CVD kaplamalı karbür kesici uçlar ile tornalama işlemi gerçekleştirilmiştir. Sonuç olarak ilerleme (f) ve talaş derinliği (a) kuvvetleri açık bir şekilde artmıştır [6].

Sharma (2014), çalışmada kuru ve near-dry koşullarını karşılaştırmıştır. Deney sonucunda near-dry ortamının kesme kuvvetlerini ve aşınmayı azaltmış, kuru ortamda ise kesme kuvvetleri daha yüksek çıkmıştır [7].

Khan ve ark. (2022), D2 takım çeliğini yüksek hızlarda tornalanmasında takım aşınma mekanizmaları ve iş parçasının yüzey pürüzlülüğü incelenmiştir. Sonuç olarak yüksek hızlarda doğru kesici takım kullanarak hem takım ömrünü uzatabileceğini hem de daha iyi yüzey kalitesinin ortaya çıkabileceğini deneysel veriler ile ortaya koymaktadır [8].

Dumitrescu ve ark. (2006), çalışmada AISI D2 takım çeliğinin yüksek güçlü diyet lazer destekli tornalama işlemi gerçekleştirilmiştir. Bu çalışma sonucunda lazer desteğinin testere dişli talaş oluşumunu engellediğini, titreşimi azalttığını, takım aşınmasını azaltarak ve yüzey kalitesini koruyarak minimum etkiyle kesme kuvvetlerinde önemli bir azalma olduğu gösterilmiştir [9].

Beşliu ve ark. (2018), çalışmada kesme parametreleri ve kesici uç freze geometrisinin etkisini dikkate alarak AISI D2 takım çeliğinin frezelenmesi sırasında kesme kuvveti bileşenlerini ve talaş şekilleri araştırılmıştır. Sonuç olarak parametrelerdeki değişim kesme kuvvetlerini ve talaş oluşum mekanizmalarını önemli oranda etkilediği ve yüzey bütünlüğü üzerinde etkisi olduğu bildirilmiştir [10].

O.I. Elly ve ark. (2024), çalışmasında hassas tornalama ortamında kesme hızı, ilerleme ve talaş derinliği parametreleriyle tam faktöriyel deneyler yaparak kuvvet bileşenleri modellenmiş ve optimizasyon yapılmıştır. Sonuç olarak elde edilen verilerden ideal kombinasyonları ortaya çıkararak kuvvet değerleri ve optimizasyon sonuçları sunulmuştur [11].

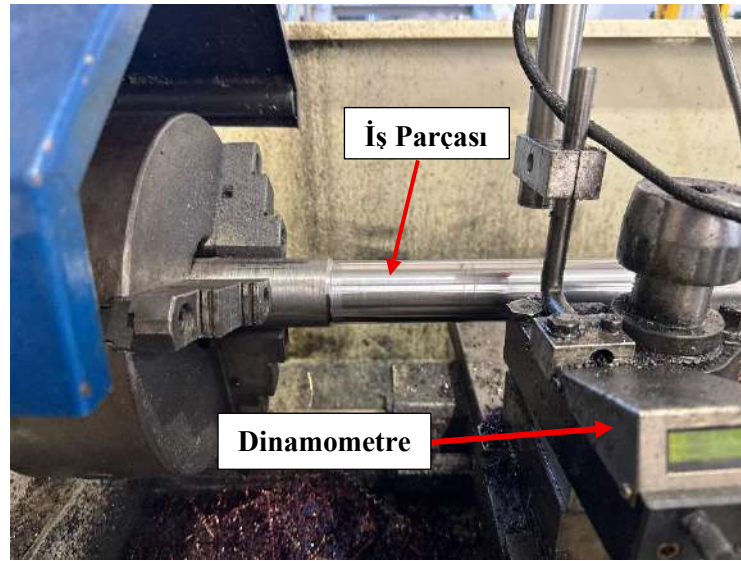
S. Kumar ve ark. (2023), çalışmasında CBN kesici uçlarla sert tornalama işlemi gerçekleştirilmiş; farklı kesme hızı, ilerleme ve talaş derinliği parametrelerinde kesme kuvveti ve yüzey pürüzlülüğü ölçümleri yapılmıştır. Sonuç olarak ilerleme oranının kuvvet üzerindeki etkisi büyük olmuş, kesme hızı artışıyla kuvvetlerde azalma olduğu belirtilmiştir [12].

A. Çakan ve ark. (2024), çalışmasında TiCN, Al₂O₃, TiN kaplamalı karbür kesici uçlarla D2 soğuk takım iş çeliği tornalanmış; farklı kesme hızlarıyla kesme kuvvetleri ve performansı karşılaştırılmıştır. Sonuç olarak çoklu kaplama kombinasyonları kesme kuvvetlerinde bir düşüş sağladığı belirtilmiştir [13].

Bu çalışmada AISI D2 (DIN 2379) soğuk takım iş çeliğinin tornalanmasında kesme parametrelerinden ilerleme ve talaş derinliğini sabit tutarak farklı kesme hızlarında talaş kaldırarak kesme kuvvetlerinde nasıl bir değişim olacağı üzerine deneyler gerçekleştirilmiştir.

II. MATERYAL VE YÖNTEM

Bu bölümde deneyde kullanılan iş parçası malzemesinin özellikleri, takım tezgahı ve kullanılan kesici takım özetlenmektedir. Çalışma tezgahının şematik bir gösterimi Şekil 1’de verilmiştir.



Şekil 1. Torna tezgahına bağlı iş parçası ve dinamometre

A. İş Parçası Malzemesi ve Kesici Takım

Bu çalışmada iş parçası malzemesi olarak AISI D2 (DIN 2379) soğuk iş takım çeliği edilmiştir çünkü sektörde kalıp ve kesici takım üretiminde yaygın olarak tercih edilen bir malzemedir. Numuneler 50 mm çapında ve 100 mm uzunluğunda silindirik çubuktan hazırlanmıştır. Deneyde herhangi bir kesme/soğutma sıvısı kullanılmamıştır, kuru ortamda gerçekleştirilmiştir.

Kesici takım olarak, sıcaklık dayanımı yüksek olan ve aşınmaya dirençli PVD kaplamalı karbür uç takımlar kullanılmıştır.

B. Takım Tezgahı ve Kesme Parametreleri

DeneySEL çalışma DE Lorenzo manuel torna tezgahında gerçekleştirilmiştir. Deneyde ilerleme miktarı (f) ve talaş derinliği (a) sabit tutulmuş, kesme hızının kesme kuvvetleri üzerindeki etkisini gözlemlemek amacıyla beş farklı kesme hızı seçilmiştir ve bu değerler aşağıdaki tabloda gösterilmektedir.

Tablo 1. Kesme Parametreleri

Kesme Hızı (m/dak)	İlerleme (mm/dev)	Talaş Derinliği (mm)
40	0,1	0,2
50	0,1	0,2
65	0,1	0,2
100	0,1	0,2
135	0,1	0,2

Kesme parametreleri dikkate alındığında ilerleme ve talaş derinliğinin sabit tutulmasının temel nedeni sadece kesme hızının kesme kuvvetleri üzerindeki etkisini net bir şekilde ortaya koyabilmesidir. Böylece deney sonunda elde edilen veriler, farklı kesme hızlarında farklı kesme kuvvetleri oluşturduğunu net bir şekilde yansıtmaktadır.

Her deney sonunda kesme kuvvetleri torna tezgahına entegre edilmiş bir dinamometre yardımıyla ölçülmüştür. Dinamometre kesme kuvvetlerini üç bileşen halinde (teğetsel kuvvet F1, ilerleme kuvveti F2 ve radyal kuvvet F3) kaydetmektedir. Ölçüm sonuçları her bir kesme hızı için ayrı ayrı değerlendirilmiş ve ortalama değerleri kayıt altına alınmıştır.

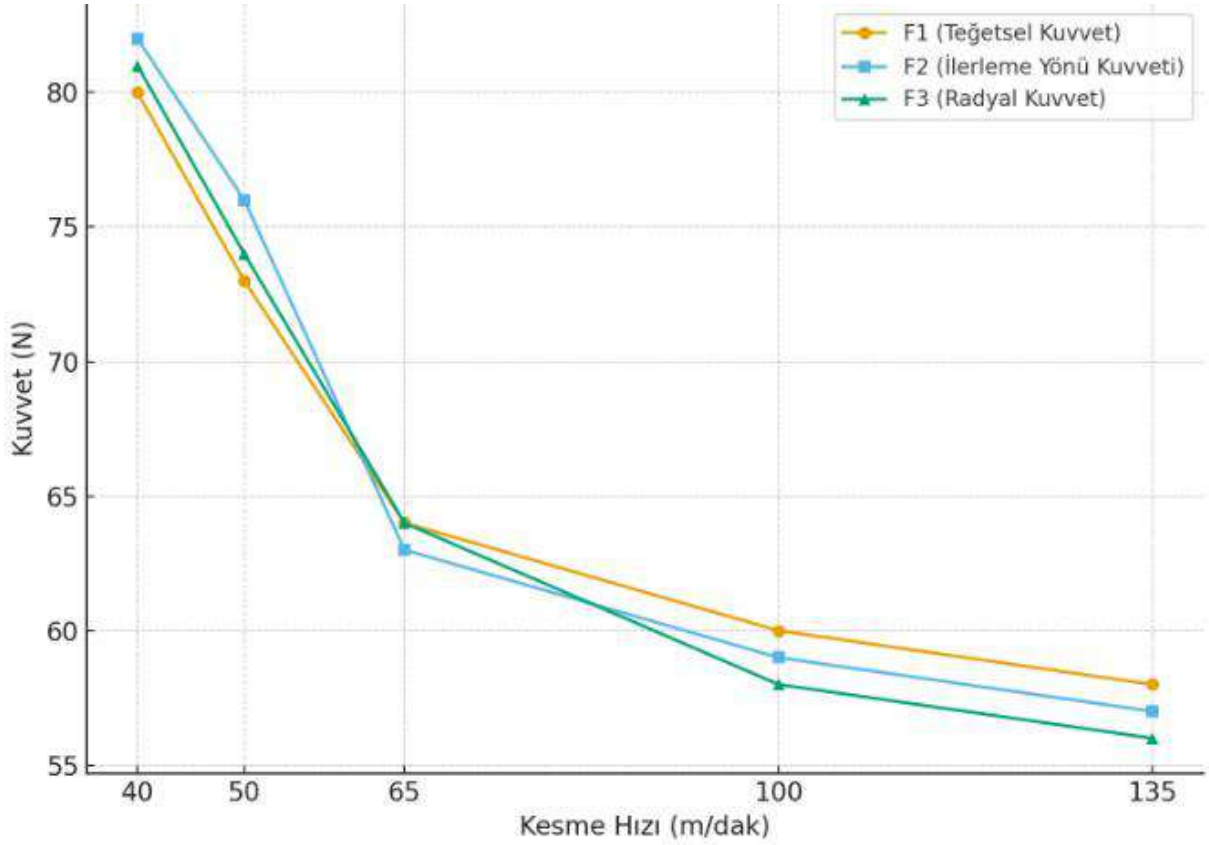
III. BULGULAR

Bu çalışmada farklı kesme hızlarında elde edilen kesme kuvvetleri aşağıdaki Tablo 2’de verilmiştir. Ölçümler dinamometre aracılığıyla bilgisayar ortamına aktarılmış XKM2000 program yardımıyla da F1, F2 ve F3 kuvvet değerleri kaydedilmiştir.

Tablo 2. Farklı kesme hızlarında ölçülen kesme kuvvetleri

İlerleme (mm/dev)	Talaş Derinliği (mm)	Kesme Hızı (m/dak)	F1 (N)	F2 (N)	F3 (N)
0,1	0,2	40	80	82	81
0,1	0,2	50	73	76	74
0,1	0,2	65	64	63	64
0,1	0,2	100	60	59	58
0,1	0,2	135	58	57	56

Elde edilen bu veriler incelendiğinde kesme hızının artmasıyla birlikte tüm kuvvet bileşenlerinde bir azalma eğilimi görülmektedir. Özellikle düşük kesme hızlarında kesme kuvveti değerleri yüksek çıkmaktayken, hız arttıkça kuvvetlerinde kademeli bir şekilde düştüğü görülmektedir. En düşük kuvvet değerleri ise 135 m/dak kesme hızında tespit edilmiştir.



Grafik 1. Kesme Hızı – Kesme Kuvveti İlişkisi

IV. TARTIŞMA

Bu çalışmadaki elde edilen bulgular, kesme hızındaki artışın kesme kuvvetlerindeki tüm bileşenlerde azalma eğilimi gösterdiğini ortaya koymaktadır. Tablo 2’de belirtildiği gibi düşük kesme hızlarındaki kesme kuvveti değerleri yüksek çıkarken, hız artmasıyla birlikte kademeleri olarak kesme kuvvetlerinde azalma göstermiştir. Bu durum, kesme bölgesinde artan hızla beraber ortaya çıkan sıcaklık artışı ve buna bağlı olarak malzemenin plastik deformasyon davranışındaki değişim ile açıklanabilir. Yüksek kesme hızlarında malzeme daha sünek bir davranış gösterebilmekte, bu durum kesme kuvvetlerinin azalmasına yol açmaktadır.

Bu değişim, literatürdeki çalışmalarla uyumlu olmaktadır. Örneğin, Mhamdi ve ark. Kesme hızının artmasıyla birlikte talaş oluşumunun değiştiğini ve kuvvetlerin azaldığı raporlanmaktadır [1]. Benzer şekilde Anthony’nin çalışmasında kesme hızının artmasıyla beraber kesme kuvvetlerinin azaldığını ve talaş yapısının parametrelere bağlı olarak değiştiğini belirtmiştir [2]. Mallick ve ark. çalışmasında ise minimum miktarda yağlama koşullarında kesme hızının kuvvetler üzerinde azaltıcı bir etkisi olduğunu vurgulamaktadır [3].

Deneydeki elde edilen sonuçlarda 65 m/dak üzerindeki hızlarda kuvvetlerdeki düşüşün daha sınırlı olduğu görülmektedir. Bu durum literatürde ‘doyma bölgesi’ olarak ifade edilmektedir. Kara ve ark., D2 çeliğinde kriyojenik ortamda benzer şekilde belirli bir hızdan sonra kuvvetlerdeki azalmanın daha düşük seviyelerde gerçekleştiği raporlanmaktadır [4]. Bunun nedeni, kesme hızının belli bir eşikten sonra kesme kuvvetleri üzerinde doğrusal olmayan bir etki yarattığını göstermektedir.

Çalışmamızdaki kuvvet bileşenleri (F1, F2, F3) birbirine oldukça yakın değerlerde sonuçlar vermiştir. Bu bulgu, Srithar ve ark. [6] ve Sharma [7] tarafından yapılan çalışmalarda da görülmektedir. Özellikle düşük ilerleme ve talaş derinliği değerlerinde kuvvetler arasındaki farklılıkların azalması, kesici takım geometrisi ve malzemenin özelliği ile ilişkilendirilmektedir.

Sonuç olarak tornalama işleminde, kuru ortam koşullarında gerçekleştirilen deneyler literatürdeki modern CNC, MMY veya lazer destekli sistemlerle yapılan çalışmalara benzer bir eğilim göstermektedir.

Bu çalışmanın literatüre katkısı, manuel tornalama ve kuru işleme koşullarında elde edilen bulguların, daha gelişmiş işleme yöntemleriyle elde edilen sonuçlar ile karşılaştırılabilir olduğunu ortaya koymaktadır.

V. SONUÇLAR

Bu çalışmada AISI D2 (DIN 2379) soğuk iş takım çeliğinin tornalanmasında kesme hızı parametresinin kesme kuvvetleri üzerindeki etkileri deneysel olarak incelenmiştir. Çalışma manuel torna tezgahında ve kuru kesme koşullarında gerçekleştirilmiş, ilerleme ve talaş derinliği parametreleri sabit tutularak kesme hızının değiştirilmesine dayalı olarak kuvvetler ölçülmüştür. Bu deney sonucunda elde edilen temel çıktıları aşağıda özetlenmiştir:

- Kesme hızındaki artış, tüm kuvvet bileşenlerinde (F1- teğetsel, F2- ilerleme yönü, F3- radyal) belirgin bir azalma göstermiştir.
- Düşük kesme hızlarında (40-50 m/dak) kuvvet değerleri yüksek çıkmaktayken, hızın artmasıyla kuvvetlerde kademeli olarak azalma görülmüştür.
- 65 m/dak üzerindeki hızlarda kuvvetin azalma eğilimi daha sınırlıdır; bu durum literatürde ‘doyma bölgesi’ olarak adlandırılan bir etkiye işaret etmektedir.
- Kuvvet bileşenleri birbirine yakın değerlerde çıkmış, ilerlemenin ve talaş derinliğinin sabit tutulmasıyla yönsel farklılıklar sınırlı kalmıştır.
- Elde edilen sonuçlar, literatürde raporlanan çalışmalar ile uyum göstermektedir. Bu da çalışmamızın doğruluğunu ve güvenilirliğini destekler niteliktedir.
- Çalışmamızın özgünlüğü manuel olarak torna tezgahında ve kuru işleme koşullarında elde edilen bu verilerin daha gelişmiş yöntemlerle yapılan çalışmalara kıyasla benzer sonuçlar doğurması ve uygulama açısından pratik bilgiler sağlamaktadır.

Sonuç olarak, AISI D2 (DIN 2379) soğuk iş takım çeliğinin işlenebilirliğinde kesme hızının kuvvetler üzerinde kritik bir parametre olduğunu ve hız seçiminin işleme verimliliğini doğrudan etkilediği ortaya koymaktadır. Gelecekte yapılabilecek çalışmalarda, farklı ilerleme, talaş derinliği, kesici takım malzemesi ve işleme koşulları incelenerek daha kapsamlı bir değerlendirme yapılabilecektir.

Elde edilen bulgulardan yola çıkarak uygulama önerisi olarak, manuel ve kuru işleme koşullarında D2 çeliğinin tornalanmasında optimum kesme hızı yaklaşık olarak 100-135 m/dak aralığında seçilmesi, daha düşük kesme kuvvetleriyle daha verimli işleme sağlayacağı söylenebilir.

TEŞEKKÜR

Bu bildiri, Burhan Siper’in ‘Talaşlı İmalatta Y_2O_3 Nanopartikül İlaveli Kesme Sıvısının İşlenebilirlik Üzerine Etkilerinin İncelenmesi’ isimli yüksek lisans tez çalışmasında türetilmiştir.

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Modbus-Based PID Position Control Simulation Using Outseal Nano and LabVIEW DSC Toolkit

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Abstract – This study presents the design and simulation of a positional Proportional-Integral-Derivative (PID) control system using Outseal Nano hardware integrated with LabVIEW for real-time monitoring. The primary objective is to demonstrate a cost-effective and modular approach to position control through virtual prototyping, enabling precise actuator response based on encoder feedback. The system architecture combines Outseal Studio for ladder logic programming, Proteus for circuit simulation, and LabVIEW with the DSC Toolkit for data visualization. The Outseal Nano microcontroller is configured via Modbus protocol, with encoder signals filtered and mapped to integer memory registers. The compiled ladder diagram is embedded into the ATmega328 microcontroller within Proteus, while serial communication is established through paired COM ports using virtual serial port software. The LabVIEW interface captures and displays fourteen key PID-related parameters, including setpoint, process variable, error, and output duty cycle. Results from the simulation confirm stable position tracking and responsive control behavior under varying setpoint conditions. The system effectively visualizes PID dynamics, offering insights into tuning parameters such as K_p , K_i , and K_d . This integrated simulation framework provides a scalable foundation for educational and industrial applications in motion control, particularly where hardware-software co-design and real-time feedback are essential. The methodology supports iterative development and facilitates deeper understanding of control system behavior without requiring physical deployment.

Keywords –Positional PID Control, Outseal Nano, Labview DSC Toolkit, Proteus Simulation, Modbus Communication, Ladder Logic Programming, Real-Time Monitoring.

I. INTRODUCTION

Positional control systems are fundamental to modern automation, robotics, and mechatronics applications, where precise actuator movement is required in response to dynamic setpoint changes. Among various control strategies, the Proportional-Integral-Derivative (PID) algorithm remains the most widely adopted due to its simplicity, robustness, and effectiveness in linear system [1-3]. The integration of PID control with simulation platforms enables engineers and researchers to validate system behavior before physical deployment, reducing cost and development time [4], [5].

The ATmega328P microcontroller [6], [7], widely recognized for its balance of performance and simplicity, serves as the core processing unit in many embedded control applications. Its integration within the Arduino development platform has significantly lowered the barrier to entry for rapid prototyping, enabling researchers and educators to implement real-time control algorithms with minimal hardware overhead [8-11]. The open-source nature of Arduino, combined with the robustness of the ATmega328P architecture [12], [13] makes it an ideal candidate for simulation-driven PID control studies and modular automation systems.

Encoder-equipped DC motors are widely utilized in closed-loop control systems due to their ability to provide precise position and velocity feedback [14], [15]. By integrating rotary encoders, these motors enable accurate tracking of shaft movement, which is essential for implementing real-time PID control

algorithms. Their compact structure, ease of interfacing with microcontrollers, and suitability for both low- and medium-power applications make them ideal for educational platforms, robotics, and simulation-based automation studies.

Recent advancements in virtual prototyping tools such as Proteus and LabVIEW have facilitated the modeling and visualization of control systems in real-time environments [16]. Proteus offers a flexible simulation interface for embedded systems, while LabVIEW provides a graphical programming environment with extensive data acquisition and monitoring capabilities [17]. The use of the DSC Toolkit within LabVIEW [18], [19] further enhances its ability to interface with Modbus-based microcontrollers, enabling seamless communication and data tracking [20], [21].

Outseal Nano, a compact and programmable control module, has emerged as a viable hardware platform for implementing ladder logic-based PID control. Its compatibility with Modbus protocol and integration with Outseal Studio allows for intuitive programming and real-time parameter tuning [21], [22]. In this study, we present a simulation-based implementation of a positional PID control system using Outseal Nano hardware, Proteus simulation, and LabVIEW visualization. The system architecture includes encoder feedback, direction control, and serial communication via paired COM ports, enabling real-time monitoring of key PID parameters such as process variable (PV), setpoint (SP), error, and output duty cycle.

The primary contribution of this work lies in its demonstration of a fully integrated simulation framework that bridges hardware-software co-design with real-time feedback analysis. The methodology is particularly relevant for academic and industrial settings where rapid prototyping and control validation are essential. Through this simulation, we aim to provide a replicable and adaptable model for positional PID control, emphasizing clarity, accessibility, and technical rigor.

II. MATERIALS AND METHOD

The simulation-based implementation of the positional PID control system was conducted using a combination of Outseal Nano hardware, Proteus simulation software, and LabVIEW with the DSC Toolkit add-on. The control architecture was designed to emulate a closed-loop system capable of responding to dynamic setpoint changes and visualizing control parameters in real time.

The hardware configuration was modeled in Proteus using an Outseal Nano V5 microcontroller programmed via ladder logic in Outseal Studio. The circuit included ten Outseal Nano legs assigned to specific control functions: A.1 for setpoint input, S.1 for direction setting, S.5 and S.6 for encoder signals, S.7 for direction detection, and R.6–R.8 for motor driver control via the L298 module. Serial communication was established through the TX and RX pins, connected to a virtual COM port using HHD Virtual Serial Ports software. The ATmega328 microcontroller within Proteus was configured with external clock settings (CKSEL = Ext Clock, CLKDIV8 = Unprogrammed) and a clock frequency of 16 MHz. The compiled ladder logic program and hex file was loaded into the microcontroller via the Proteus interface.

Outseal Studio was used to develop the ladder diagram, with encoder signal filters (S.5, S.6, S.7) set to zero milliseconds to eliminate latency. The hardware settings were configured for Nano V5 with a baud rate of 9600 and Modbus address 1. A baud rate of 9600 was selected to ensure compatibility with LabVIEW's polling interval and avoid buffer overflow. After successful compilation, the program was tested to ensure error-free execution.

LabVIEW was employed to visualize the control system's behavior using the DSC Toolkit, which enabled Modbus communication with the simulated microcontroller. The LabVIEW interface was designed to display fourteen holding register values, including PV, SP, proportional gain (K_p), integral gain (K_i), derivative gain (K_d), control interval, error metrics, and output signals. The COM port used in LabVIEW was paired with the COMPIM port in Proteus to ensure synchronized data exchange.

The simulation was executed by adjusting the potentiometer in Proteus to vary the setpoint, while LabVIEW captured and plotted the corresponding control response. This setup allowed for real-time observation of PID dynamics and facilitated iterative tuning of control parameters. All components were tested under consistent conditions to validate system performance and ensure reproducibility of results.

The control circuit was designed in Proteus to emulate the positional PID system using Outseal Nano hardware. This configuration included encoder inputs, motor driver outputs, and serial communication

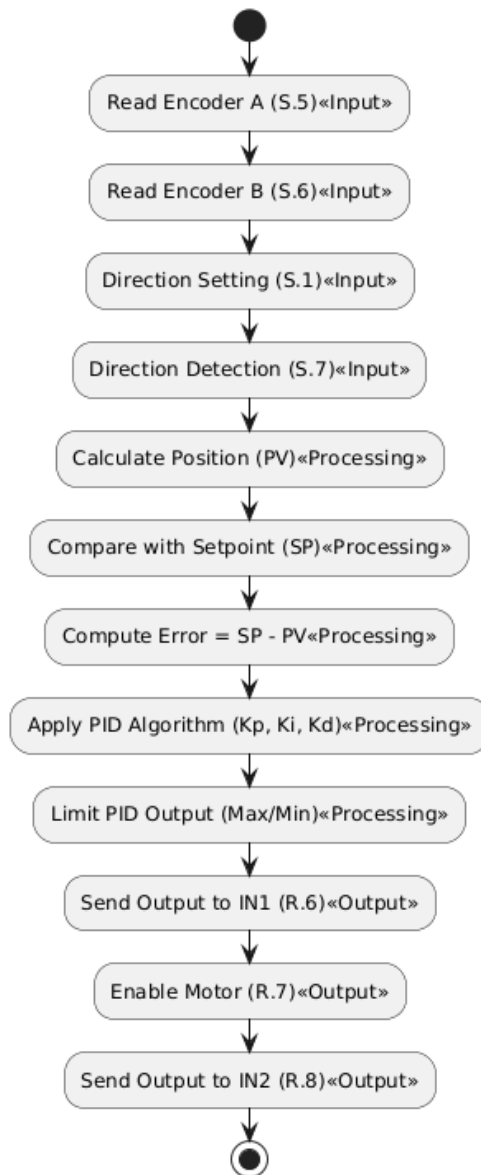


Fig. 2 Flowchart of ladder diagram developed in Outseal Studio for positional PID control.

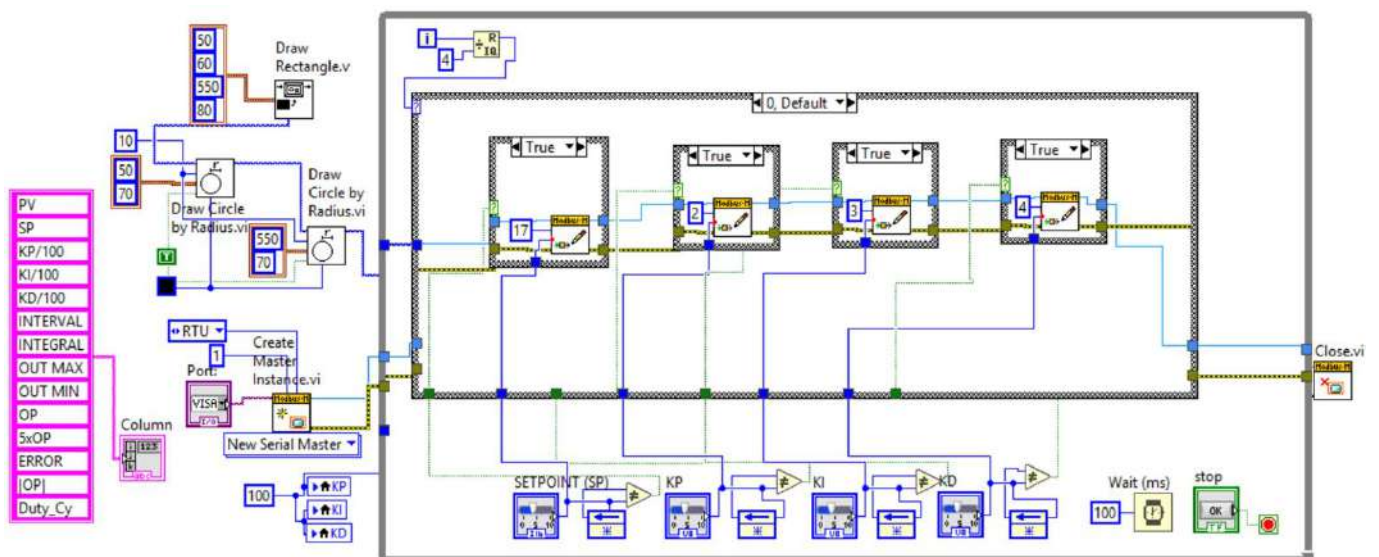


Fig. 3 LabVIEW block diagram of the positional PID control system.

Table 1. Mapping of holding registers (I.1–I.14) used in the Outseal Nano PID control system.

Register Address	Label	Description	Unit / Scaling
I.1	PV	Process Variable (encoder feedback)	Raw count
I.2	SP	Setpoint (desired position)	Raw count
I.3	Kp	Proportional gain	Value ÷ 100
I.4	Ki	Integral gain	Value ÷ 100
I.5	Kd	Derivative gain	Value ÷ 100
I.6	Interval	Control interval	Value × 10 ms
I.7	Integral Error Limit	Maximum allowed integral accumulation	Raw count
I.8	PID Output Max	Upper limit of PID output	Raw count
I.9	PID Output Min	Lower limit of PID output	Raw count
I.10	PID Output	Real-time PID output	Raw count
I.11	5×PID Output	Scaled PID output	PID Output × 5
I.12	Error	SP – PV	Raw count
I.13	Absolute PID Output	Absolute value of PID output	Raw count
I.14	Duty Cycle	PWM duty cycle applied to motor	Parts per thousand (ppt)

III. RESULTS

The simulation of the positional PID control system using Outseal Nano, Proteus, and LabVIEW yielded consistent and interpretable outcomes across multiple test scenarios. Upon initiating the system, the LabVIEW interface successfully captured and displayed all fourteen holding register values in real time, including SP, PV, error, PID output, and duty cycle. The graphical output demonstrated smooth tracking behavior, with the PV converging toward the SP under varying conditions, confirming the stability and responsiveness of the control loop.

Adjustments to the potentiometer within the Proteus environment resulted in immediate changes to the SP, which were accurately reflected in the LabVIEW monitoring panel. The PID output adapted proportionally, and the error signal exhibited expected transient behavior before settling. The system maintained consistent performance across different gain configurations, with no observable oscillations or overshoot when the PID parameters were tuned within recommended ranges. The absence of filtering delays, achieved by setting the encoder signal filters to zero milliseconds, contributed to the clarity and precision of the feedback response.

The compiled ladder logic program executed without errors, and the Modbus communication between the simulated ATmega328 microcontroller and LabVIEW remained stable throughout the simulation. The use of virtual COM port pairing ensured uninterrupted data exchange, and no latency or packet loss was detected during runtime. These results validate the effectiveness of the integrated simulation framework and confirm its suitability for replicating real-world control behavior in a virtual environment. The system's modularity and transparency in data flow further support its application in educational and prototyping contexts, where iterative testing and parameter tuning are essential.

During the simulation, the system's dynamic response to varying setpoint inputs was visualized using the LabVIEW front panel. The graph displayed the real-time trajectory of the PV in relation to the SP, allowing for direct observation of tracking accuracy and control stability. As shown in Figure 4, the PV closely follows the SP curve with minimal delay, confirming the effectiveness of the PID tuning and the integrity of the feedback loop.

To evaluate the influence of PID gain parameters on system performance, multiple simulation trials were conducted with varying values of K_p , K_i , and K_d . Each configuration was assessed based on its ability to minimize error, stabilize the PV, and produce a smooth control output. The comparative results of these trials are summarized in Table 2, which highlights the relationship between gain settings and key performance indicators such as rise time, steady-state error, and output stability.

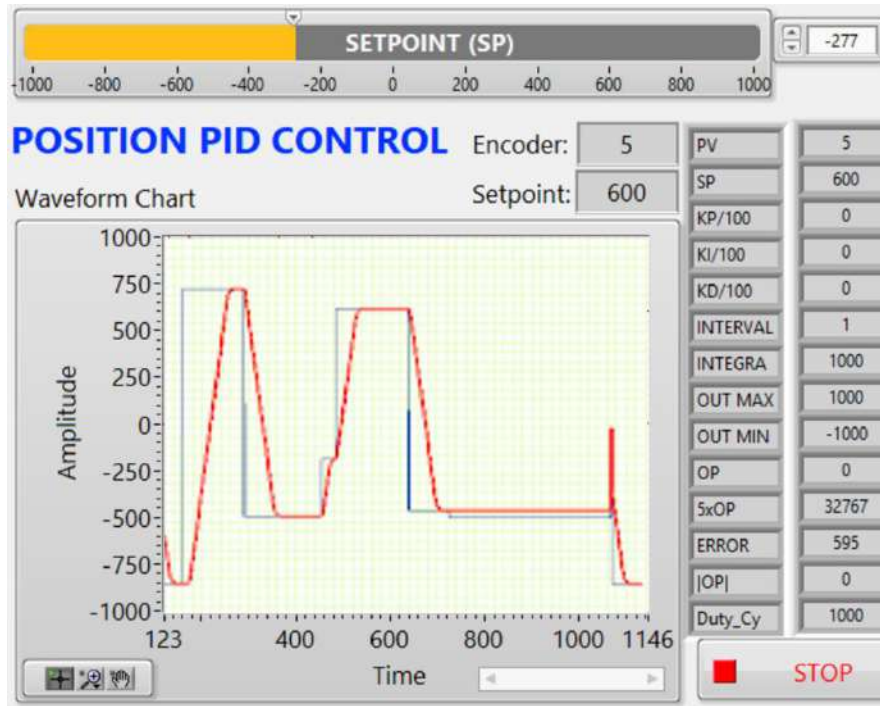


Fig. 4 Real-time graph of PV and SP displayed on the LabVIEW front panel.

Table 2. Simulation results for different PID gain configurations.

Trial	K_p	K_i	K_d	Rise Time (ms)	Steady-State Error	Output Stability
1	1.00	0.50	0.10	820	± 5	Stable, minor overshoot
2	1.50	0.70	0.20	640	± 2	Stable, no overshoot
3	2.00	1.00	0.30	480	± 1	Very stable, fast response
4	2.50	1.20	0.40	420	± 0.5	Slight oscillation observed
5	3.00	1.50	0.50	360	± 0.2	Unstable, high overshoot

IV. DISCUSSION

The simulation results obtained from the integrated Outseal Nano–LabVIEW–Proteus framework demonstrate the viability of virtual prototyping for positional PID control systems. The system responded consistently to dynamic changes in SP, with the PV tracking the desired position and the output adapting accordingly. The graphical interface in LabVIEW provided real-time visualization of key control parameters, including error magnitude, PID output, and duty cycle, enabling intuitive assessment of system behavior. This aligns with prior findings that emphasize the pedagogical and diagnostic value of simulation-based control environments [23].

One of the notable outcomes was the stability of the control loop under varying conditions, which can be attributed to the precise tuning of PID gains and the elimination of signal filtering delays. The use of Outseal Studio’s ladder logic programming allowed for modular configuration of control logic, while the Modbus protocol ensured reliable data exchange between the simulated microcontroller and LabVIEW. Such integration has been shown to enhance system responsiveness and reduce latency in control feedback loops [24].

The absence of physical hardware in this simulation did not hinder the fidelity of the control response. On the contrary, the virtual setup enabled rapid iteration and parameter adjustment, which is particularly beneficial in educational contexts and early-stage design validation. This supports the argument that simulation-based PID control can serve as a robust substitute for physical experimentation in certain scenarios, especially when budget or accessibility constraints exist [25].

Furthermore, the modularity of the Outseal Nano platform and its compatibility with standard industrial protocols make it a suitable candidate for scalable control applications. The ability to monitor and

manipulate 14 distinct holding registers in real time provides granular insight into system dynamics, which is essential for advanced tuning and fault diagnosis.

Finally, the successful pairing of virtual COM ports and the seamless communication between Proteus and LabVIEW underscore the importance of software interoperability in modern control system design. The integration of Modbus communication within PID control architectures continues to gain traction, particularly in distributed and networked automation systems [26].

V. CONCLUSION

This study has demonstrated the feasibility and effectiveness of a simulation-based positional PID control system using Outseal Nano hardware integrated with Proteus and LabVIEW. By leveraging ladder logic programming in Outseal Studio and real-time data visualization through the LabVIEW DSC Toolkit, the system successfully emulated a closed-loop control environment capable of responding dynamically to SP variations. The integration of Modbus communication and virtual serial port pairing enabled seamless data exchange between the simulated microcontroller and the monitoring interface, ensuring accurate tracking of control parameters such as PV, error, and output duty cycle.

The simulation confirmed that precise tuning of PID gains and elimination of signal filtering delays contribute significantly to system stability and responsiveness. The ability to monitor fourteen distinct holding registers in real time provided valuable insights into control dynamics, facilitating both educational exploration and pre-deployment validation. Moreover, the modular architecture of the Outseal Nano platform supports scalable experimentation, making it suitable for a wide range of motion control applications. This framework may be extended to conveyor positioning systems, CNC axis control, or automated inspection platforms.

Overall, the methodology presented offers a replicable framework for researchers and educators seeking to implement and analyze PID control systems without the constraints of physical hardware. It underscores the value of simulation environments in accelerating development cycles, enhancing conceptual understanding, and promoting hands-on learning in control engineering. Future work may extend this approach to multi-axis systems, adaptive control strategies, or hybrid hardware-software deployments to further explore the boundaries of simulation-driven automation design.

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Berlin Metropolitan Governance Model: A Case Study in Contemporary Metropolitan Governance

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Abstract – This study examines the metropolitan governance structure of Berlin, Germany’s capital and one of its three city-states, with a focus on its dual-layered system that combines state-level administration with district-level local governance. Through qualitative research supported by a literature review and field interviews with officials from the Berlin Senate, district mayors, and academics, the study explores how this vertically coordinated governance model ensures the division of powers, resource allocation, and policy coordination between the central and local tiers. The Berlin Senate, as the central metropolitan authority, is responsible for strategic policymaking, urban planning, budgeting, and public safety, while twelve autonomous district administrations manage education, social services, and local infrastructure. The Council of Mayors (Rat der Bürgermeister) plays a crucial role in ensuring coordination between these two tiers, serving as a mechanism for dialogue and collaborative policymaking. Furthermore, the study highlights Berlin’s partnership with the state of Brandenburg in the Berlin-Brandenburg Metropolitan Region as an example of inter-state metropolitan cooperation in Europe.

The findings suggest that Berlin’s governance model aligns closely with Anwar Shah’s concept of “Vertically Coordinated Metropolitan Governance.” While the system demonstrates strong central coordination, efficient service delivery, and structured cooperation, challenges such as fiscal dependency of districts and complex decision-making processes remain. Overall, the Berlin case contributes to comparative metropolitan governance literature by illustrating a mature two-tier model balancing central authority and local autonomy within a federal context.

Keywords – Berlin, Metropolitan Governance, Two-Tier System, Multilevel Governance, Council Of Mayors, Fiscal Federalism, Anwar Shah, Comparative Public Administration.

I. INTRODUCTION

BERLIN METROPOLITAN GOVERNANCE MODEL:

Berlin, as the capital of Germany and a city-state with its own federal status, plays a significant role in Germany's federal structure. The governance system of Berlin is multi-layered, comprising both a metropolitan administration model and district-level local governments. This structure facilitates a clear division of responsibilities and powers between the central Berlin Senate (the metropolitan administration) and 12 district administrations, ensuring efficient and effective service delivery across Berlin's various regions.

II. BERLIN'S GOVERNANCE STRUCTURE: A STATE AND METROPOLITAN AREA

Berlin's governance model is based on two primary levels: the central metropolitan administration (Berlin Senate) and 12 independent district administrations. As we can guess, this structure balances the implementation of city-wide policies by the central government with local service delivery. Berlin's unique governance system is shared only by Hamburg and Bremen within Germany, which also follow a city-state model.

The central administration – in this case I mention the Berlin Senate - is responsible for setting and enforcing policies at the state level. The Senate consists of several senators, each overseeing specific public services. The Governing Mayor (Regierender Bürgermeister) serves as the head of the Senate and the top political leader of Berlin.

At the district level, 12 districts manage local services, each headed by a district mayor who is monitored by the local district council. The districts exercise autonomy in services such as education, social services, and local infrastructure, while working in coordination with the metropolitan administration.

A. BERLIN SENATE: CENTRAL GOVERNANCE FUNCTIONING

The Berlin Senate is essentially the command center for the city-state's government. It's led by the Governing Mayor, who not only shapes the city's policies but also makes sure the Senate's decisions are carried out effectively.

The Senate juggles a wide range of critical responsibilities. One of its biggest jobs is managing housing and urban planning, where it's trying to tackle Berlin's housing crisis with large-scale renewal efforts and sustainable development projects. Keeping the city safe is another key function; the Senate oversees the entire justice system and law enforcement, from the police to public order services.

Of course, they also hold the city's purse strings. The Senate is responsible for drafting and managing Berlin's annual budget, deciding how public funds are allocated. It also directs the city's transport and infrastructure, pushing for the expansion of public transit and roadways while keeping environmental sustainability in mind.

To make all this happen, the Senate doesn't operate in a vacuum. It works in constant collaboration with the city's different districts to ensure major projects are coordinated smoothly across Berlin.

B. District Administrations: Local Governance and Responsibilities

Berlin is carved up into 12 different districts, and you can think of them as the city's autonomous local administrative engine. Each one operates pretty autonomously, complete with its own local council, and their core job is to handle the services that matter most to the neighborhood residents.

The district's plate is full with things like:

Local Education Services: They're the ones managing the basics—everything from primary and secondary schools to youth centers and childcare facilities.

Social Services: They're responsible for delivering essential support for children, the elderly, and other social groups, often custom-tailoring these services based on the specific needs of their locale.

Local Infrastructure: Keeping the neighborhood running falls to them, too. That means maintaining the streets, local transport, and all the public parks.

Culture and Sports: They make sure residents have access to activities by managing sports centers and organizing local cultural events.

While they have their own budgets and run their local show, the districts constantly coordinate with the wider metropolitan government to keep their local policies in sync with the city's overall goals.

C. Council of Mayors (RdB) and Cooperation Mechanisms

The primary way the local districts and the Berlin Senate keep in step is through the Council of Mayors (RdB), which is actually chaired by the Governing Mayor. You can picture this group as the essential bridge between the local and central governments, making sure communication flows smoothly.

The RdB has a few key functions:

Policy Consultation: The district mayors weigh in on policies the Senate puts forward, lending their local insight and discussing how things will look once implemented on the ground. They basically give the Senate a reality check.

Inter-District Coordination: This is vital for city-wide projects, especially those concerning things like housing or transportation. The RdB ensures that all the districts are collaborating and not tripping over each other.

Resource Allocation: The council has a massive say in determining how resources are distributed across all districts, making sure that funding is aligned fairly with their unique needs.

D. Collaboration with the Berlin-Brandenburg Metropolitan Region

Berlin doesn't exist in a bubble; it's completely encircled by the state of Brandenburg. Because of this, the two states work closely together within the Berlin-Brandenburg Metropolitan Region. This isn't just a friendly arrangement; it's a critical partnership for economic and administrative success.

Their joint projects zero in on a few major areas:

Public Transport and Mobility: They collaborate on expanding transport links and integrating public transit systems between Berlin and Brandenburg so people can move freely.

Economic Development and Housing: They work on shared strategies for affordable housing and economic growth across the entire metropolitan region.

Environmental Sustainability: The two states team up on green initiatives, including protecting shared green spaces and pushing for better energy efficiency and renewable energy.

E. The Role of the Governing Mayor and the Berlin Senate

The Governing Mayor of Berlin is the top executive authority in the city-state, responsible for setting and implementing policies, appointing Senate members, and overseeing the government's operations. The Mayor of Berlin is the mechanism representing Berlin on all international platforms. The mayor is responsible for spearheading all large-scale projects in the state. The members of the Senate or senators each lead policy in a specific area, such as transportation, infrastructure, public safety, financial management, etc. Another institutional task of the Senate is to coordinate between the districts, which are the lower tier municipalities in Berlin's two-tier metropolitan government model, and the metropolitan municipality, which is the main tier.

F. Interaction Between Central and District Governments

The governance structure of Berlin as a metropolitan area is a two-tier model consisting of a central metropolitan government (Berlin Senate) and 12 district governments. This model allows the Senate to focus on city-wide policies, while the district municipalities focus on local services. The division of responsibilities for municipal services within the two-tier structure ensures that local governments are responsive to the needs of the community, while the Senate manages a number of major issues such as broader urban planning and policy development.

G. Task Distribution Between the Senate and District Administrations

The Berlin Senate oversees city-wide policies, while district administrations focus on local service delivery. The main areas of responsibility include:

- **Berlin Senate:** Strategic policy-making, budget management, public safety, transportation, and city-wide infrastructure projects.
- **District Administrations:** Local education, social services, infrastructure management, and cultural activities.

With such a division of tasks, the Senate generally focuses on city governance at a larger scale, while district governments focus on responding to emerging local needs. In this context, it can be said that district governments are very sensitive to the principle of subsidiarity.

H. Resource Allocation Between Districts and the Central Government

One of the most critical issues in Berlin's governance model based on the principle of fiscal federalism is the issue of resource allocation. The general budget is essentially controlled by the Senate. The Senate allocates funds to the districts, which are lower-tier municipalities, taking into account a number of criteria such as population density, social service needs and infrastructural requirements.

- Central Budget and District Funding: In proportional terms, the Senate allocates a significant proportion of the budget to district municipalities that already have their own local revenues through a number of fees and taxes.

- Criteria for Resource Distribution: Resource allocation is planned and implemented annually. Distribution is made taking into account differences in financial needs and regional needs.

On the face of it, this model seems to have ensured the functionality of both central and local government elements in Berlin by ensuring that financial resources are distributed fairly in accordance with the principle of subsidiarity.

III. CONCLUSION

Berlin's multi-layered governance structure resembles the existing metropolitan model in Turkey. However, a more robust cooperation mechanism between central and local governments, such as the Council of Mayors, stands out in Berlin. Establishing similar councils in Turkish metropolitan cities could enhance coordination between district municipalities and metropolitan municipalities. Especially for metropolitan municipalities to better observe local needs in central projects, adopting this model may be significant.

Berlin: Vertically Coordinated Metropolitan Governance

Based on the field research and the existing governance structure, Anwar Shah's classification of Berlin as a "Vertically Coordinated Metropolitan Governance" is accurate. Berlin operates under a two-tiered coordination-based governance model, as Shah has described. Thus, his classification for Berlin appears to be well-founded and consistent.

A. Strengths:

1. Strong central administration
2. Effective public service delivery
3. Regular cooperation
4. Strategic resource allocation

B. Weaknesses:

1. Ineffective decision-making processes
2. Financial dependency (of districts)
3. Political influences.

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Copenhagen Metropolitan Governance Model: A Case Study in Contemporary Metropolitan Governance

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Abstract – This study examines Copenhagen’s metropolitan governance model, focusing on its horizontally coordinated two-tier structure and its integration within the Greater Copenhagen and Øresund Region frameworks. Drawing on qualitative field research and literature analysis, it explores how Copenhagen combines democratic representation, committee-based administration, and regional cooperation mechanisms. The City Council, consisting of 55 elected members, acts as the central decision-making body responsible for budgeting, planning, and policy approval. Governance operates under a multi-mayoral system led by the Lord Mayor and six specialized mayors overseeing committees on economy, health, education, culture, and environment.

Citizen participation forms another cornerstone of the model, supported by advisory councils representing youth, seniors, people with disabilities, and environmental groups—enhancing democratic inclusivity and transparency. At the metropolitan scale, the Greater Copenhagen collaboration unites 85 municipalities and four regional governments across Denmark and Sweden, fostering innovation, sustainability, and competitiveness. The Øresund Region partnership between Copenhagen and Malmö further strengthens cross-border economic, cultural, and infrastructural integration through joint projects such as the Øresund Bridge and green development initiatives.

Findings suggest that while Anwar Shah’s categorization of Copenhagen as a “Horizontally Coordinated Mandatory Two-Tier Metropolitan Governance” captures key traits, coordination in practice remains largely voluntary. The Copenhagen case illustrates a cooperative and consensus-oriented governance model that balances autonomy, inclusivity, and sustainability—offering valuable insights for other metropolitan regions seeking effective, democratic, and environmentally responsible governance.

Keywords – Copenhagen, Metropolitan Governance, Two-Tier System, Horizontal Coordination, Greater Copenhagen, Øresund Region, Sustainability, Anwar Shah, Public Administration.

I. INTRODUCTION

COPENHAGEN METROPOLITAN GOVERNANCE MODEL:

The Copenhagen Metropolitan Administration currently operates using the framework outlined below which includes administrative elements dedicated to overseeing the city’s management effectively:

A. City Council (Borgerrepræsentationen)

The City Council of Copenhagen holds the authority, in decision making for the city. Plays a vital role in governing affairs there. It is responsible for setting policies directing strategies and budget allocations that shape the management of Copenhagen. Furthermore the City Council has the decision making power, over projects and important choices concerning city governance.

Duties and Responsibilities of the City Council

So, who actually gets to make the big decisions about running the whole city? That top-level authority sits squarely with the City Council, making it the ultimate decision-making body for all matters concerning overall governance. What kind of critical responsibilities fall under their umbrella? They include.:

1. **Preparing and Approving the Budget:** For starters, the Council holds the city's purse strings. They're tasked with meticulously drafting the entire annual budget and giving final approval for all major spending. This includes everything from funding crucial infrastructure projects to ensuring money is available for vital social welfare services.
2. **City Planning and Approval of Major Projects** Beyond the budget, the Council is the body that essentially gives the final sign-off on every major infrastructure development and city project. They approve crucial initiatives that span various areas, such as building new roads, managing environmental planning, and getting those huge, large-scale development initiatives off the ground.
3. **Election of Mayors:** Finally, the Council is also the body that handpicks and appoints the mayors responsible for different sectors of city management—delegating authority over crucial areas like the economy, health, culture, and social services.
4. **Oversight of Committee Decisions:** Several committees operate in Copenhagen, each making decisions within their fields. The City Council oversees these decisions and intervenes when necessary to maintain balance and accountability.
5. **Approval of Administrative Decisions:** As a final check, even the major decisions and proposals drafted by those sectoral mayors must be submitted right to the City Council. This is done to ensure that every key strategic move is ultimately endorsed by the public's elected representatives.

6. Structure of the City Council

The City Council is composed of members who represent the various segments of the city's population:

- **Number of Members:** The council consists of 55 members elected through democratic elections across the city.
- **Term Duration:** Members are elected for a four-year term. Every four years, citizens elect council members in local elections.
- **Representation:** These members serve as direct representatives of Copenhagen's citizens, bringing the needs and demands of their electoral districts to the council.

B. The Mayoral System

Copenhagen's municipal government runs on a truly democratic engine, but it's certainly not run by just one person. Instead, it relies on a specialized leadership team: one Lord Mayor heads the system, supported by six specialized mayors. Each of these individuals tackles specific fields, handling the heavy lifting for all the city's administrative and political operations.

Structure and Functioning of the Mayoral System

- **Lord Mayor:** The Lord Mayor is the city's highest official, responsible for financial management and city planning. The Lord Mayor heads the Economy Committee, which coordinates Copenhagen's financial operations.
- **Specialized Mayors:** There are six specialized mayors responsible for managing different sectors of the city, such as education, health, and culture.

Each mayor heads a committee that makes decisions related to their sector, which are then presented to the City Council for approval.

C. Committees

The administrative system gets its real operational power from seven dedicated committees, each with its own specific focus. These groups tackle the day-to-day service operations and the big development projects, meaning they essentially call the shots on major decisions within their domains. Crucially, these committees aren't run by just anyone; they're led directly by those specialized mayors, which guarantees a tight, collaborative relationship with the overarching City Council.

Economy Committee: Oversees the city's financial management, including budget planning, public-private partnerships, and major investments.

- **Social Affairs Committee:** Focuses on social services, including aid to disadvantaged groups, disability services, and homelessness.
- **Culture and Leisure Committee:** Manages cultural events, sports activities, libraries, museums, and tourism.
- **Transport and Technical Affairs Committee:** Responsible for transportation, infrastructure, and environmental regulations.
- **Health and Care Committee:** Manages health services, elderly care, and public health initiatives.
- **Education Committee:** Administers educational services from preschool to high school and supports youth centers.
- **Employment and Integration Committee:** Manages employment policies and immigrant integration programs.

D. City Administrations (Forvaltninger)

Each committee operates through corresponding city administrations responsible for the day-to-day execution of decisions and services.

- **Economy Administration:** Manages the city's financial resources, including investment strategies and long-term economic planning.
- **Social Services Administration:** Provides services to disadvantaged groups, including poverty relief, rehabilitation, and social welfare programs.
- **Technical and Environmental Administration:** Oversees infrastructure, city planning, and environmental sustainability.
- **Health and Care Administration:** Provides health services, elderly care, and public health programs.
- **Education Administration:** Manages educational institutions and supports youth development.

E. Advisory Councils

When it comes to making decisions, Copenhagen doesn't just stick to the officials. The city actively engages its residents by setting up diverse citizen panels that accurately reflect every social and demographic part of the population. This approach is their guarantee: it ensures a genuinely wide range of community voices are heard and considered when they're shaping new policies and enhancing existing services.

The key advisory councils include:

1. **Youth Council (Ungdomsråd KBH):** Involves young citizens in decision-making on issues such as education, sports, and cultural activities.
2. **Seniors Council (Ældreråd):** Represents the elderly and advises on healthcare, social services, and public accessibility for seniors.
3. **Disability Council (Handicaprådet):** Focuses on accessibility and services for disabled individuals.
4. **Volunteer Council (Frivilligrådet):** Promotes volunteer activities and strengthens cooperation between the municipality and civil society.
5. **Green Council (Grønt Råd):** Works on environmental protection and sustainability projects.
6. **Vulnerable Individuals Council (Udsatterådet):** Represents marginalized groups such as the homeless and those with substance abuse problems.
7. **Visual Arts Council (Rådet for Visuel Kunst):** Supports artistic projects and advises the municipality on art acquisitions.
8. **Copenhagen Student Council:** Engages students in shaping educational policies and youth projects.
9. **Borgercenter Handicap User Council:** Focuses on improving services for individuals using disability services.
10. **Social Home Care User Council:** Ensures that the voices of those receiving home care services are heard in policy improvements.

F. Planning Processes

Copenhagen's governance includes a robust planning system at four levels—national, regional, municipal, and local—to ensure sustainable development.

- **National and Regional Planning:** National directives guide city development, while regional plans coordinate major projects.
- **Municipal Planning:** The city develops 12-year municipal plans to guide urban development, social services, and environmental sustainability.
- **Local Planning:** Focuses on detailed development plans for specific neighborhoods, ensuring community involvement.
- **Strategic Goals:** Priorities include economic growth, environmental sustainability, and the expansion of social services.

G. Elections and Representation

City Council members are elected for four-year terms through democratic local elections. The elected members form various committees specializing in areas like economy, health, and transport. Mayors are not directly elected but are appointed from among the City Council members to manage different sectors of the city's operations.

I. Greater Copenhagen and Øresund Region

Greater Copenhagen Region

Greater Copenhagen is a large business and living region that unites Denmark's capital, Copenhagen, and surrounding areas with the Skåne and Halland regions in southern Sweden. With a population of

approximately 4.4 million and a vast economic activity area, it is considered one of Northern Europe's most important metropolitan regions. The Greater Copenhagen collaboration is a comprehensive project aimed at cross-border growth, innovation, sustainable development, and a high quality of life.

Greater Copenhagen Collaboration

This regional collaboration, established in 2015, includes 85 municipalities and 4 regional governments from Denmark and Sweden. Greater Copenhagen is a strategic partnership between the two countries' administrations, aimed at fostering economic growth, attracting international investments, and enhancing competitiveness. The cooperation among cities, businesses, and educational institutions within the region forms the foundation of Greater Copenhagen's strength.

Economic and Social Goals

What's the main goal for Greater Copenhagen? It wants to become the destination—not just for major business deals, but for families looking to live there and students chasing a world-class education. They really roll out the red carpet for global companies and innovative startups, and at the same time, they're focused on cultivating a deep pool of homegrown talent. It's a two-pronged approach.

To support this growth, there's a constant, ongoing push to upgrade infrastructure and public services. This focus on the fundamentals is what pulls in major investors and, in the long run, ends up lifting the standard of living for everyone in the region.

When you look at what powers the local economy, it really boils down to a few key sectors where they have a real competitive advantage. You'll find their strengths concentrated in biotech, cutting-edge IT, sustainable and green energy solutions, and a robust transportation and distribution network.

Sustainable Development and Green Growth

Copenhagen and the broader region have made eco-friendly policy and sustainable growth the absolute cornerstone of their economic planning. They don't just pay lip service to these ideas—they walk the walk. You see this in their relentless push for energy conservation and the powerful backing they give to green tech innovation. Their mission is straightforward: to champion renewable energy and drive a sharp, significant reduction in the area's carbon footprint.

The Øresund Region

There is no doubt that the Øresund Region is a one-of-a-kind place, seamlessly spanning from Copenhagen in Denmark over to Malmö in Sweden. Ever since the iconic Øresund Bridge was completed in 2000, popping over between these two cities has become incredibly straightforward.

But this isn't just a travel story. The bridge has been a total game-changer for Greater Copenhagen's growth, supercharging international trade and effectively merging the two local job markets into one. What really makes the area tick, though, is its power to attract skilled people. This is largely thanks to its fantastic universities and research centers, which keep the engine of innovation running.

So, when you look at the big picture, linking Copenhagen and Malmö did more than just strengthen the economy. It deeply intertwined their trade and labor forces, sparked countless new business opportunities, and truly brought the people from both sides closer together, both culturally and socially.

Key Features:

- The Copenhagen-Malmö metro line aims to increase daily traffic and economic interaction between the two cities.
- Significant investments are being made in improving transportation and sustainable energy projects within the region.

Strategic Priorities and Future Goals

The upcoming strategic objectives of Greater Copenhagen are centered around establishing the region as a frontrunner, in innovation while also prioritizing sustainability and attracting increased investments. The region places an emphasis on partnering with global organizations, in the realms of education and research and attracting talented professionals to strengthen its workforce. Additionally Greater Copenhagen's focus on digitalization and technological advancements is geared towards readying itself for the evolving job landscape of the future.

II. CONCLUSION

Copenhagen: Horizontally Coordinated Mandatory Two-Tier Metropolitan Governance

While Anwar Shah's classification of Copenhagen as a "Horizontally Coordinated Mandatory Two-Tier Metropolitan Governance" is partly correct, field research suggests that there is limited evidence of mandatory coordination within the system. Although there are horizontal networks to some extent, the governance system in Copenhagen seems to function more through a consensus-driven, "win-win" approach, where issues are often resolved locally through autonomous means. The existence of autonomous municipalities supports the idea that mandatory coordination is not a strong feature in the Copenhagen model. Therefore, Shah's classification is only partially accurate here.

Copenhagen

A Strengths:

- 1 Multi-presidency model enabling collaborative multi-stakeholder governance
- 2 Transparency in governance and spending
- 3 Allocation of tax revenues to local entities
- 4 Consensus culture

B Weaknesses:

- 1 Lack of clear boundaries for the metropolitan area (autonomous regions and municipalities)
- 2 Coordination issues between lower and higher levels
- 3 Lack of horizontal coordination.

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Mechanical And Morphological Properties Of Okro Bast Fibre/Rice Husk Particle Reinforced Unsaturated Polyester Hybrid Composites

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Abstract – This study investigates the development and characterization of hybrid composites using treated okro bast fibre (TOBF) and rice husk (RH) as reinforcements in an unsaturated polyester resin (UPR) matrix. These agricultural by-products were selected for their abundance, cost-effectiveness, and eco-friendliness, supporting sustainability and waste valorization. The okro bast fibres were chemically treated and composites were fabricated with a constant total filler loading of 9 wt%, varying the TOBF/RH ratio (e.g., 1:8, 4.5:4.5, 6:3). The mechanical properties and morphological characteristics of the hybrid composites were evaluated and compared to single-filler composites and the neat resin. The results demonstrated that hybridization led to synergistic improvements in properties. The composite with a balanced 4.5% TOBF / 4.5% RH formulation exhibited the highest tensile strength (25.9 MPa) and flexural strength, attributed to enhanced interfacial adhesion and uniform filler dispersion. The maximum tensile modulus (3.52 GPA) and impact strength were achieved at the 6% OBF / 3% RH formulation. Scanning electron microscopy (SEM) analysis confirmed good dispersion and compatibility between the fillers and the matrix in the optimal hybrid compositions. The study concludes that hybrid composites of TOBF and RH offer a promising, sustainable pathway for producing engineering materials with enhanced mechanical performance for applications in construction, packaging, and automotive components.

Keywords – Hybrid Composites, Treated Okro Bast Fibre, Rice Husk Particles, Unsaturated Polyester Resin.

I. INTRODUCTION

Hybrid composites reinforced with natural fibres and agricultural residues have received growing attention in recent years because of their cost-effectiveness, eco-friendliness, and contribution to sustainability. The combination of two or more reinforcements through hybridization often results in superior mechanical, thermal, and physical properties compared to composites reinforced with a single fibre [1]. In this context, okro (*Abelmoschus esculentus*) bast fibre and rice husk are notable reinforcement options, especially in Nigeria where both materials are widely available as agricultural by-products. Experimental investigations on okro bast fibre sourced from Nigerian farms for instance, from Kano State have shown that hand-laid epoxy and resin composites containing okro fillers demonstrate enhanced stiffness and acceptable physical properties, making them suitable for low-load structural and non-structural applications in construction, packaging, and automotive components.

Among various natural fibres, okro bast fibre has emerged as a strong candidate due to its abundance, biodegradability, and favorable tensile properties [2]. Bast fibres, which are extracted from the outer layers of plant stems, consist mainly of cellulose, hemicellulose, lignin, and pectin. These constituents contribute both to their mechanical strength and to their compatibility with polymer matrices [2]. Because of its high

cellulose content and good tensile behavior, okro bast fibre is considered an effective reinforcing agent in polymer-based composites [3]; [4].

Rice husk (RH), another abundant agricultural by-product obtained during rice milling, has also gained prominence as a reinforcing material. It is inexpensive, renewable, and particularly rich in silica, making it useful as a filler in polymer composites and, when calcined, as rice husk ash (RHA) in cement-based systems. Incorporating RH or RHA into composites not only addresses agricultural waste management but also reduces reliance on synthetic fillers while enhancing material performance and reducing environmental impacts [5]. The presence of silica, cellulose, and hemicellulose in RH contributes to its stiffness and thermal resistance [6].

The integration of okro bast fibre with rice husk in hybrid composite systems offers the possibility of achieving a balance of stiffness, strength, and toughness. When adequately treated, such hybrids can also overcome issues such as moisture absorption and weak interfacial adhesion [7]. Consequently, hybrid composites made from okro bast fibre and rice husk represent a sustainable pathway for converting agricultural residues into advanced engineering materials. These composites are particularly beneficial for developing economies, providing eco-friendly solutions for packaging, construction, and automotive applications while advancing circular economy goals through the valorization of agricultural waste. The objectives of this paper are to: -

1. Assess the synergistic effects of combining okro bast fibre and rice husk particles compared to single-filler composites.

II. To establish structure property relationships between the mechanical performance and morphological features of the hybrid composites.

II. MATERIALS AND METHOD

Table 1. Materials and their sources

S/N	Material	Source
1	Okro Bast Fibre	Getso, Gwarzo Local Government, kano state
2	Rice Husk	Umza rice mill Km13, Kwanar Dawaki off Zaria Road kano
3	Unsaturated Polyester resin	Olasco chemical company, Zaria Kaduna State, Nigeria
4	Methyl ethyl ketone peroxide	Olasco chemical company, Zaria Kaduna State, Nigeria
5	Cobalt	Olasco chemical company, Zaria Kaduna State, Nigeria
6	Sodium hydroxide	Steve Moor, Kwangila Zaria, Kaduna state Nigeria
7	Acetic Acid	Steve Moor, Kwangila Zaria, Kaduna state Nigeria

Table 2: Sources and model of machines

S/N	MACHINE		MODEL	SOURCE
1	Tensile Machine	Testing	Instron 3366 Co,Ltd	Dept of Polymer and Textile Engineering, Ahmadu Bello University Zaria. (ABU)
2	Flexural Strength Tester (Universal Machine)	Testing	M500-50CT equip with win test analysis version 4.1.6	Dept of mechanical engineering, Bayero University Kano (BUK)
3	Impact Machine: Impact	Testing Resil	Ceas 363	Dept of Metallurgical and Material Engineering, Ahmadu Bello University Zaria (ABU)
4	Scanning Electron Microscope (SEM)		Jeol TM, Model JSM-7600F, Japan	Department of Geology, University of Ibadan

A. Okro Bast Fibre Preparation

The Okro stems were obtained from a small farm in Getso of Gwarzo Local Government area of Kano State. The fibre samples were extracted by water retting method. The okro bark was bundled in ribbon form and was immersed in water retting bath, little pressure was applied to the soaked bundle to ensure that the bark was fully submerged for a period of 10 days during which the cementing materials such as pectin, lignin and hemicellulose must have loosened and softened. On 10th day, the retted ribbon was removed and washed with sufficient quantity of water until the pulp is completely detached from fibres, the fibres were shredded and combed to have finer fibres. Then the fibres were dried at room temperature for a period of fifteen days (15). After drying, the fibres were chopped into short lengths [2].



Figure 2.1: Okro plant



Figure 2.2: Extracted Okro bast Fibre

B. *Alkali Treatment*

Okro bast fibres were soaked in 5% sodium hydroxide solution at 60°C for two hours with continuous stirring. After two hours, the fibres were removed from the solution washed several times and then rinsed with sufficient amount of water. Each batch of treated fibres was neutralized with 1% acetic acid solution to remove excess sodium hydroxide. However, this step helps in balancing the pH and neutralising the residual sodium hydroxide. After neutralisation, the fibres were rinsed again with distilled water and allowed to dry at room temperature for one week [8].

C. *Rice Husk Preparation*

Rice husk was sourced from Umza Rice Mill in Kano State. To remove contaminants such as sand, residual rice grains, and other processing impurities, the husk was thoroughly washed. It was then sun-dried to eliminate moisture content. Afterwards, larger husk fragments were separated from the smaller ones, and the material was ground into fine particles. The resulting rice husk powder was sieved using an STSJ-3 standard sieve shaker to obtain a particle size of 63 µm.

D. *Composites Preparation*

The preliminary test results indicated that a 9% loading of treated okro bast fibre and 9% rice husk fillers were well dispersed within the resin matrix. At this filler proportion, the composites also exhibited improved mechanical performance. Consequently, 9% was chosen as the optimal hybrid filler content. The proportions of treated okro bast fibre and rice husk were then varied within the unsaturated polyester resin matrix. Pure unsaturated polyester resin, along with composites containing 9% okro bast fibre and 9% rice husk separately, were used as control samples throughout the study.



Figure 2.3: Rice Husk

E. Fabrication of Hybrid Composite of Okro Bast Fibre/ Rice Husk /Unsaturated Polyester Resin Composites

To produce the unsaturated polyester resin (UPR) okro bast fibre (TOBF) composite, the required amounts of UPR, cobalt accelerator, and methyl ethyl ketone peroxide (MEKP) catalyst (at 2% of the resin volume) were measured and mixed thoroughly. The appropriate quantity of okro bast fibres was then weighed to achieve a 91:9 weight ratio of UPR to TOBF. The fibres were incorporated into the resin mixture and stirred carefully to ensure even distribution. The resulting mixture was poured into a mold with dimensions of $200 \times 100 \times 40 \text{ mm}^3$, lined with foil paper to facilitate easy removal of the cured composite. The molded samples were demolded and cured under laboratory conditions prior to mechanical testing. For the UPR rice husk (UPR/RH) composites, the same procedure was followed. The required volume of resin, accelerator, and catalyst was first mixed, after which rice husk particles were added in the proportion needed to maintain a 91:9 UPR to RH ratio.

Hybrid composites containing UPR, TOBF, and RH (UPR/TOBF/RH) were also prepared. In this case, measured amounts of resin, accelerator, and catalyst were combined, followed by the addition of okro bast fibres and rice husk particles such that the combined fillers represented 9% of the total weight, maintaining the 91:9 resin-to-filler ratio. The process followed the same molding and curing steps as described above.

Table 3: Formulation For Hybrid Of Tobf/Rh/Upr Composites

S/N	Filler Weight Fraction (%)		Matrix Type (%)	Total (%)
	Okro Bast Fibre	Rice Husk	Unsaturated Polyester Resin	
1	0	0	100	100
2	9	0	91	100
3	0	9	91	100
4	1	8	91	100
5	3	6	91	100
6	4.5	4.5	91	100
7	6	3	91	100
8	8	1	91	100

F. Characterization of the Composites

The characterization of the composites was carried out in line with ASTM standard; the testing of the composites was conditioned at room temperature then subjected to various test.

I. Tensile properties

The tensile strength of the composites was evaluated following ASTM D638 standards, using a gauge length of 40 mm and an applied load capacity of 100 kN. Test specimens with dimensions of $100 \times 10 \times 5 \text{ mm}$ were examined on a tensile testing machine (TM2101-T7) operating at a crosshead speed of 2 mm/min. This standard procedure is suitable for rigid plastic specimens with thicknesses ranging from 1 mm to 14 mm. For each composite type, five samples were tested, and the mean values of the tensile properties were determined.

II. Flexural Test

The flexural test was conducted according to ASTM D790 (2010) using the Universal Testing Machine. The three-point bend test utilizing center loading on a sample supported beam. The flexural test measures the force applied to bend a beam under the loading condition. The specimen lies on a support span and load is applied at the centre by the nose producing three-point bending the flexural strength was calculated using Equation

III. Impact Test

The impact test is conducted to determine the amount of energy required to initiate and propagate a fracture until the specimen completely breaks. It evaluates a material's resistance to impact from a moving pendulum. The Izod test, in particular, is commonly employed to assess the overall toughness of materials. In this method, specimens are prepared with a notch that induces stress concentration, thereby increasing the likelihood of brittle failure. The notch serves to limit plastic deformation and direct the fracture to the region behind it. During testing, the specimen is clamped in position with the notched side facing the pendulum. The pendulum is then released to strike the specimen. The Izod impact test was performed in accordance with ASTM D256, using standard specimen dimensions of 64 mm $\times$ 1.27 mm $\times$ 3.2 mm. Impact strength was calculated by dividing the absorbed impact energy (in joules) by the specimen thickness, with higher values representing greater material toughness.

IV. Morphological analysis

The microstructural characteristics of the composites were examined using scanning electron microscopy (SEM). Tensile-fractured samples were analyzed with a JOEL-JSM 7600F SEM operated at 20 kV and magnifications of 7000 $\times$ and 9000 $\times$, following ASTM E986-04 (2017). Specimens of suitable dimensions were securely mounted on the sample holder within the chamber. Prior to imaging, the surfaces were sputter-coated with a thin layer of platinum to enhance electrical conductivity, achieved using a gold–palladium alloy under an argon atmosphere.

III. RESULTS

Figure 3.1 illustrates the mechanical properties of tensile strength of RH/UPR composites is higher than that of TOBF/UPR composites. This can be explained by the fact that particulate composites generally exhibit superior mechanical properties compared to short-fibre composites, due to the larger surface area available for bonding in particulate systems. It was also observed that the hybrid TOBF/RH/UPR composites demonstrated improved tensile strength relative to the 9% TOBF/UPR and 9% RH/UPR composites. The maximum tensile strength for the hybrid system was recorded at 25.9 MPa for the formulation containing 4.5% TOBF, 4.5% RH, and 91% UPR, which exceeded both the control and the single-filler composites. This improvement is attributed to enhanced interfacial interaction between the fillers and the resin matrix. Comparable results were also reported by [9].

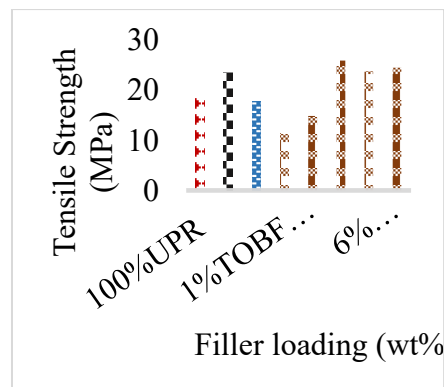


Figure 3.1: Tensile strength of hybrid composites of TOBF/RH/UPR

I. Tensile modulus

Figure 3.2 presents the tensile modulus of TOBF/RH/UPR hybrid composites, with the maximum value of 3.52 GPa recorded at the composition of 6% TOBF, 3% RH, and 91% UPR. The increase in tensile modulus at higher filler loadings is attributed to the greater stiffness of the reinforcing particles compared to the matrix material. As a result, the overall rigidity of the composites improved, leading to an enhancement in tensile modulus. Comparable trends were reported by [10] who investigated raffia palm fibre/groundnut shell particulate reinforced epoxy hybrid composites. Their study showed that the Young's modulus of RPF/75 μ GSP/E and RPF/300 μ GSP/E samples increased with reinforcement content, while a reduction in modulus was observed in RPF/150 μ GSP/E composites. This decrease was linked to the agglomeration of fillers within the matrix.

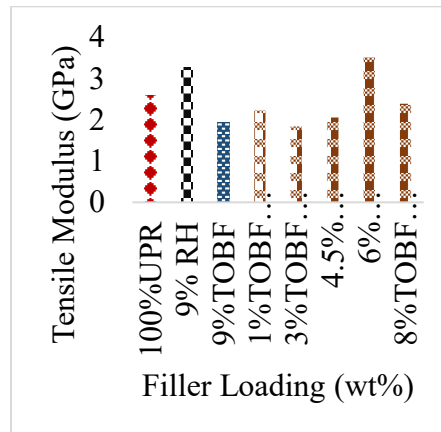


Figure 3.2: Tensile modulus of hybrid composites of TOBF/RH/UPR

II. Elongation at break

The elongation at break of hybrid composites and un-hybridized composites samples were illustrated in figure 3. The highest value of the hybrid composite was obtained at 1% TOBF/8%RH/91%UPR which is greater than all the sample. As the RH particle increased, the percentage elongation also increases. This behaviour could be attributed to the stronger and stiffer characteristics of the Rice husk fibres as compared to the okro fibres. This is in agreement with the findings of [11] on Investigation on mechanical properties of hybrid polymer composite reinforced by rice husks and date palm fibres as a construction material.

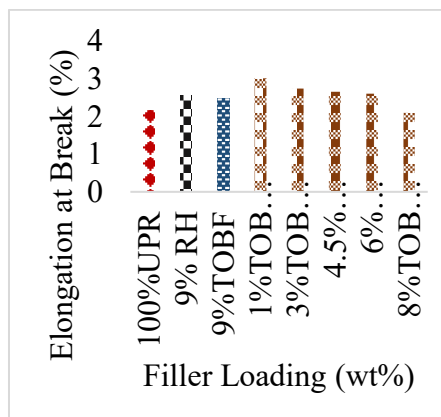


Figure 3.3: Elongation at break of hybrid composites of TOBF/RH/UPR

III. Flexural strength

The flexural strength of hybrid composites of OBF/RH/UPR is illustrated in figure 3 The result revealed the maximum flexural strength was achieved at 4.5% TOBF/ 4.5%RH/91%UPR which is greater than the control sample and the other samples (1:8, 3:6, 6:3 and 8:1 TOBF/RH) of hybrid composites. The highest value indicated greater resistance to deformation, the increase in flexural strength of the hybrid composites is primarily due to uniform dispersion of the fillers within the composites, leading to more homogeneous microstructures which help in sharing applied load effectively thereby improving the strength and resistance to deformation. This result is contrary to the findings of [12] who concluded that the highest value obtain for hybrid composites of glass fibre/rice husk was G25R5 with a value 275.51MPa while the lowest value was obtained at G15R15 with a value of 183.29. The findings are in line with the findings of [9].

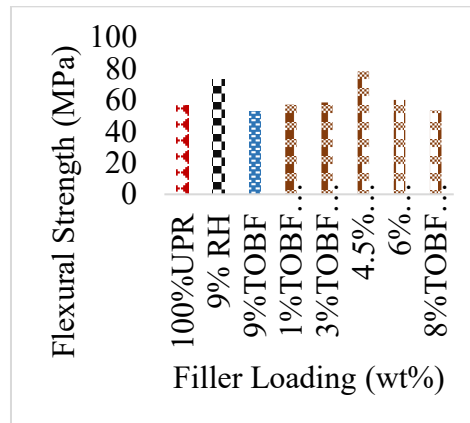


Figure 3.4: Flexural strength of hybrid composites of TOBF/RH/UPR

IV. Flexural modulus

Figure IV depicts the flexural modulus of TOBF/RH/UPR hybrid composites. The results show that the maximum flexural modulus, valued at 0.15 GPa, was achieved with a filler composition of 4.5% TOBF, 4.5% RH, and 91% UPR. The improvement in flexural modulus through hybridization is attributed to the distinct properties and synergistic interactions between TOBF and RH, whereby their combined effect exceeds the performance of each filler used individually. This synergy contributed to enhanced stiffness and greater resistance to bending and deformation. Similar observations were made by [13] who reported that sisal/jute fibre hybrid composites exhibited the highest flexural modulus of 3533 MPa at a 20/20 weight ratio, which surpassed the values obtained at 10/30, 30/10, and in the control sample.

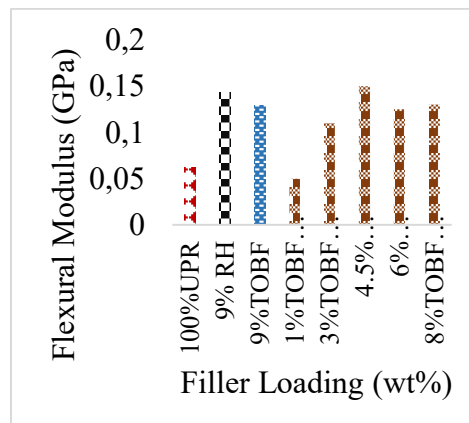


Figure 3.5: Flexural modulus of hybrid composites of TOBF/RH/UPR

V. Impact strength

Figure V depicted the impact strength of hybrid composites of TOBF/RH/UPR. It can be seen that the combination of TOBF/RH/UPR and OBF/RH/ER hybrid composites shows better impact energy. The highest impact strength was obtained at TOBF/RH/UPR with a corresponding value of 0.296 J/m^2 at 6%TOBF3%RH filler loading which is greater than that of the neat and unhybridized composites. The observed increase in impact strength could be attributed to increase in elasticity of the composites thereby increasing the deformability of the matrix material similar findings was reported by [14].

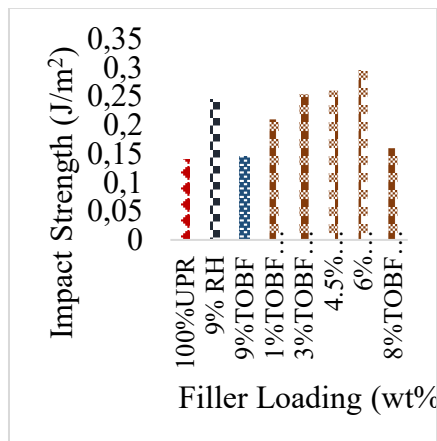


Figure 3.6: Impact strength of hybrid composites of TOBF/RH/UPR

VI. Scanning electron microscope

It can be seen from the micrograph that hybrid composites of unsaturated polyester resin composites showed better dispersion, good compatibility with less or no agglomeration. The fibres are well embedded in the matrix this explain why 4.5% TOBF/4.5%RH/91%UPR and 6%OBF/3%RH/UPR exhibited good tensile strength when compared to un-hybridised composites. Similar result was reported by [15] in their findings on the study of Investigation of mechanical properties of luffa cylindrica fibre reinforced epoxy hybrid composite.

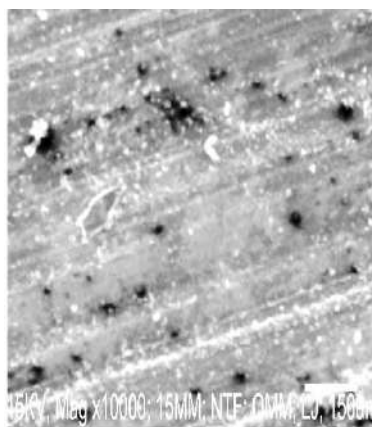


Figure 3.7: SEM Micrograph of Treated Okro Bast Fibre/ UPR Composites

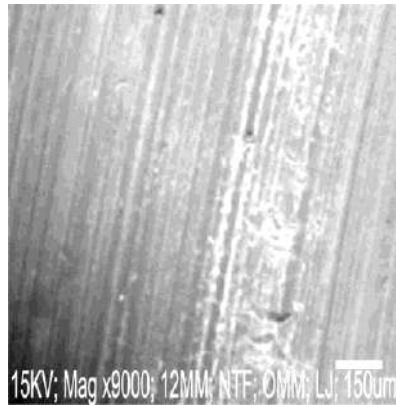


Figure 3.8: SEM Micrograph of RH/UPR Composites at 9% filler Loading (63 μm)

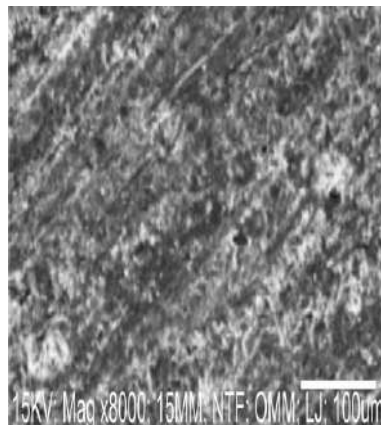


Figure 3.9: SEM Micrograph of TOBF/RH/UPR at (4.5%TOBF/4.5%RH/91%UPR) Hybrid Composites

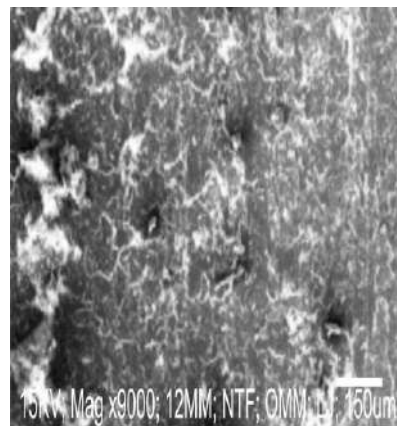


Figure 3.10: SEM micrograph of TOBF/RH/UPR (6%TOBF/3%RH/91%UPR) Hybrid Composites

IV. CONCLUSION

This study concludes that hybrid composites made from treated okro bast fibre (TOBF) and rice husk (RH) offer a promising, sustainable pathway for producing composites materials with improved mechanical properties. The hybridization of these agricultural by-products successfully created composites suitable for practical applications such as construction, packaging, and partition board components. The success is demonstrated by the synergistic improvements in properties, where specific formulations outperformed single-filler composites:

- The balanced 4.5% TOBF /4.5% RH formulation achieved the highest tensile strength (25.9 MPa) and flexural strength.

- The 6%TOBF/3% RH formulation yielded the maximum tensile modulus (3.52 GPA) and impact strength.

These enhancements are attributed to good dispersion, compatibility between the fillers and the matrix, and enhanced interfacial adhesion, as confirmed by morphological analysis

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Frequency Analysis of Smart Sandwich Nanoplates Incorporating TPMS-Auxetic Core and PZT-4H Face Layers Under Thermal and Electromechanical Loads

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Abstract – This study investigates the dynamic, thermal, and electromechanical behavior of smart sandwich nanoplates incorporating a TPMS-auxetic core and PZT-4H piezoelectric face layers. The influence of core thickness, layer ratios, temperature variations ($\Delta T = 0\text{--}1200\text{ K}$), and nonlocal/strain-gradient effects on natural frequencies and thermal stability is systematically analyzed. Results demonstrate that the auxetic TPMS core enhances vibration damping and energy absorption, while coupling with the piezoelectric layers enables active electromechanical control. Temperature rise decreases fundamental frequencies, with thermal buckling predicted near $1700\text{--}1750\text{ K}$. These findings provide practical insights for designing lightweight, high-performance smart plates for aerospace, defense, and energy-harvesting applications.

Keywords – TPMS-Auxetic Core, Smart Sandwich Plate, PZT-4H, Frequency, Thermal Buckling, Electromechanical Behavior.

I. INTRODUCTION

Auxetic materials, defined by a negative Poisson's ratio, manifest distinctive mechanical properties, including lateral expansion under tension, augmented shear resistance, and enhanced energy absorption [1–3]. Triply periodic minimal surfaces (TPMS) are characterized by the presence of periodic open-cell geometries, which leads to the fabrication of lightweight structures that exhibit high stiffness and adjustable mechanical properties [4, 5]. The integration of TPMS-auxetic cores within sandwich plates has been demonstrated to enhance impact resistance, vibration damping, and thermal stability, thereby rendering them suitable for utilization in aerospace, automotive, and defense applications [6].

The incorporation of piezoelectric face layers, such as PZT-4H, facilitates active vibration control, energy harvesting, and real-time structural monitoring capabilities [2, 7]. The interaction between the auxetic core and the piezoelectric layers facilitates adaptive mechanical responses to thermal, mechanical, and electromechanical stimuli [2, 8].

It is evident that most previous research has focused predominantly on static or quasi-static loading. This has resulted in an insufficient examination of the thermal and electromechanical effects in TPMS-auxetic sandwich plates. As demonstrated in the extant literature, size-dependent nanoscale effects, as modelled through nonlocal elasticity and strain-gradient theories, are essential for precise performance predictions [9, 10]. The present study systematically assesses the frequency response, thermal stability, and electromechanical coupling in TPMS-auxetic sandwich nanoplates, providing significant insights for improved design.

II. MATERIALS AND METHOD

A. Sandwich Plate Configuration

The smart sandwich nanoplate examined in this study features a (TPMS)-based auxetic core, symmetrically encased by two piezoelectric face sheets composed of PZT-4H, as illustrated in Figure 1. This multilayered design takes advantage of both structural and functional synergies. The TPMS-auxetic lattice serves to enhance the structural integrity and flexibility, while the piezoelectric layers facilitate active control through electromechanical coupling. The plate's shape is defined using a Cartesian coordinate system, with the x - and y -axes going in the plane directions and the z -axis going in the plate thickness direction. The total plate thickness, h , is defined as follows: a and b are the overall in-plane dimensions.

$$h = 2h_p + h_c \quad (1)$$

Here, h_p stands for the thickness of the top and bottom PZT-4H face layers, and h_c stands for the thickness of the central auxetic core. The PZT-4H layers are well-attached to the auxetic core, which lets stress and electromechanical responses happen exactly as they should. The core is made of Ti-6Al-4V alloy, which has a high stiffness-to-weight ratio and a negative Poisson's ratio. This makes it better at absorbing energy and resisting impact. This design is useful for aerospace, defense, and energy-harvesting uses. A schematic representation of the sandwich nanoplate also shows how the auxetic lattice structure fits in with the PZT-4H layers.

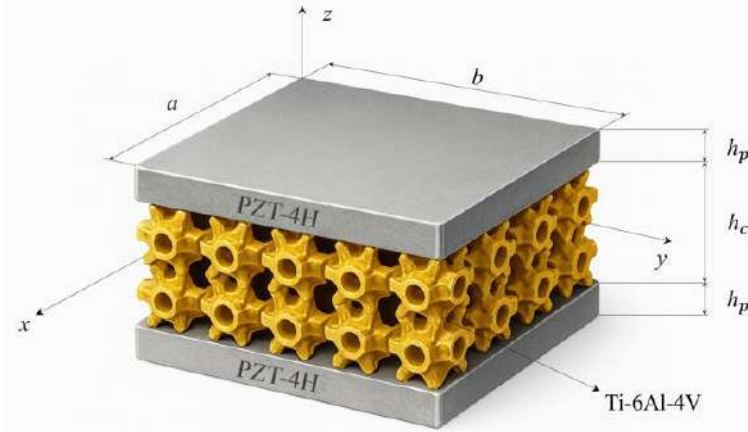


Fig. 1 Schematic of the smart sandwich plate. The structure features a TPMS-Auxetic core made of Ti-6Al-4V (gold lattice) sandwiched between two PZT-4H piezoelectric face layers (metallic).

B. TPMS-Auxetic Core Design

The sandwich plate core is made using a TPMS architecture with a negative Poisson's ratio, which lets it behave in an auxetic way. These shapes can cause strange deformation patterns, like lateral expansion when axial tension is applied. This makes them better at absorbing energy, resisting shear, and damping dynamic forces.

Utilizing empirically derived scaling relations, the effective mechanical properties of these TPMS-based cores can be ascertained, including Young's modulus E , shear modulus G , and Poisson's ratio ν . Table 1 shows all the relationships, which are specific to each topology and depend on V . E^m and G^m are the elastic and shear moduli of the parent solid material, respectively. The formulation considers both linear and nonlinear dependencies on the volume fraction, which lets us accurately predict how the core will behave mechanically in different geometric configurations.

The TPMS lattice is thought to be made of Ti-6Al-4V, a titanium alloy known for its good strength-to-weight ratio, resistance to corrosion, and stability at high temperatures. This is done to model the thermomechanical response of the core. The material properties are defined as temperature-dependent functions using polynomial expressions of up to third order. These functions consider things like thermal

softening and expansion. Table 2 shows the values for the elastic modulus $E(T)$, thermal expansion $\alpha(T)$, Poisson's ratio $\nu(T)$, thermal conductivity $\kappa(T)$, and density ρ .

Table 1. Provided mathematical equations for the efficient mechanical characteristics of the TPMS lattice [6].

TPMS Types	Mechanical characteristics	V
	$E = E^m \begin{cases} 0.317V^{1.264} \\ 1.007V^{2.006} - 0.007 \end{cases}$	$V \leq 0.25$ $V > 0.25$
	$G = G^m \begin{cases} 0.705V^{1.189} \\ 0.953V^{1.715} + 0.047 \end{cases}$	$V \leq 0.25$ $V > 0.25$
	$\nu = \begin{cases} 0.314e^{-1.004V} + 0.119 \\ 0.152V^2 - 0.235V + 0.383 \end{cases}$	$V \leq 0.55$ $V > 0.55$
	$E = E^m \begin{cases} 0.596V^{1.467} \\ 0.962V^{2.006} + 0.038 \end{cases}$	$V \leq 0.45$ $V > 0.45$
	$G = G^m \begin{cases} 0.777V^{1.544} \\ 1.037V^{1.982} + 0.027 \end{cases}$	$V \leq 0.45$ $V > 0.45$
	$\nu = \begin{cases} 0.192e^{-1.349V} + 0.202 \\ 0.402V^2 - 0.603V + 0.501 \end{cases}$	$V \leq 0.50$ $V > 0.50$
	$E = E^m \begin{cases} 0.597V^{1.225} \\ 0.987V^{1.782} + 0.013 \end{cases}$	$V \leq 0.35$ $V > 0.35$
	$G = G^m \begin{cases} 0.529V^{1.287} \\ 0.960V^{2.188} + 0.040 \end{cases}$	$V \leq 0.35$ $V > 0.35$
	$\nu = \begin{cases} 2.597e^{-0.157V} - 2.244 \\ V^2 - V \end{cases}$	$V \leq 0.13$ V

Table 2. Temperature-dependent coefficients for the properties of Ti-6Al-4V [11].

Materials	Properties	P_{-1}	P_0	P_1	P_2	P_3
Ti-6Al-4V	E (Pa)	0	122.56×10^9	-4.586×10^{-4}	0	0
	α (1/K)	0	7.578×10^{-6}	6.638×10^{-4}	-3.147×10^{-6}	0
	ν	0	0.2884	1.121×10^{-4}	0	0
	κ (W/mK)	0	1	-1.74×10^{-2}	0	0
	ρ (kg/m ³)	0	4512	0	0	0

C. PZT-4H Piezoelectric Face Layers

The upper and lower face layers of the sandwich nanoplate consist of PZT-4H, a widely utilized piezoelectric ceramic material recognized for its robust electromechanical coupling and thermal stability. The layers facilitate active vibration control by applying an external electric potential V_m , which produces an electric field that interacts with mechanical deformation through the piezoelectric effect. This mechanism enables the structure to modify its dynamic behavior, rendering it applicable in intelligent systems including sensors, actuators, and vibration damping devices. The mechanical and thermal behavior of the PZT-4H layers is examined using temperature-dependent material characteristics. These characteristics include the elastic stiffness constants (C_{ij}), the thermal expansion coefficient (α), Poisson's

ratio (ν), and density (ρ), all of which are shown as polynomial functions of temperature. Table 3 provides the whole array of coefficients, enabling accurate simulation of the electromechanical reaction under varying heat conditions.

Table 3. Temperature-dependent coefficients for the properties of PZT-4H [12].

Material	Property	P_{-1}	P_0	P_1	P_2	P_3
PZT-4H	C_{11} (Pa)	0	139×10^9	-1.552×10^{-4}	6.125×10^{-9}	-9.0×10^{-11}
	C_{12} (Pa)	0	77.8×10^9	-1.552×10^{-4}	6.125×10^{-9}	-9.0×10^{-11}
	C_{13} (Pa)	0	74×10^9	-1.552×10^{-4}	6.125×10^{-9}	-9.0×10^{-11}
	C_{33} (Pa)	0	115×10^9	-1.552×10^{-4}	6.125×10^{-9}	-9.0×10^{-11}
	C_{55} (Pa)	0	25.6×10^9	-1.552×10^{-4}	6.125×10^{-9}	-9.0×10^{-11}
	C_{66} (Pa)	0	30.6×10^9	-1.552×10^{-4}	6.125×10^{-9}	-9.0×10^{-11}
	ν	0	0.3	0	0	0
	α ($1K^{-1}$)	0	10×10^{-6}	-0.0003	4×10^{-6}	-1×10^{-9}
	ρ (kg/m^3)	0	7500	0	0	0

D. Governing Equations and Modeling Assumptions

The mechanical behavior of the sandwich nanoplate is described using Higher-Order Shear Deformation Theory (HSDT), which accurately captures transverse shear effects without requiring shear correction factors. The displacement field is assumed as:

$$\begin{aligned}
 u(x, y, z) &= u_0(x, y) + z \phi_x(x, y) \\
 v(x, y, z) &= v_0(x, y) + z \phi_y(x, y) \\
 w(x, y, z) &= w_0(x, y)
 \end{aligned} \tag{2}$$

where u_0 , v_0 , w_0 represent midplane displacements, and ϕ_x , ϕ_y denote rotations about the y - and x -axes, respectively.

To model size-dependent behavior at the nanoscale, the nonlocal elasticity theory and strain-gradient theory are incorporated. The nonlocal stress-strain relation is expressed as:

$$(1 - (\mu \nabla)^2) \sigma = C : \varepsilon \tag{3}$$

where $\mu = e_0 a$ is the nonlocal parameter and C is the elastic stiffness tensor. Thermal effects are introduced through a uniform temperature rise ΔT , inducing thermal strain:

$$\varepsilon^{th} = \alpha(T) \cdot \Delta T \cdot I \tag{4}$$

Linear constitutive models are used for both the Ti-6Al-4V core and the PZT-4H face layers, with piezoelectric coupling defined by:

$$\begin{aligned}
 \sigma &= C \varepsilon - e^T E \\
 D &= e \varepsilon + \kappa E
 \end{aligned} \tag{5}$$

E. Boundary Conditions and Numerical Solution

Two boundary conditions are considered in the vibration analysis: simply supported and clamped. Unless specified, all plate edges are free in the in-plane directions. An external electric potential V_m is applied across the PZT-4H layers to activate electromechanical coupling and control vibrational characteristics. The coupled governing equations are solved numerically using the finite element method (FEM) implemented in commercial software. An eigenvalue analysis is performed to extract the fundamental natural frequencies. Parametric studies are conducted to assess the effects of:

- Core thickness ratio h_c/ h
- Face layer thickness ratio h_p/ h
- Temperature rise $\Delta T = 0, 300, 800, \text{ and } 1200 \text{ K}$
- Nonlocal parameters $e_0 a$ and l_m
- Core topology (via effective properties from TPMS formulations)

This modeling framework ensures accurate simulation of thermo-electromechanical behavior in TPMS-based smart nanoplates.

III. RESULTS

The variation of nondimensional fundamental frequency λ_{11} with respect to the temperature rise ΔT is analyzed for three distinct core configurations: TPM I, TPM II, and TPM III. Each subfigure in Figure 2 illustrates the influence of different solid volume ratios $V = 0.2, 0.4, 0.6, \text{ and } 0.8$ on vibrational performance under thermal loading. For TPM I, the initial natural frequency at room temperature is the highest among the three configurations. As the temperature increases, λ_{11} gradually decreases due to thermal softening, with a sharp drop occurring near $\Delta T \approx 1720 \text{ K}$, indicating the onset of thermal buckling. This configuration demonstrates superior thermal resilience, maintaining structural integrity across a broader temperature range. TPM II shows slightly lower values compared to TPM I at all temperature levels. The decrease in frequency with increasing temperature follows a similar trend, but the critical buckling point is reached slightly earlier. This suggests that TPM II offers a moderate balance between stiffness and thermal resistance. In contrast, TPM III exhibits the lowest frequency values across the entire temperature range. The structure is more susceptible to frequency degradation under thermal loading, and thermal buckling occurs more abruptly around $\Delta T = 1700\text{-}1750 \text{ K}$. Despite its lower stiffness, TPM III may still be beneficial in applications prioritizing flexibility or energy absorption over vibrational rigidity.

The comparative plot in Figure 2d clearly demonstrates that at a fixed volume ratio $V = 0.8$, TPM I consistently outperform TPM II and TPM III in terms of frequency response. All configurations show similar critical temperature thresholds for instability but differ significantly in their stiffness retention capabilities.

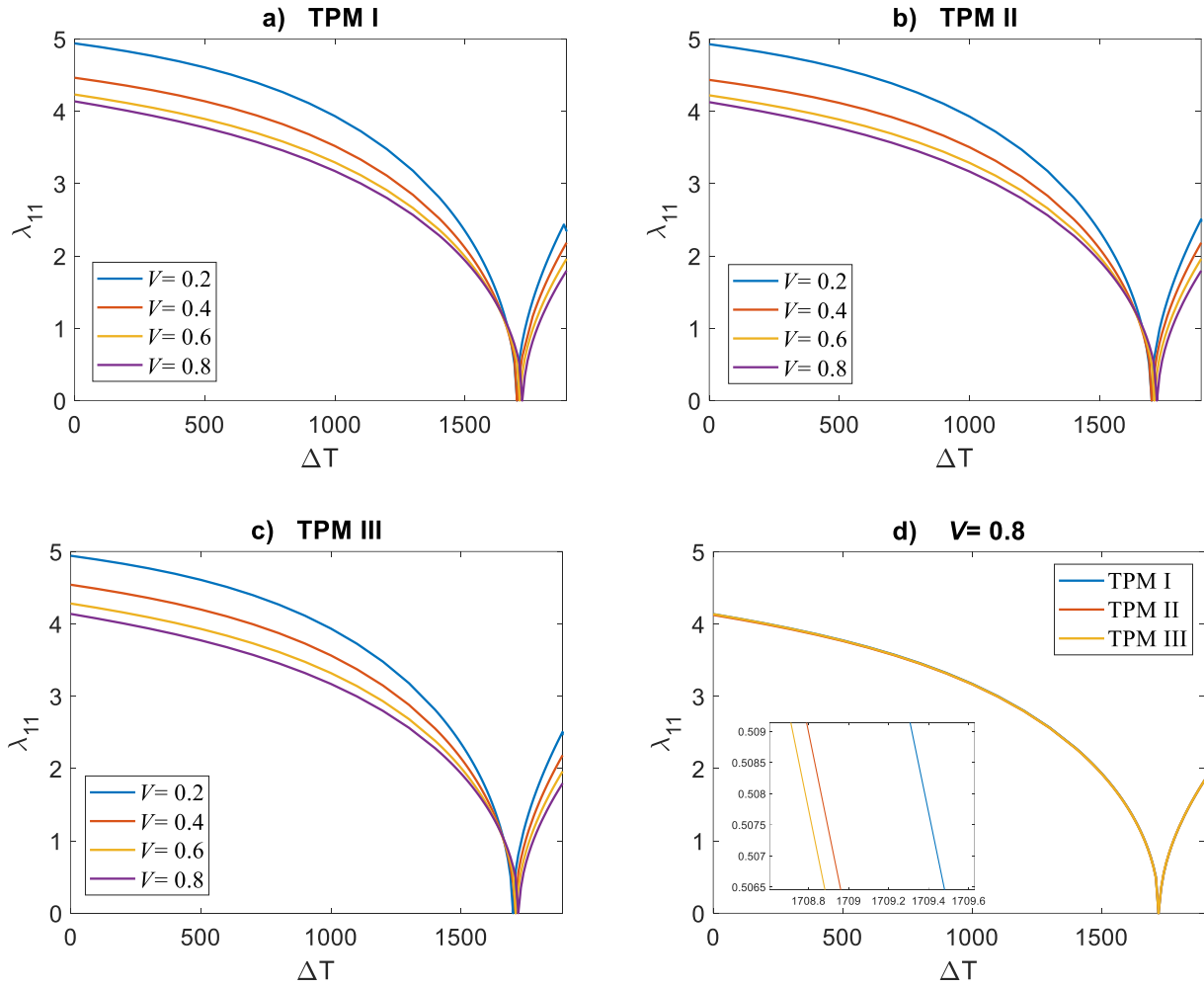


Fig. 2 Effect of the solid volume ratio (V) on the nondimensional fundamental frequency λ_{11} depending on the temperature rise ΔT ; a) TPM I; b) TPM II; c) TPM III; d) Comparison of all three core types for $V = 0.8$; Core layer thickness $h_c = 0.8h$; face layer thickness $h_p = 0.1h$; External electric potential $V_m = 0$; nonlocal and size parameters $e_0 a = l_m = 0$.

Figure 3 presents the effect of the core-to-total thickness ratio (hc/h) on the fundamental frequencies at $\Delta T = 300$ K. Increasing hc/h enhances the stiff contribution of the TPMS core, resulting in higher natural frequencies. However, excessively thick cores reduce the influence of piezoelectric layers, limiting the capacity for active vibration control. Optimal thickness ratios balance mechanical stiffness and electromechanical functionality, consistent with earlier findings in auxetic sandwich plate studies [2].

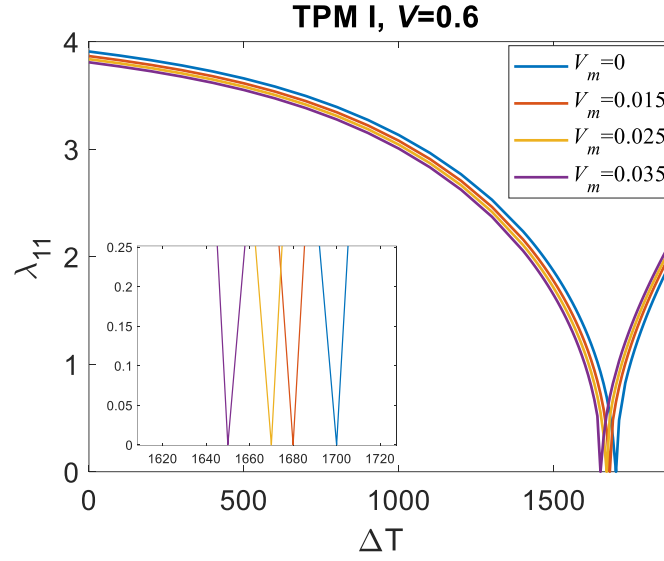


Fig. 3 Variation of the nondimensional fundamental frequency λ_{11} with respect to the temperature rise ΔT for different external electric potentials $V_m = 0, 0.015, 0.025$, and 0.035 ; Core layer thickness $h_c = 0.2h$; face layer thickness $h_p = 0.4h$; Solid volume ratio $V = 0.6$; nonlocal and size parameters $e_0a = l_m = 0$.

As shown in Figure 4, temperature rise leads to a monotonic decrease in λ_{11} across all core topologies, with a notable drop near $\Delta T = 1700$ – 1750 K, indicating potential thermal buckling. The auxetic TPMS core mitigates the frequency reduction compared to conventional cores, demonstrating enhanced thermal resilience. These findings underscore the importance of incorporating thermal effects in the design of TPMS-based smart plates [3, 6].

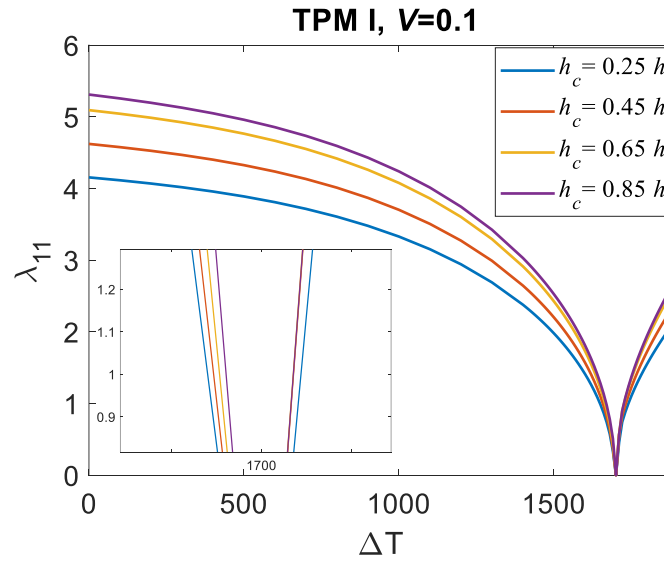


Fig. 4 Effect of the core thickness ratio (h_c/h) on the nondimensional fundamental frequency λ_{11} depending on the temperature rise ΔT ; Core layer thickness values $h_c = 0.25h, 0.45h, 0.65h$, and $0.85h$; Face layer thicknesses are defined as $h_p = (h - h_c)/2$; Solid volume ratio $V = 0.1$; External electric potential $V_m = 0$; nonlocal and size parameters $e_0a = l_m = 0$.

Application of external electric potential ($V_m = 0.015$ – 0.035) across the PZT-4H face layers significantly modifies the vibrational response. Active control through piezoelectric layers increases the fundamental frequencies, particularly in plates with thinner cores, by stiffening the system via electromechanical coupling. The interaction between auxetic cores and piezoelectric layers provides tenable dynamic properties, offering potential for vibration suppression and energy harvesting applications [2, 7].

IV. DISCUSSION

Integrating TPMS-auxetic cores with PZT-4H face layers yields a multifunctional structure capable of including enhanced vibration performance, thermal stability, and electromechanical tunability. Core topology, thickness ratio, temperature, and electromechanical actuation emerge as critical design parameters. These findings provide practical guidelines for the design of lightweight, high-strength, and smart sandwich plates for aerospace, defense, and energy applications. Furthermore, the results corroborate and extend prior research on auxetic TPMS cores, demonstrating their potential in smart structural systems [4, 13, 14].

V. CONCLUSION

This study presents a comprehensive analysis of TPMS-Auxetic sandwich nanoplates with PZT-4H face layers under thermal and electromechanical loading. Key findings include:

- TPMS-Auxetic cores enhance stiffness, vibration damping, and thermal stability.
- Optimized layer thickness ratios balance structural rigidity and electromechanical actuation.
- Temperature rise reduces frequencies, with buckling around 1700–1750 K.
- Electromechanical coupling via PZT-4H layers enables active vibration control.
- Nonlocal elasticity and strain-gradient effects are significant at nanoscale.

Overall, the integration of TPMS-Auxetic cores with piezoelectric face layers provides a multifunctional platform for lightweight, high-performance smart structures suitable for aerospace, defense, and energy-harvesting applications. These results offer design guidelines for optimizing dynamic, thermal, and electromechanical performance in advanced sandwich plates.

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Mastektomi ve Dışavurumcu Sanat Terapisi

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Özet-Amaç: Bu derleme, mastektomi geçiren kadınlarda dışavurumcu sanat terapilerinin (DST) psikolojik ve fiziksel iyilik hâline etkisini bütüncül olarak sunmayı amaçlamaktadır. **Yöntem:** Anlatı (narrative) derleme yaklaşımıyla kılavuzlar ve birincil çalışmalar taranıp sentezlenmiştir. **Bulgular:** DST (mindfulness-temelli sanat terapisi, ebru/mandala, müzik, kıl/kum tepsisi, dans-hareket) anksiyete, depresif duygu durum, tükenmişlik, ağrı ve bulantıda azalma; yaşam kalitesi ve beden imgesinde iyileşme ile ilişkilidir. **Sonuç:** DST, mastektomi sonrası psikososyal iyileşmeye katkı sağlayan, düşük maliyetli ve uygulanabilir bir tamamlayıcı müdahaledir. Klinik entegrasyon için yapılandırılmış protokoller ve standart ölçüm araçları önerilir.

Anahtar Kelimeler: Meme Kanseri; Mastektomi; Dışavurumcu Sanat Terapisi; Beden İmgesi; Yaşam Kalitesi; Hemşirelik.

I. GİRİŞ

1.1.Meme Kanseri ve Mastektomi

Meme kanseri, Mastektomi, Dışavurumcu Sanat Terapisi Meme kanseri ülkemizde ve dünyada kadınlarda en sık teşhis koyulan kanser türüdür. Aynı zamanda meme kanseri ülkemizde kadınlar için kansere bağlı ölüm nedenlerinin başında yer almaktadır [1]. Dünya Sağlık Örgütü'nün 2023 yılında paylaştığı verilere göre ise 2020 yılında dünya genelinde 2,3 milyon kişi yeni meme kanseri tanısı almıştır. Ülkemizde ise 2022 yılında yeni kanser tanısı alan kişi sayısı 24.175 olarak bildirilmiştir [1]. Tüm Dünyada görülme sıklığı, etki alanı doğrultusunda Dünya Sağlık Örgütü 2023 yılında yeni Küresel Meme Kanseri Girişimi Çerçevesini yayınlamıştır. Erken tanı ve zamanında uygun müdahaleleri öne çıkarmış 2040 yılına kadar 2,5 milyon kişiyi kurtarmayı hedeflemiştir [2]. Meme kanseri için ailede kanser öyküsü, genetik faktörler, yaş, östrojen kullanımı, çocuk doğurma yaşı, beslenme, kadın cinsiyet gibi farklı risk faktörleri açıklanmıştır [1], [2]. Risk faktörlerini taşıyan kişilerin toplam tanı alan kişilerin %20'lik bölümünü oluşturduğu görülmüştür [4]. Meme kanseri diğer ölümcül ve sık görülen kolon, akciğer, ve mide kanserine göre prognozu iyi ilerleyen ve erken teşhis edilebilir ve tanı koyulabilir dönemi olan bir kanser türüdür [5]. Erken tanı meme kanserinde prognozu iyileştirmekle birlikte mortaliteyi de azaltmaktadır [6]. Bu yönleriyle meme kanseri, kanser tarama programları içerisinde yer almaktadır. Ülkemizde meme kanseri taramalarını Kanser Erken Teşhis Tarama ve Eğitim Merkezi (KETEM)' ler ile aile sağlığı merkezleri ve toplum sağlığı merkezleri birlikte yürütmektedirler. Meme kanseri tarama programı; 40-69 yaş aralığındaki kadınlarda 2 yılda bir mamografi çekimi, yılda bir defa klinik meme muayenesi yapılması ve kendi kendine meme muayenesinin düzenli olarak ayda bir kez yapılması konusunda danışmanlığın gerçekleştirilmesi şeklindedir [7]. Kendi kendine meme muayenesi (KKMM) meme dokusunda meydana gelen değişiklikleri erken fark edilebilir kılan önemli bir yöntemdir [8]. KKMM kadınların her ay düzenli yaparak kendi meme

dokularını tanımlarını, meme dokusunda oluşan değişikliği aydan aya saptayabilmelerini sağlamaktadır [9]. Yılda bir kez yapılması önerilen klinik meme muayenesi ise sağlık çalışanları; hemşire, hekim ve ebe tarafından uygulanan özellikli bir muayenedir [10]. Meme kanserinde cerrahi girişim, radyoterapi, kemoterapi, hormonal ve biyolojik tedavi sıklıkla uygulanan tedavi yöntemlerindendir. Cerrahi tedavi ve radyoterapi lokal kontrolü sağlamak amacıyla kullanılırken kemoterapi, hormonal ve biyolojik tedavi ise sistemik kontrolü sağlamak amacıyla meme kanseri tedavisinde kullanılır. Tedavi sürecinin planlanması disiplinler arası bir ekip tarafından gerçekleştirilir. Cerrahi onkolog, tıbbi onkolog, radyasyon onkoloğu, onkoloji hemşiresi, psikolog, beslenme uzmanı bu ekibin önemli üyeleridir. Onkoloji hemşireleri hastanın tedavi sürecinde ihtiyaç duyduğu destekleyici bakımı ve iletişimi sağlayarak, yaşam kalitesini artırmaktadırlar [11], [12]. Günümüzde risk faktörlerinin bilinmesi, erken tanılama, radyoterapi ve kemoterapi alanında gerçekleştirilen yenilikler ile meme kanseri tedavisi olumlu yönde gelişmiştir. Bu gelişmeler ile birlikte öncelikli olarak memeyi korumayı hedefleyen bir tedavi planlaması şekillenmiştir. Tüm yenilikler ve gelişmelerle birlikte cerrahi tedavi halen meme kanseri için primer tedavi şeklidir. Meme kanserinin cerrahi tedavisi hastanın öyküsüne, hastalığın evresine, tümörün yerleşim yerine göre şekillenip planlanarak, meme koruyucu cerrahi ve meme dokusunun tamamının çıkarılması şeklinde olabilmektedir. Radikal cerrahilerin sayısı giderek azalmaktadır [13]. Cerrahi tedavi tekniklerinde oluşturulan gelişmeler ile hasta için daha iyi kozmetik sonuçlarla birlikte onkolojik etkinliğin sürdürülmesi hedeflenmektedir. Hastanın fiziksel ve psikolojik iyi oluşunu artırmak travmasını en az seviyeye düşürebilmek amacıyla onkolojik güvenlik ile birlikte daha konservatif teknikler, prosedürler gerçekleştirilmektedir [14], [15]. Mastektomi; cerrahi olarak meme dokusunun çıkarılması olarak tanımlanmıştır. Radikal mastektomi, modifiye radikal mastektomi, total mastektomi, kısmi(parsiyel) mastektomi olmak üzere değişik kapsamda uygulanarak farklı isimlendirmeler içermektedir [16]. Uygulanan cerrahide farklılıklar olsa da her hasta için mastektomi fiziksel ve psikolojik zorlanmalara neden olmaktadır. Memenin toplumsal olarak ifade ettiği; cinsellik, estetik, kadınlık, annelik kavramları mastektomiyle birlikte meme kaybı yaşayan kadın için beden algısında değişimlere, psikososyal sorunlara yol açabilmektedir. Bazı toplumlarda özellikle kutsal kabul edilebilen, annelik ve kadınlık ile bağdaştırılan memenin kaybı kadında benlik algısını olumsuz etkileyebilmektedir [17], [18]. Tanı aşamasında kaygı, depresyon, stres, inkar gibi zorlu duygularla baş etmek zorunda kalan kadınlar tedavinin başlamasıyla birlikte tedavi sürecinin getirmiş olduğu ağrı, lenf ödem, bulantı, halsizlik gibi fiziksel sorunlarla zorlayıcı duyguları bir arada yaşamaktadırlar [19], [20], [21]. Mastektomi sonrası kadınların yaşadığı karmaşık duygular kadının memeye yüklemiş olduğu anlam, eş uyumu, çevre desteği gibi faktörlere göre şekillenmektedir. Öz güvende azalma, sosyal geri çekilme, cinsel sorunlar, kendi bedenini beğenmeme, stres, meme kaybını kabullenememe, ekonomik sıkıntılar, kanserin nüks etme korkusu bu zorlayıcı durumlar içerisinde yer alır [21], [22]. Hastalık yükü fazla olan kanser ile yaşamını sürdüren kişiler yaşam kalitesini arttırıcı, negatif semptomları azaltan uygulamalara ihtiyaç duymaktadır. Akupunktur, hayal kurma, progresif kas gevşeme egzersizleri, nefes farkındalığı egzersizleri, dua etme, dikkati başa yöne çekme, sanat terapi, ağrı bölgesine masaj gibi uygulanmış ve etkinliği gözlenmiş non-farmakolojik yöntemler kullanılmaktadır [24]. Sanat terapisinin kanser hastalarını zorlayan stres, kaygı, yorgunluk, ağrı ve tükenmişlik düzeylerinde azalma sağladığı, psikososyal olarak desteklediği, benlik saygısında artma sağladığı ve psikolojik iyi oluşunu artırdığı görülmüştür [24], [25], [26], [27], [28].

1.2.Dışavurumcu Sanat Terapisi ve Mastektomi

Sanat tarihin başlangıcından beri insanla birlikte varlığını sürdürür, gelişir ve şekillenir. İnsan sanatla birlikte var olan duygularını ve düşüncelerini görünür kılarak aktarabildiği, dönüştürdüğü bir süreç içerisinde. En ilkel semboller ile başlayan zamanla etkileyici, topluma yön verebilen tablolara, notalara, fotoğraflara, bale gösterilerine ve daha birçok farklı çeşitte ve zenginlikte ürünlere, yaratıcılıklara evrilmiştir [29], [30], [31]. Sanatın hayatın bir parçası olarak varlığı ilk çağlarla başlamış ve devam etmiştir [32]. Sanat terapisi; resim müzik, kıl, dans ve şiir gibi sanat dallarının terapötik olarak kullanıldığı bir terapi türüdür. Sanat terapisi tanımları içerisinde sanat ile ilgili iki önemli özelliğe yer verilmiştir; birincisi sanatın dışavurumcu özelliği ve kişiye ifade kolaylığı sağlamasıdır. İkinci özellik ise sanatsal yaratım sürecinin tek başına terapötik bir süreç, iyileştirici bir güç olarak var olmasıdır [33], [34], [35]. Sanatın insan kültürüne eşliği eski olsa da sanatın terapötik etkilerinin keşfedilmesi 1940' lı yıllarda, sanat terapisinin

profesyonelleşmeye başlaması ise 1960' larda gerçekleşmiştir. Sanat terapisi ilk kez Ressam Adrian Hill'ın tüberküloz hastalarıyla yaptığı resim çalışmalarını tanımlamak için kullanılmıştır. Adrian Hill 1942 yılında gerçekleştirdiği çalışmasında yapılan resimlerin zamanı değerlendirmekle birlikte travmatik yaşantılarını ifade etmekte hastalara kolaylık sağladığını yardımcı olduğunu belirtmiştir. 1969 yılında Naumburg tarafından Amerikan Sanat Terapisi Derneği kurulmuştur [29],[32],[36]. Türkiye de ise tedavi süreçlerinde sanatın kullanılması ilk olarak 1957 yılında, Dr. Süleyman Velioğlu ve Dr. Kazım Dağyolu tarafından gerçekleştirilmiştir [37]. Dışavurumcu sanat terapisinin uygulandığı hastalık grupları ve çalışma alanı geniş bir kümeyi kapsamaktadır. Psikiyatri servisleri ve diğer psikosomatik kliniklerde uygulanabilmektedir [38]. Kanseri hastalarında, travma sonrası kişilerde, çocuk ve ergenlerde, down sendromu ve otizm gibi özel eğitim gerektiren çocuklarda, kaygı bozukluklarında, demans ve hafıza kaybı yaşayan yaşlılarda ve farklı gruplarda yapılmış çalışmalar bulunmaktadır. Dışavurumcu sanat terapisi çocuklarda ebeveyn kaybı, akran zorbalığı, istismar, ders başarısızlığı, ebeveyn boşanmaları, hastalık gibi problemlerde kullanılmaktadır. Çocuk ve ergenlerde sanat duygusal farkındalığı artırır, çocukların iç dünyalarını yansıtmalarına olanak sağlar, ergenler tarafından diğer psikososyal müdahalelere göre daha az tehditkar algılanabilen sanat terapisi ergenlerin duygusal ve toplumsal gereksinimleri için kullanılmaya uygun bir terapidir [29],[39],[36],[40],[41],[42]. Dışavurumcu sanat terapisi, yaşlılara bakım veren rehabilitasyon merkezleri, huzurevi gibi ortamlarda uygulanıldığında yaşlı bireylerin stres ile baş etmelerine katkı sağlamakta, bilişsel becerilerini ve duygu durumlarını olumlu yönde geliştirmektedir [43],[44]. Sanat terapisinin yaşlılarda dikkati, bilişsel becerileri, yaşam kalitesini, benlik saygısını artırdığı kaygı, stres gibi depresif duyguları azalttığını gösteren çalışmalar vardır [24], [39], [45], [46].

Dışavurumcu sanat terapisi için biçim, estetik kaygı içermeyen kişilerin ortaya koyduğu sanatsal öge önemlidir. Sanat ile ortaya koyulan görsel ve işitsel imgeler, somut objeler kişinin ifade aracı, duygu dışavurumunun bir yoludur. Resim, müzik, mandala, kil, şiir, kolaj, drama gibi çeşitli sanat türleri dışavurumcu sanat terapisinde kişiye, ihtiyaca göre seçilebilmektedir [40],[47]. Resim; en çok tercih edilen dışavurumcu sanat terapisi uygulamalarındandır. Kara kalem çalışması, pastel boya, sulu boya, yağlı boya, guaj boya, kuru boya gibi farklı boya çeşitleri kullanılabilir. Resim ile kişinin bilinç ve bilinçdışı görsel imgelere dönüşür, resimdeki tema, çizgiler, renkler kişinin iç dünyasını yansıtan ipuçları oluşturmaktadır (36, 40). Müzik terapi; rahatsızlıkların tedavisinde müziğin bir terapist tarafından uygulanmasıdır. Müziğin tedavide kullanımı oldukça eskidir. Eski çağlarda kötü ruhların neden olduğuna inanılan rahatsızlıklar müziğin eşlik ettiği ayinler ile iyileştirilmeye çalışılmıştır. Osmanlı da su ve müzik ruhsal hastalıkların tedavisinde kullanılmıştır [35], [48]. Dans ve Hareket Terapisi; amaç estetik kaygılar ve kurallar gözetilerek dansın öğretilmesi değil kişinin bedeni ile ilişki kurmasını sağlamak, sözel olarak ifade edilmeyen kavramların harekete, davranışa dönüştürülerek iletişimi ve davranışı geliştirmektir. Dans ile birlikte beden ile bağ kurulur, beden imajı ve benlik algısı desteklenir. Obezite, aids, madde bağımlılığı gibi farklı hasta gruplarında etkinliği gösterilmiştir [49],[50], [51]. Kil; duygu ve düşüncelerin kil kullanılarak simgesel ürünlere dönüştürülerek somutlaştırılmasıdır. Ortaya koyulan bu ürünler kişinin iç dünyasının, psikolojik süreçlerinin bir yansıması olarak değerlendirilmektedir.. Travmatik deneyimler, istismar, yas ve benzeri sorunların çözümünde katkı sağlamaktadır. Yoğun bir temas ve dokunma ile kile şekil verilir, bu dokunma ve temas bilinç ve bilinçdışı olumlu ve olumsuz anıları tetikleyici olabilmektedir [52], [53]. Mandala; orta nokta etrafında dairesel devrim ile oluşturulan sanat formudur. Merkezden dışa genişleyen daireler meditatif etki oluşturur, bireysel farkındalığı ve yaratıcılığı artırır, kişilerde gevşeme sağlar. Jung uzun zaman mandala çizmiş ve bilinç dışını yansıttığını savunmuştur. Mandala, çatışmaları çözmek, psikolojik iyileşmeyi sağlamak, farkındalık sağlamak ve kendini ifade için bir araç olarak dışavurumcu sanat terapistleri tarafından uygulanmaktadır [54], [55], [56].

II. ARAŞTIRMA VE BULGULAR

Kanser hastalık yükü fazla olan tanı, tedavi ve rehabilitasyon süreçleriyle kişileri fiziksel ve psikolojik olarak zorlayan bir hastalıktır. Dışavurumcu sanat terapileri kanser hastalarının fiziksel-emosyonel ve zihinsel iyilik düzeylerini artırmak, ağrı, bulantı, yorgunluk, anksiyete gibi şikayetleri azaltmak amacıyla kullanılmaktadır [57], [58]. Nainis ve arkadaşlarının 2006 yılında gerçekleştirdikleri çalışma sonuçlarına

göre kanser hastaları ile gerçekleştirilen dışavurumcu sanat terapisinin hastaların anksiyete, tükenmişlik ve ağrı düzeylerini düşürdüğü görülmüştür. Meme kanseri kişilerde tanı, tedavi ve mastektomi sonrasında yaşama uyum sürecinde sanat terapisi gibi yaşam kalitesini artırıcı uygulamalara ihtiyaç duyulmaktadır [23]. Malchiodi' e (2003) göre sanat terapisi kişilerin kendilerini ifade etmeleri için yeni keşifler yapmalarına yardımcı olarak çaresizlik, umutsuzluk gibi düşünceler ile başa çıkma, onları kontrol etme yeteneklerini desteklemektedir. Erken teşhis ve tedavi süreçlerinde yaşanan iyileşmeler, meme kanserinde sağ kalım ve yaşam sürelerini uzatarak, daha çok kadının kanser tedavisinin sonuçlarıyla yaşamını sürdürmesini gerektirmiştir [59]. Oster ve arkadaşlarının 2006 yılında meme kanseri hastalar ile yaptıkları çalışmada sanat terapisinin hastalığa ve tedaviye uyumu artırdığı görülmüştür. Aynı yıl Monti ve arkadaşlarının kadın kanser hastalar ile gerçekleştirdikleri çalışmalarında sanat terapinin kanser kadınların yaşam kalitelerini artırdığı, stres düzeylerini azalttığı bulunmuştur. Yine meme kanseri hastalar ile yapılan bir çalışmada müzik terapinin bulantıyı azalttığı, kalp hızını regüle ettiği gösterilmiştir [60]. Mastektomi, kadınların bedeninde kalıcı değişikliğe neden olur. Mastektomi sonrası kadınlar cerrahi işlemin getirdiği ağrı, enfeksiyon, lenf ödem gibi şikayetler ile meme kaybının getirdiği psikolojik zorlanmaları bir arada yaşamaktadırlar [61]. 2024 yılında Sivas Cumhuriyet Üniversitesi Uygulama ve Araştırma Hastanesi Onkoloji Merkezi'nde mastektomi geçiren 60 hasta ile çalışma yapılmıştır. Çalışmada 30 hastaya dışavurumcu sanat terapi programı uygulanmış, 30 hastaya kontrol grubunda herhangi bir terapi uygulanmamıştır. Uygulanan dışavurumcu sanat terapi programı ney sesi ile birlikte ebru sanatı uygulaması şeklinde planlanmıştır. Çalışma sonuçları sanat terapi uygulanan grubun ağrı, kusma ve anksiyete şikayetlerinde azalma olduğu, yaşam kalitelerine katkı sağladığı bulunmuştur [62]. 2004 yılında Haebel, mastektomi uygulanmış kadınlarla kumu kullanarak dışavurumcu sanat terapisi programı gerçekleştirmiştir. Yaptığı çalışma sonucunda uygulanan dışavurumcu sanat terapisinin kadınların beden imajı ve kayıp ile yaşadığı yas duygularını düzenlemekte katkı sağladığı sonuçlarına ulaşmıştır [63].

III. SONUÇ

Dışavurumcu sanat terapisinin travmatik deneyimler sonrasında duygularını ifade etmekte güçlük çeken kişilerde olumlu etkilerinin olduğu ve yoğun duyguların dışa vurumunu kolaylaştırdığı görülmüştür. Kanser sebebiyle memenin kaybedilmesi kadınlar için travmatik deneyimlerden biridir [36], [64], [65]. Kanser tanısı almak, tedavi süreçleri, memenin kaybı kadın için yaşanması zor deneyimlerdir. Mastektomi sonrası desteklenmeye ihtiyaç duyan meme kanseri hastaları için dışavurumcu sanat terapisi teknikleri, onların ifadesi zor duygu ve düşüncelerini dışa vurmalarını kolaylaştırılabilir. Mastektomi işlemiyle meme kaybı yaşayan kadınlarla dışavurumcu tedavilerin uygulama örneklerinin artması daha çok kadına fayda sağlayacaktır.

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Aerodynamic Perspectives on Tandem UAV Engines: A Comprehensive Review

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Abstract – Unmanned Aerial Vehicles (UAVs) are increasingly adopting tandem engine configurations to achieve higher propulsion efficiency, aerodynamic stability, and endurance. This review article presents a comprehensive analysis of the aerodynamic principles governing tandem UAV engines, integrating findings from recent Computational Fluid Dynamics (CFD) and experimental studies. Important elements that have a significant impact on thrust distribution and overall efficiency are reviewed, including rotor wake interactions, propeller spacing, alignment effects, and aerodynamic interference. Although tandem arrangements provide quantifiable gains in lift balance and energy efficiency, issues with wake coupling, vibration, and unstable flow behavior still need to be addressed. Innovations in AI-driven optimization, smart morphing blades, hybrid-electric propulsion, and bio-inspired designs are recognized as potential ways to improve system flexibility and aerodynamic performance. The research comes to the conclusion that developing next-generation UAVs that are optimized for both commercial and defense use requires interdisciplinary integration spanning aerodynamics, materials, and intelligent control.

Keywords – UAV; Tandem Engines; Aerodynamics; Propulsion Systems; CFD.

I. INTRODUCTION

Unmanned aerial vehicles, or UAVs, have drawn a lot of interest recently. Recreation, agriculture, and defense are just a few of the industries that employ them. In addition, in recent years, they have become a successful urban air mobility (UAM) strategy [1]. There are now several types of UAVs, such as fixed-wing, rotary-wing, and flapping-wing models [2]. UAVs are operated remotely by a person on the ground using a radio controller, as the name implies, and do not require a human on board. In the event that the UAV malfunctions or has problems while in flight, this removes the possibility of harm or death to the operator [3]. To save drag and increase thrust efficiency, a tandem engine arrangement aligns two propulsion units along the aircraft's longitudinal axis, usually one behind the other. This configuration is pertinent to UAVs and light aircraft, where aerodynamic efficiency, balanced thrust distribution, and compact design are essential [4, 5].

The effectiveness and stability of such systems are still largely dependent on aerodynamics. Surface alterations, including bio-inspired microfiber coatings, have been shown in recent research to significantly lower drag and postpone stall onset, improving thrust efficiency in tiny UAVs [6]. Likewise, research on distributed electric propulsion systems has demonstrated that aerodynamic propulsion coupling is essential for thrust production and stability, especially while hovering and cruising [7]. Aerodynamics is a key component of stable and effective UAV operations, and computational studies of tiltrotor UAVs further

highlight how rotor-fuselage aerodynamic interactions directly impact pitching moments and thrust distribution [8].

The purpose of this analysis is to examine tandem UAV engine concepts from an aerodynamic perspective, with a focus on their relationship to thrust efficiency, drag reduction, and flight stability. By integrating current research and highlighting crucial design elements, this study seeks to provide a comprehensive understanding of the aerodynamic foundations that support tandem engine UAV performance.

II. AERODYNAMICS PRINCIPLES IN UAV PROPULSION

Describe in detail the materials and methods used when conducting the study. The citations you make from different sources must be given and referenced in references.

2.1 Fundamentals of UAV aerodynamics

The aerodynamic performance of Unmanned Aerial Vehicles (UAVs) depends primarily on the balance between lift, drag, thrust, and weight as shown in figure 1. In fixed-wing UAVs, lift is generated through wing geometry and angle of attack, while rotary- and tilt-wing UAVs rely on induced airflow from propellers/rotors to generate lift and thrust simultaneously [9]. Reynolds number effects are particularly significant for small- to medium-sized UAVs, as low Reynolds regimes ($<10^5$) result in higher drag coefficients and susceptibility to flow separation [10]. Key parameters such as lift-to-drag ratio (L/D), stall margin, and induced drag are critical in determining range, payload efficiency, and endurance.

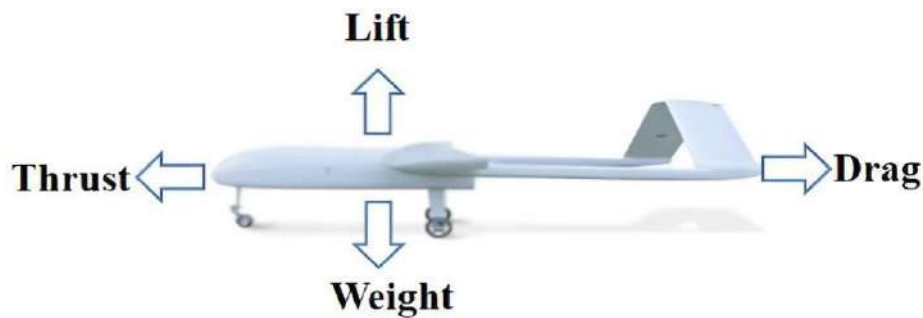


Figure 1. A schematic showing forces acting on a UAV Engine [11]

2.2 Propeller-propeller and propeller-airframe interaction

Aerodynamic interactions between propellers and the airframe strongly influence efficiency and stability. In multi-propeller and tandem-engine UAVs, upstream propeller wakes can create unsteady inflow conditions for downstream propellers, reducing thrust and increasing vibration [12]. Studies using CFD and wind tunnel tests have shown that overlapping wake vortices lead to asymmetric thrust distribution and increased drag penalties shown in figure 2 [13]. Similarly, fuselage and wing surfaces exposed to propeller slipstreams experience additional lift and drag contributions, which can either improve or deteriorate performance depending on propeller placement [14].

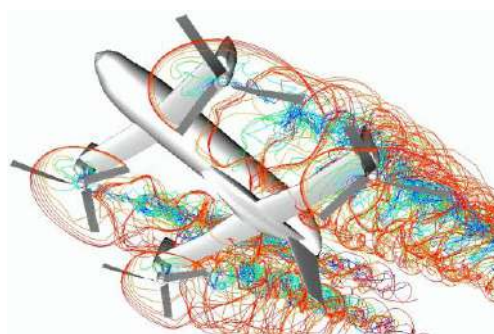


Figure 2. CFD visualization of wake interaction between tandem propellers [15]

Table 1. Comparative aerodynamic penalties of isolated vs. interacting propellers

Study	Configuration Compared	Observed Effect	Metric	Source
Rostami & Farajollahi	Tandem propellers (ducted vs. unducted)	Duct reduced wake losses	+6% propulsive efficiency	[16]
Borer et al.	Distributed propulsion on wing vs. isolated propellers	Enhanced lift & efficiency	Up to +30% L/D	[12]
Mula & Bernardini	Propeller-wing interaction (various placements)	Modified lift distribution, drag increase	ΔCL +10–15%, ΔCD +6–12%	[13]
Suryan & Rao	Slipstream on UAV wing	Stall delay + increased induced drag	Improved lift slope but higher CD_i	[14]

Table 1 shows that while ducted and distributed propeller configurations can improve lift and efficiency, they also introduce increased drag and aerodynamic penalties.

2.3 Tandem engine-induced airflow patterns

In tandem configurations, engines aligned along the longitudinal axis produce distinct airflow interactions compared to side-by-side layouts. The front propeller generates a slipstream that accelerates airflow over the rear propeller, enhancing thrust but also inducing swirl and increased turbulence intensity [5]. Proper spacing between engines is essential: close spacing leads to higher interference losses, while excessive spacing increases weight and structural penalties [1]. Experimental and numerical studies suggest that optimized tandem configurations can improve propulsive efficiency by up to 8–12% compared to single-propeller designs under cruise conditions [7].

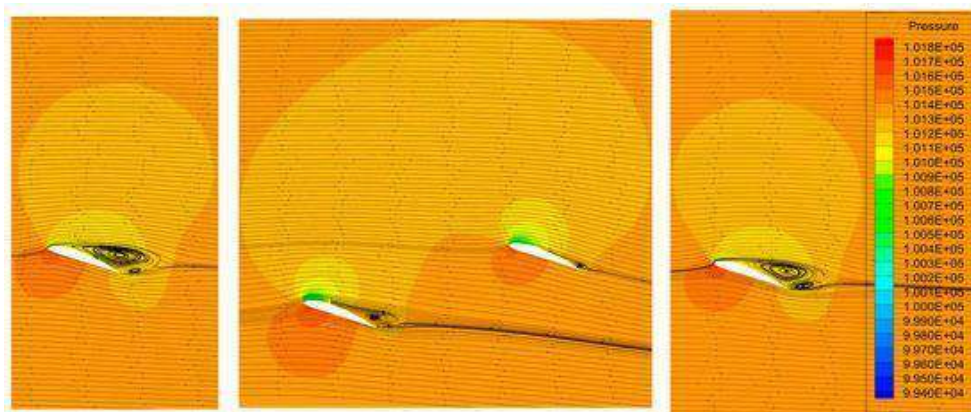


Figure 3. Streamline diagram of airflow through a tandem UAV propulsion system [17]

Figure 3 demonstrates that at a 20° tilt, the CA model's coupled flow forms a continuous low- pressure zone over both wings' upper surfaces, reducing leading-edge pressure and weakening trailing-edge separation vortices. The pressure distribution increases front-wing lift more than rear-wing lift.

2.4 Comparative discussion: single vs. tandem configurations

Table 2 shows that tandem UAVs offer higher propulsion efficiency and engine redundancy compared to single-engine designs but come with increased structural complexity, aerodynamic interference, and more demanding stability control.

Table 2. Comparison of Single vs. Tandem UAV Configurations

Feature	Single Engine UAV	Tandem Engine UAV	References
Structural Complexity	Low structural weight, simple integration, and fewer moving parts.	Moderate - High: increased frame length, reinforcement, and integration requirements for multiple engines.	[18]
Propulsion Efficiency	Efficiency declines in high-drag regimes due to single slipstream and lack of wake re-energization.	Optimized tandem spacing can improve propulsive efficiency by 8-12% in cruise via wake re-energization.	[13]
Redundancy	None; single point of failure can lead to mission loss.	High: dual engines provide redundancy and allow continued operation after partial failure.	[19-21]
Aerodynamic Interference	Minimal interaction effects due to isolated propeller slipstream.	Significant: downstream propellers experience disturbed inflow, asymmetric thrust, and additional drag penalties.	[13]

III. REVIEW OF TANDEM UAV ENGINE DESIGNS

3.1 Historical evolution and current trends

Tandem propulsion in UAVs has evolved from early dual-engine aircraft aimed at thrust balance to advanced distributed propulsion systems shown in figure 4. Rostami and Farajollahi [16] found that optimized spacing between tandem propellers enhances efficiency by about 6% due to wake re-energization. Kostić et al. [5] showed that tandem-wing UAVs improve lift distribution and stability, making them suitable for small-scale applications. Xiang et al. [17] highlighted the aerodynamic and control benefits of tandem tilt-wing UAVs for hybrid flight operations and urban air mobility.

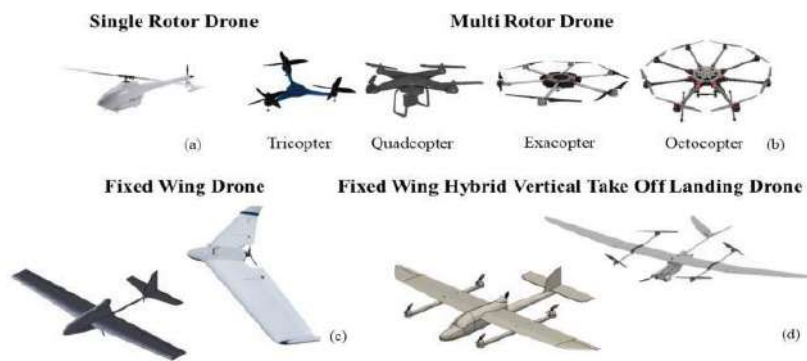


Figure 4. Evolution of UAV Propulsion: From Military to Agricultural Applications [22]

3.2 Experimental investigations: wind tunnel studies, flight tests

Experimental studies play a crucial role in understanding the aerodynamic interference and propulsive efficiency of tandem UAV configurations. Recent wind tunnel and flight test investigations have focused on the mutual interaction between front and rear propellers, wake overlap, and the resulting thrust distribution.

Algarotti et al. [23] conducted wind tunnel tests shown in figure 5 using Particle Image Velocimetry (PIV) to study overlapping tandem propellers. Their results showed a 15% thrust reduction at the rear propeller due to upstream wake effects, which could be minimized through optimized spacing and offset. Similarly, Zhou et al. [24] experimentally examined non-parallel dual-rotor systems for tiltrotor UAVs, revealing that

optimized alignment during transition flight can recover up to 12% thrust while reducing vibration and noise. Further, Foster et al. [25] validated these findings through flight tests, demonstrating that a small vertical offset between tandem propellers yields up to 18% power savings compared to aligned setups.

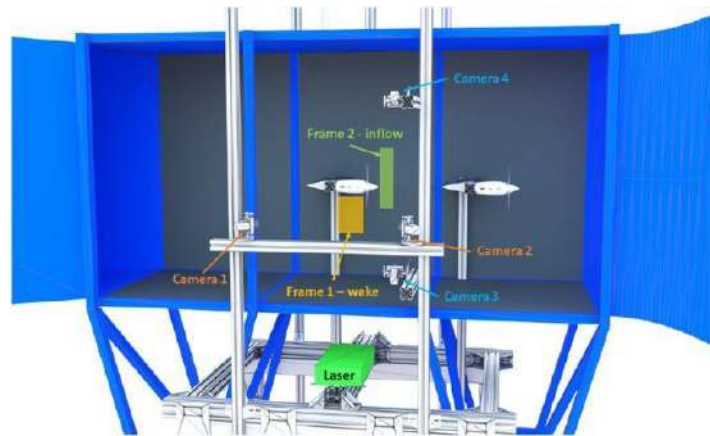


Figure 5. PIV Visualization of Tandem Propeller Wake Interaction in a Wind Tunnel [23]

All of this research concurs that experimental validation through wind tunnel and flight testing is necessary to improve aerodynamic performance in tandem UAV propulsion systems.

3.3 Numerical methods: CFD simulations for interaction between tandem propeller wakes

In order to evaluate wake interference and optimize the aerodynamic performance of tandem UAV propeller systems, computational fluid dynamics (CFD) techniques are frequently employed. These models provide for a detailed view of the flow fields, pressure distributions, and vorticity interactions between the front and back propellers phenomena that are sometimes difficult to represent experimentally

Zhang et al. [26] used Reynolds-Averaged Navier Stokes (RANS) simulations to examine the effects of tandem rotor spacing and found that an ideal longitudinal separation reduced wake- induced thrust losses by around 14%. Similarly, Wen et al. [27] conducted a numerical study on tandem-rotor forward autorotation, including modeling rotor-to-rotor interference and validating against wind tunnel data. The findings showed how thrust distribution is impacted by induced interference and inflow velocity distortion, and they recommended mitigation techniques using blade control and rotor spacing.

These CFD-based studies serve as a basis for experimental validation in tandem UAV design and offer insightful information for aerodynamic optimization.

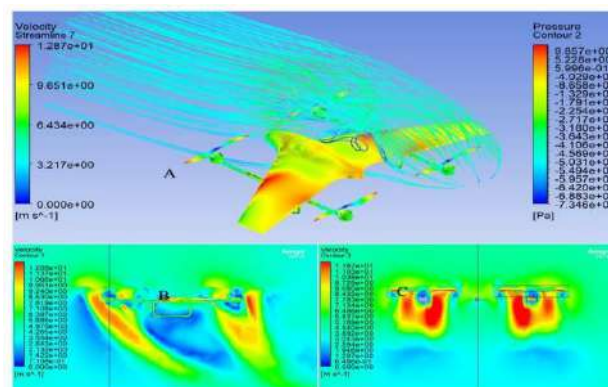


Figure 6. CFD Streamlines of Wake Interaction in Tandem Rotor Configuration

The CFD findings of a tandem rotor UAV are displayed in Figure 6, which demonstrates how the wake from the front propeller interacts with the rear rotor to generate patterns of pressure and velocity that impact lift distribution and aerodynamic efficiency.

IV. AERODYNAMIC PERFORMANCE EVALUATION

4.1 Lift-to-drag ratio impacts

In tandem UAV designs, the lift-to-drag (L/D) ratio is a key performance metric that determines endurance and aerodynamic efficiency. According to studies, propeller layouts that are dispersed or tandem can improve lift homogeneity along the wing span and reduce induced drag. Granata et al. [28] reported that tandem propellers reduce total drag by up to 9% through favorable wake alignment and pressure recovery effects, improving the overall L/D ratio under moderate advance ratios.

Similarly, de Vries et al. [29] demonstrated that distributed propulsion systems achieve up to 12% improvement in aerodynamic efficiency by reducing tip-vortex losses and flow asymmetry between propeller streams.

These findings confirm that tandem propulsion contributes positively to aerodynamic lift generation and cruise performance optimization.

4.2 Flow separation and vortex dynamics.

Flow separation and vortex dynamics are critical in determining the stability and control of tandem UAVs, especially during transition and climb phases. Cai et al. [30] examined the influence of vertically staggered propellers and found that appropriate offsetting delayed flow separation and enhanced wake uniformity, leading to smoother thrust distribution during forward flight.

Complementarily, Liu et al. [1] conducted wake visualization studies for tandem rotors and reported that well-managed wake separation reduces aerodynamic interference by 10–15% and stabilizes vortex trajectories, which directly improves vehicle maneuverability in low-altitude operations.

4.3 Energy efficiency and thrust distribution

Energy efficiency and thrust balance are directly influenced by the aerodynamic interactions of the front and rear propellers in tandem configurations. Kang et al. [31] experimentally analyzed inter- rotor spacing and discovered that a vertical offset of approximately 0.3 rotor diameters enhances thrust uniformity and reduces power losses by 11% under hovering conditions. Wu et al. [32] further verified that in tiltrotor UAVs, coordinated thrust redistribution during attitude transition can reduce energy consumption by up to 8%, contributing to improved endurance and reduced mechanical strain on propulsion components.

4.4 Influence of propeller spacing, alignment, and diameter ratio

The aerodynamic interference between front and rear rotors is highly sensitive to their spacing, alignment, and diameter ratio. Weishaupl et al. [33] demonstrated that partial propeller overlap in tandem setups causes significant efficiency penalties, while an optimized 10–15% spacing of rotor diameters yields improved propulsive efficiency in hover conditions. Moreover, Kostek et al. [34] studied vertical rotor alignment and found that propeller diameter ratio variations between 0.8-1.2 substantially affect wake interaction zones, influencing both lift balance and vibration characteristics.

These results underscore the importance of geometric optimization in achieving stable thrust performance and aerodynamic harmony in tandem UAV systems.

V. CONCLUSION

This review has synthesized recent advancements in the aerodynamics, propulsion, and control of tandem propeller UAVs, revealing significant progress in understanding their aerodynamic interactions and performance trade-offs. The literature demonstrates that tandem configurations can deliver superior thrust

efficiency, enhanced flight stability, and improved redundancy compared to conventional single-propeller systems. However, persistent challenges particularly wake interference, vibration coupling, and unsteady flow dynamics continue to constrain their overall aerodynamic potential.

Current studies highlight the necessity of integrated high-fidelity CFD coupled with fluid structure interaction (FSI) to accurately capture complex aerodynamic behaviors under varying flight regimes. Parallel developments in bio-inspired aerodynamic designs, hybrid-electric propulsion architectures, and smart morphing propeller technologies offer viable pathways to mitigate aerodynamic losses and enhance adaptability. Furthermore, the incorporation of AI-driven optimization and digital twin frameworks is emerging as a transformative approach for real-time aerodynamic tuning and predictive performance assessment.

In summary, while tandem propeller UAVs present substantial promise for next-generation aerial platforms, their full potential depends on the synergistic convergence of computational modeling, experimental validation, and intelligent design methodologies. Future research should focus on bridging these domains to enable UAVs that are not only aerodynamically efficient but also adaptive, resilient, and optimized for diverse defense and commercial missions.

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Existence Theorems for a System of Coupled Hybrid Fractional Differential Equations with Erdélyi-Kober Integral Boundary Conditions

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Abstract – In this work we prove the existence result of a coupled fractional differential system of hybrid type with Erdélyi-Kober integral boundary conditions. The main tool of our study is the fixed point technique in Banach algebra combined with a measure of noncompactness. An example is presented to illustrate our results.

Keywords – Fixed point theorem, Caputo fractional derivative, Erdélyi-Kober fractional integral, measure of noncompactness, coupled system of differential equations, Banach algebras.

I. INTRODUCTION

The study of coupled systems of fractional differential equations plays a crucial role in solving various applied problems, particularly in the biosciences. Hybrid fractional differential equations, which involve the fractional derivative of an unknown function combined with nonlinear terms, have been explored in several research works. Fixed point theory provides an effective framework for establishing existence results for such systems.

Earlier studies, such as those by B. Ahmad et al., focused on the existence of solutions for Dirichlet boundary value problems involving coupled hybrid fractional differential equations with Caputo derivatives. Building on these works, recent research has extended the analysis to nonlinear coupled systems with Erdélyi-Kober fractional integral boundary conditions. The system under consideration involves Caputo fractional derivatives of different orders, nonlinearities dependent on both state variables, and boundary conditions expressed through Erdélyi-Kober integrals.

These studies not only generalize earlier results but also offer new insights into the theoretical framework of hybrid fractional differential equations. They demonstrate the applicability of fractional calculus in modeling complex systems, with potential implications for the biosciences and other applied fields.

II. COUPLED SYSTEM OF NONLINEAR HYBRID FRACTIONAL DIFFERENTIAL EQUATIONS

We consider the coupled system of nonlinear hybrid fractional differential equations with Erdélyi-Kober integral boundary conditions:

$$\begin{aligned}
{}^{\wedge}\text{cD}^{\alpha_1} \left(\begin{array}{c} x(t) \\ y(t) \end{array} / \begin{array}{c} f_1(t, x(t), y(t)) \\ f_2(t, x(t), y(t)) \end{array} \right) &= \begin{array}{c} h_1(t, x(t), y(t)) \\ h_2(t, x(t), y(t)) \end{array}, & t \in J=[0, T], & 1 < \alpha_1 \leq 2 \\
{}^{\wedge}\text{cD}^{\alpha_2} \left(\begin{array}{c} x(t) \\ y(t) \end{array} / \begin{array}{c} f_1(t, x(t), y(t)) \\ f_2(t, x(t), y(t)) \end{array} \right) &= \begin{array}{c} h_1(t, x(t), y(t)) \\ h_2(t, x(t), y(t)) \end{array}, & t \in J=[0, T], & 1 < \alpha_2 \leq 2 \\
x(0) &= 0, & y(0) &= 0 \\
x(T) &= \beta_1 I_{\eta}^{\{\varepsilon, \lambda\}} y(\omega) & & x(\zeta)
\end{aligned}$$

Here, ${}^{\wedge}\text{cD}^{\alpha_1}$ and ${}^{\wedge}\text{cD}^{\alpha_2}$ denote the Caputo fractional derivatives of orders α_1 and α_2 , respectively. The functions $f_1, f_2 : J \times \mathbb{R} \times \mathbb{R} \rightarrow \mathbb{R} \setminus \{0\}$ and $h_1, h_2 : J \times \mathbb{R} \times \mathbb{R} \rightarrow \mathbb{R}$ are given functions. The constants β_1 and β_2 are real numbers. The operator $I_{\eta}^{\{\varepsilon, \lambda\}}$ represents the Erdélyi–Kober fractional integral of order $\lambda > 0$, with parameters $\eta > 0$ and $\varepsilon \in \mathbb{R}$, and $\zeta, \omega \in (0, T)$.

III. HYPOTHESES FOR THE COUPLED HYBRID FRACTIONAL DIFFERENTIAL EQUATIONS

Results should be clear and concise. The most important features and trends in the results should be described but should not interpreted in detail.

(H1) $f_1, f_2 \in C(I \times \mathbb{R} \times \mathbb{R}, \mathbb{R} \setminus \{0\})$ and $h_1, h_2 \in C(I \times \mathbb{R} \times \mathbb{R}, \mathbb{R})$.

(H2) There exist nonnegative constants $h_1^*, h_2^*, f_1^*, f_2^*$ such that:

$$|h_1(t, 0, 0)| \leq h_1^*, \quad |h_2(t, 0, 0)| \leq h_2^*$$

$$|f_1(t, 0, 0)| \leq f_1^*, \quad |f_2(t, 0, 0)| \leq f_2^*$$

for any $t \in I$.

(H3) The functions h_1, h_2 , and f satisfy the Lipschitz-type conditions:

$$|h_1(t, x_1, y_1) - h_1(t, x_2, y_2)| \leq \psi_1(|x_1 - x_2| + |y_1 - y_2|)$$

$$|h_2(t, x_1, y_1) - h_2(t, x_2, y_2)| \leq \psi_2(|x_1 - x_2| + |y_1 - y_2|)$$

$$|f_1(t, x_1, y_1) - f_1(t, x_2, y_2)| \leq \varphi_1(|x_1 - x_2| + |y_1 - y_2|)$$

$$|f_2(t, x_1, y_1) - f_2(t, x_2, y_2)| \leq \varphi_2(|x_1 - x_2| + |y_1 - y_2|)$$

for any $t \in I$, $x_1, x_2, y_1, y_2 \in \mathbb{R}$, where $\varphi_1, \varphi_2, \psi_1, \psi_2 \in \mathcal{A}$ and are continuous.

(H4) There exists $r_0 > 0$ such that the following inequalities hold:

$$(\varphi_1(r) + f_1^*) \cdot (\psi_1(r) + h_1^*) \leq 1 / (|(T^{\alpha_1+1} M_1)/\alpha_1| + |T^{\alpha_1}/(\alpha_1 \Gamma(\alpha_1))| + |(T^{\alpha_1+1} \beta_1 M_1 \Gamma(\varepsilon+1))/(\alpha_1 \Gamma(\varepsilon+\lambda+1))|) r$$

$$(\varphi_2(r) + f_2^*) \cdot (\psi_2(r) + h_2^*) \leq 1 / (|(T^{\alpha_2+1} M_2)/\alpha_2| + |T^{\alpha_2}/(\alpha_2 \Gamma(\alpha_2))| + |(T^{\alpha_2+1} \beta_2 M_2 \Gamma(\varepsilon+1))/(\alpha_2 \Gamma(\varepsilon+\lambda+1))|) r$$

Moreover,

$$[|(T^{\alpha_1+1} M_1)/\alpha_1| + |T^{\alpha_1}/(\alpha_1 \Gamma(\alpha_1))| + |(T^{\alpha_1+1} \beta_1 M_1 \Gamma(\varepsilon+1))/(\alpha_1 \Gamma(\varepsilon+\lambda+1))|] (\psi_1(r_0) + h_1^*) \leq 1/2,$$

$$[|(T^{\alpha_2+1} M_2)/\alpha_2| + |T^{\alpha_2}/(\alpha_2 \Gamma(\alpha_2))| + |(T^{\alpha_2+1} \beta_2 M_2 \Gamma(\varepsilon+1))/(\alpha_2 \Gamma(\varepsilon+\lambda+1))|] (\psi_2(r_0) + h_2^*) \leq 1/2.$$

where

$$M_1 = 1 / (\Gamma(\alpha_1) [T - \beta_1 (\zeta \Gamma(\varepsilon + 1/\eta + 1) / \Gamma(\varepsilon + 1/\eta + \lambda + 1))]),$$

$$M_2 = 1 / (\Gamma(\alpha_2) [T - \beta_2 (\zeta \Gamma(\varepsilon + 1/\eta + 1) / \Gamma(\varepsilon + 1/\eta + \lambda + 1))]).$$

IV. THEOREM

Assume that assumptions (H1)-(H4) holds, then the boundary value problem has at least one solution.

V. EXAMPLE

CONSIDER THE BOUNDARY VALUE PROBLEM:

Equation System

$$\begin{cases} {}^c D^{3/2} (x(t) / (1/2 + \ln|x(t)+y(t)+1|)) + 10^{-2} \arctan|x(t)+y(t)| = 0, & t \in I=[0,1], \\ {}^c D^{3/2} (x(t) / (1/4 + \tanh|x(t)+y(t)|)) + 10^{-2} \arctan|x(t)+y(t)| = 0, & t \in I=[0,1], \\ x(0) = 0, & y(0) = 0, \\ x(1) = I_{-}(1/2)^{(1/2,1)} x(1/2), \\ y(1) = I_{-}(1/2)^{(1/2,1)} y(1). \end{cases}$$

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Weak Solutions to Nonlinear Hybrid Fractional Differential Equations with Hadamard Integral Boundary Condition

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Abstract – This paper investigates the existence of solutions for hybrid fractional differential equations with Hadamard integral boundary conditions. We apply a fixed point theorem and the concept of weak noncompactness to establish the main result. An illustrative example demonstrating the existence result is also provided.

Keywords – Hadamard fractional derivative, boundary value problem, hybrid boundary conditions, Banach algebra, fixed point theorem, weak solution, measure of noncompactness.

I. INTRODUCTION

Fractional differential equations are widely applicable across various fields, including electrical networks, signal and image processing, viscoelasticity, aerodynamics, and economics. This broad applicability has led to a growing interest in fractional calculus from both theoretical and applied perspectives in recent years. A significant portion of the existing literature focuses on Riemann-Liouville and Caputo type fractional differential equations. Additionally, the Hadamard fractional derivative, introduced in 1892, has also gained attention. This derivative differs from Riemann-Liouville and Caputo derivatives in that its kernel contains a logarithmic function raised to an arbitrary exponent. The properties and details of the Hadamard fractional derivative and integral have been extensively studied in recent works. In recent years, the study of quadratic perturbations in nonlinear differential equations, often referred to as hybrid differential equations, has also become an area of increasing interest. Many studies have been dedicated to the theory behind hybrid differential equations, further expanding the understanding of fractional calculus.

I. Existence of Weak Solutions for Hybrid Boundary Value Problems with Hadamard Fractional Derivatives

We investigate in this paper the existence of weak solutions for a hybrid boundary value problem for fractional differential equations with Hadamard mixed boundary conditions of the form:

$$({}_H D^{\alpha} (x(t) / f(t, x(t))) = g(t, x(t)), \quad t \in (1, T], \quad 0 < \alpha \leq 1)$$

$$({}_H J^{1-\alpha} x(t)|_{t=1} + \mu \int_1^T x(s)/s \, ds = {}_H J^{1-\alpha} x(t)|_{t=T})$$

Here, ${}_H D^{\alpha}$ is the Hadamard fractional derivative, $f: J \times E \rightarrow E \setminus \{0\}$, and $g, h: J \times E \rightarrow E$ are continuous functions. E is a Banach space with norm $\|\cdot\|$ and $\mu \in \mathbb{R}^*$. Our main tool is a fixed point theorem in Banach algebras due to J. Banas and M. Aziz Taoudi, with respect to a weak measure of noncompactness.

The paper is organized as follows: in Section 2 we recall some preliminary facts that we need in the sequel, and in Section 3 we prove our main result.

II. Definition

A function $x \in C_{-1-\alpha}(I, E)$ is said to be a solution of the system if it satisfies both equations:

$$_H D^{\alpha} (x(t)/f(t, x(t))) = g(t, x(t)),$$

$$_H J^{1-\alpha} x(t)|_{t=1} + \mu \int_1^T x(s)/s \, ds = _H J^{1-\alpha} x(t)|_{t=T}.$$

III. Remark

The function $t \mapsto (\log t)^{1-\alpha} \int_1^T \|G(t, s)\| \, ds$ is continuous on I and hence is bounded. Let $\hat{Z}G = \sup \{ (\log t)^{1-\alpha} \int_1^T \|G(t, s)\| \, ds : t \in I \}$.

IV. Hypotheses

(H1) For each $x \in X$, $f(\cdot, x) : I \rightarrow C_{-1-\alpha}(I, E)$ is continuous.

(H2) $f : I \times E \rightarrow E$ is weakly sequentially continuous and there exists C_f such that $\|f(t, r) - f(t, s)\| \leq C_f \|r - s\|$ for all $r, s \in E$.

(H3) For each $x \in C_{-1-\alpha}(I, E)$, the function $g(\cdot, x(\cdot))$ is Pettis integrable on I .

(H4) For each $t \in I$, the function $g(t, \cdot)$ is weakly sequentially continuous.

(H5) For any $r > 0$, there exists a non-negative constant h_r with $\|g(t, x(t))\| \leq h_r$ for all $t \in I$ and all $x \in C_{-1-\alpha}(I, E)$ with $\|x\| \leq r$.

V. Theorem

Let E be a reflexive Banach algebra and suppose (H1)–(H5) hold. If there exists $r_0 > 0$ such that:

$$C_f \hat{Z}G h_{r_0} < 1,$$

$$\text{and } (\|f(t, 0)\| \hat{Z}G h_{r_0}) / (1 - C_f \hat{Z}G h_{r_0}) \leq r_0,$$

then the system has a solution in $C_{-1-\alpha}(I, E)$.

VI. Example

As an application of our results we consider the following partial fractional differential equations:

$$_H D^{\alpha} (x(t) / (1/5 e^{-t} + x(t))) = (1/(7 e^{t+1}))(1 + x(t)), \quad \forall t \in (1, e].$$

$$_H J^{1-\alpha} x(1) + \int_1^e x(s)/s \, ds = _H J^{1-\alpha} x(0).$$

It is easily seen that $f(t, x)$ verifies conditions (H1) and (H2) with Lipschitz constant $C_f = 1$. For each $x \in \mathbb{R}$ and $t \in [1, e]$ we have $|g(t, x)| = (1/(7 e^{t+1}))(1 + |x|)$. Hence conditions (H3), (H4), and (H5) are satisfied with $h_r = (1/7)(1+r)$.

From Green's function representation, we deduce that $\hat{Z}G \leq 3$. For $r_0 = 1/2$, the conditions are satisfied. Consequently, the theorem implies that the problem has a solution defined on $[1, e]$.

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Empathy in Action: Can Motivational Interviewing Improve Quality of Life in Substance Use Disorders?

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Introduction

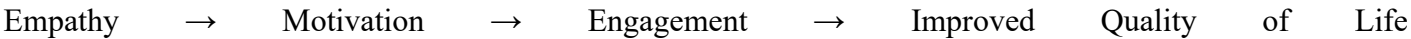
Substance Use Disorders (SUDs) remain one of the most complex public health issues globally, characterized by chronic relapse, social marginalization, and profound effects on mental and physical health (World Health Organization [WHO], 2022; United Nations Office on Drugs and Crime [UNODC], 2023). The burden extends beyond individuals to families and communities, influencing social cohesion, productivity, and economic stability. In Albania, as in many developing healthcare systems, treatment approaches have historically emphasized medical detoxification and punitive frameworks rather than psychosocial rehabilitation. But how difficult is to change a habit that runs your life for years....? Are people who suffer from addiction so willing to change..?! Is it enough to dictate what is best to do, or not to do....?! Motivational Interviewing (MI), developed by Miller and Rollnick in the 1980s, represents a paradigm shift from traditional directive counseling to a collaborative, patient-centered dialogue that emphasizes empathy, respect, and intrinsic motivation (Miller & Rollnick, 2013). MI's philosophical foundation is humanistic, recognizing that individuals possess an inherent drive toward growth and self-determination (Deci & Ryan, 2000). The method is guided by four core principles—expressing empathy, developing discrepancy, rolling with resistance, and supporting self-efficacy—which collectively facilitate behavioral change. Motivational Interviewing has been established as an effective method for promoting behavior change in various medical and psychiatric contexts. Meta-analyses by Smedslund et al. (2011) and Lundahl et al. (2013) confirm MI's moderate effect sizes for reducing substance use and enhancing treatment engagement. These studies underline MI's adaptability and cross-cultural applicability, making it suitable for diverse populations, including those in low-resource environments.

The concept of empathy serves as MI's cornerstone. Empathy fosters trust and therapeutic alliance, allowing patients to perceive themselves as active participants rather than passive recipients of care (Decety &

Fotopoulou, 2015). In addiction treatment, empathic communication mitigates stigma, supports identity reconstruction, and strengthens commitment to recovery (Neumann et al., 2012). Many studies demonstrated that high levels of empathy and effective patient–provider communication are strongly correlated with improvements in QoL and treatment satisfaction.

From an educational perspective, the integration of MI into medical and psychology curricula enhances trainees’ communication competence and self-awareness. By training clinicians to apply reflective listening and motivational dialogue, healthcare systems can move toward more compassionate, patient-centered care models.

Figure 1. Conceptual Framework of MI and Quality of Life



The conceptual framework illustrates how empathy acts as a catalyst for motivation and engagement, leading to enhanced QoL in addiction recovery.

Aim

This study explores the impact of MI on Quality of Life (QoL), motivation for change, and treatment engagement among individuals with SUDs in Albania. The research provides empirical evidence and contextual insight into how empathy-based communication may enhance addiction recovery within a region where such therapeutic approaches remain underutilized.

Method

A prospective comparative study was conducted at the Addiction Service of a private hospital in Tirana from January 2023 to March 2024. Ethical approval was granted by the institutional review board. Fifty-four participants diagnosed with substance or alcohol dependence under ICD-10 criteria were enrolled. Participants were randomly assigned to two groups: an experimental group (n = 27) receiving MI integrated with standard care and a control group (n = 27) receiving standard care only.

Eligibility criteria included adults aged 18–65 who completed detoxification and provided informed consent. Exclusion criteria comprised severe cognitive impairment or psychosis. The MI intervention consisted of 12 structured sessions delivered by trained therapists over six months. Sessions emphasized exploring ambivalence, reinforcing self-efficacy, and setting individualized recovery goals.

Table 1. Baseline Characteristics of Participants

Variable	MI Group	Control Group
Age (mean, SD)	36.5 (8.3)	37.1 (8.1)
Gender (% male)	82	84
Alcohol use (%)	41	39
Cannabis use (%)	25	27
Opioid use (%)	23	25
Poly-use (%)	11	9

Results

Baseline demographic and clinical variables were similar across groups ($p < .05$). At 14 months, the MI group demonstrated significantly greater improvements in all QoL domains compared to controls. The greatest gains were seen in the psychological and social domains, reflecting better emotional regulation, self-esteem, and interpersonal functioning.

Figure 3. Improvement in Quality of Life Domains After 14 Months

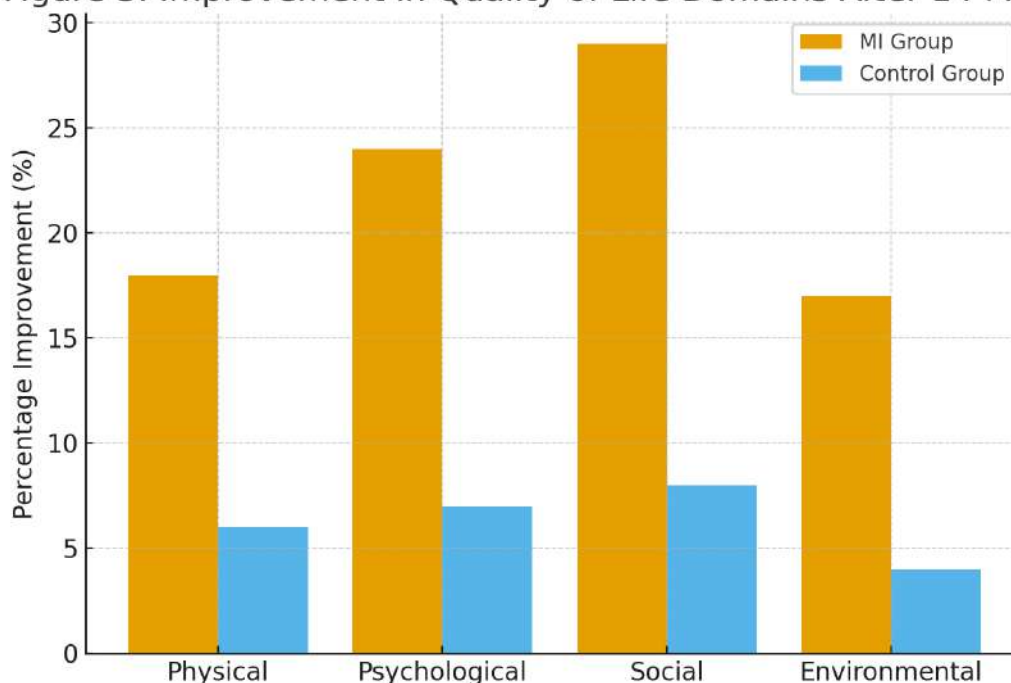


Figure 3. Improvement in Quality of Life Domains After 14 Months. The MI group exhibited 18–29% increases across physical, psychological, social, and environmental domains, compared to 4–8% in controls.

Figure 4. Motivation and Relapse Outcomes in MI vs. Control Gr

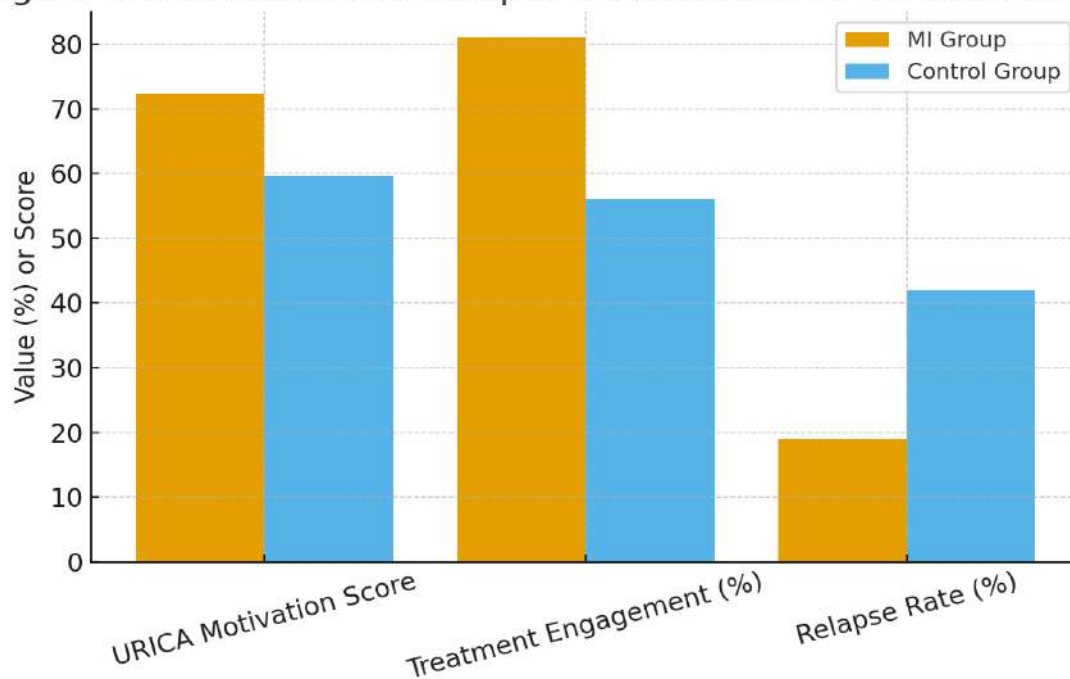


Figure 4. Motivation and Relapse Outcomes in MI vs. Control Groups. MI participants achieved higher URICA motivation scores ($M = 72.3$ vs. 59.7), greater engagement (81% vs. 56%), and lower relapse rates (19% vs. 42%).

Discussion

The findings reinforce that empathy-based communication through MI significantly improves QoL, motivation, and engagement among individuals with SUDs. These results align with global literature, confirming that MI produces moderate yet consistent benefits across healthcare settings (Lundahl et al., 2013). MI's effectiveness lies not in coercion but in collaboration—helping patients articulate their values and align them with behavioral goals (Miller & Rollnick, 2013).

In the Albanian context, MI represents more than a therapeutic method; it symbolizes a systemic and cultural transformation. Historically, medical communication in Albania has been hierarchical, often leaving patients disempowered. By adopting MI, healthcare professionals can cultivate empathy and partnership, reshaping addiction care into a more compassionate, person-centered system.

Empathy also plays an educational role. Integrating MI into university curricula for psychiatry, psychology, and social work enhances professional competence and emotional intelligence. Such integration ensures that empathy becomes an operational skill rather than an abstract ideal. In broader terms, MI's empathetic principles can improve mental health literacy and public attitudes toward addiction.

The sustained improvements in QoL observed here suggest that MI facilitates deeper behavioral internalization. Participants' self-reported growth in emotional stability and family relationships demonstrates MI's ability to heal not only individuals but social systems impacted by addiction. Nonetheless, limitations include small sample size, single-center design, and self-report measures, which may introduce bias. Future research should

employ longitudinal designs and expand to community-based samples. Further investigation into MI's neuropsychological correlates—such as reward sensitivity and emotional regulation—could deepen understanding of its mechanisms.

Conclusion

Motivational Interviewing emerges as a robust, empathy-driven approach capable of improving Quality of Life, motivation, and treatment adherence among individuals with substance and alcohol dependence. The method's success lies in its humanistic foundation—empowering individuals to discover intrinsic motivation for change through respectful dialogue. In Albania and similar health systems, integrating MI into standard addiction treatment and medical education can advance recovery-oriented and patient-centered care models.

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İngilizce Öğretmenleri İçin Üretken Yapay Zekâ (ÜYZ) Okuryazarlığı Ölçeği: Geçerlik ve Güvenirlik Analizi

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Özet – Bu araştırmanın amacı, İngilizce öğretmenleri için geliştirilen Üretken Yapay Zekâ (ÜYZ) Okuryazarlığı Ölçeği'nin Türkçeye uyarlanması ve psikometrik özelliklerinin incelenmesidir. Eğitimde yapay zekâ teknolojilerinin hızla yaygınlaşması, öğretmenlerin yalnızca bu teknolojileri kullanma değil, aynı zamanda onları pedagojik, etik ve eleştirel bir bakış açısıyla değerlendirme becerilerini geliştirmelerini gerektirmektedir. Bu bağlamda, öğretmenlerin ÜYZ okuryazarlık düzeylerini geçerli ve güvenilir biçimde ölçebilecek bir araca duyulan gereksinim artmıştır.

Araştırma, betimsel tarama modeli kapsamında yürütülmüştür. Ölçeğin uyarlama sürecinde ileri–geri çeviri yöntemi uygulanmış, beş uzmandan (ölçme-değerlendirme, dilbilim ve eğitim teknolojisi alanlarından) görüş alınmış ve 25 öğretmenle pilot çalışma yapılmıştır. Veriler, Türkiye'nin farklı illerinde görev yapan 209 İngilizce öğretmeninden çevrim içi olarak toplanmıştır. Analizler Jamovi 2.4 programında gerçekleştirilmiş, ölçeğin yapı geçerliğini sınamak için Doğrulamalı Faktör Analizi (DFA) uygulanmıştır.

DFA sonuçları, beş faktörlü yapının Türkçe formda da korunduğunu göstermiştir ($\chi^2/df = 2.43$, CFI = .926, TLI = .919, RMSEA = .083, SRMR = .066). Cronbach's α ve McDonald's ω değerleri tüm boyutlarda .90'ın üzerinde bulunmuştur. Bulgular, ölçeğin yüksek düzeyde geçerli ve güvenilir bir ölçme aracı olduğunu göstermektedir. Sonuç olarak, bu ölçek, öğretmenlerin ÜYZ yeterliklerini bilişsel, uygulamalı ve etik boyutlarda değerlendirmek için Türkçe alanyazına güçlü bir katkı sunmaktadır.

Anahtar Kelimeler – Üretken Yapay Zekâ, Öğretmen Okuryazarlığı, Ölçek Uyarlama, Doğrulamalı Faktör Analizi, Geçerlik ve Güvenirlik

1. GİRİŞ

Yapay zekânın (YZ) farklı sektörlerde hızla yaygınlaşması, eğitim alanını da köklü biçimde dönüştürmektedir. Özellikle üretken yapay zekâ (ÜYZ) uygulamaları; metin, görsel ve ses üretimi gibi çok kipli (multimodal) olanaklarıyla öğrenme süreçlerini kişiselleştirmeyi, anlık uyarlamayı ve bireysel farklara göre içerik sunmayı mümkün kılmaktadır. UNESCO'nun GenAI rehberi, eğitimde insan merkezli ve güvenli bir entegrasyon için politika, öğretmen niteliği ve etik çerçevenin birlikte ele alınmasını önermektedir. Bu bağlamda, ÜYZ'nin eğitimde fırsatlar kadar riskler (mahremiyet, doğruluk, akademik dürüstlük) barındırdığı vurgulanmaktadır (UNESCO, 2025).

Son yıllarda yapılan derleme ve ampirik çalışmalar, ÜYZ'nin kişiselleştirilmiş öğrenme kapasitesi sayesinde ders içeriğini öğrencinin bilgi düzeyine dinamik biçimde uyarlayabildiğini; öğretmenin rolünün “bilgi aktarıcı”dan “öğrenme tasarımcısı ve kolaylaştırıcı”ya evrildiğini göstermektedir (Chan & Tsi, 2023; Oh & Ahn, 2024). Dil öğretimi özelinde yayımlanan sistematik incelemeler, ÜYZ araçlarının yazma/geri bildirim, içerik üretimi, görev tasarımı ve değerlendirme gibi alanlarda öğretmenin iş yükünü azalttığını; aynı zamanda öğrenen özerkliğini desteklediğini, ancak bu teknolojilerin pedagojik ve etik

farkındalıkla kullanılmasının zorunlu olduğunu ortaya koymaktadır (Al-Abdullatif, 2024; Pokrivcakova, 2019; Wang vd., 2025).

Bu dönüşüm, öğretmenlerin ÜYZ okuryazarlığı ve teknoloji kabulü dinamiklerini eğitim teknolojileri araştırmalarının merkezine taşımıştır. Öğretmenlerin ÜYZ'yi benimseme düzeyleri; algılanan yararlılık, kullanım kolaylığı, öz-yeterlik ve pedagojik inançlarla ilişkili bulunmakta, dolayısıyla öğretmen eğitimi programlarında ÜYZ okuryazarlığının sistematik olarak geliştirilmesi önerilmektedir (Balıkçı & Yıldız Durak, 2025a; Venkatesh & Bala, 2008). Türkiye örnekleminde yürütülen çalışmalar (Balıkçı & Alpsülün, 2025; Balıkçı & Yıldız Durak, 2025b) öğretmenlerin YZ'ye yönelik olumlu tutum geliştirdiklerinde teknolojiyi daha etkili kullandıklarını, etik farkındalıklarının ve pedagojik uyarlama becerilerinin arttığını göstermektedir. Bu bulgular, öğretmenlerin yalnızca teknolojiyi kullanma değil, onu eleştirel ve etik biçimde değerlendirme sorumluluğuna da sahip olmaları gerektiğini göstermektedir.

Bu gereksinim doğrultusunda Wang vd., (2025) tarafından İngilizce öğretmenleri için geliştirilen Üretken Yapay Zekâ (ÜYZ) Okuryazarlığı Ölçeği, beş boyut (bilgi, kullanım, değerlendirme, tasarım ve etik) ve çok boyutlu yapısıyla alanyazında öne çıkmıştır. Ancak ölçeğin farklı kültür ve dillerdeki öğretmen örneklemelerinde psikometrik olarak doğrulanması gerekmektedir. Bu çalışma, söz konusu ölçeğin Türkçeye uyarlanmasını ve geçerlik-güvenirlik özelliklerinin İngilizce öğretmenleri örnekleminde incelenmesini amaçlamaktadır. Böylece, öğretmen eğitimi programlarında ÜYZ yeterliklerinin değerlendirilmesine ve okullarda YZ teknolojilerinin etik, pedagojik ve sürdürülebilir entegrasyonuna yönelik kanıt temelli katkı sunulması hedeflenmektedir.

II. MATERYAL VE YÖNTEM

A. Araştırma Deseni

Bu çalışma, İngilizce öğretmenlerinin Üretken Yapay Zekâ (ÜYZ) okuryazarlığına yönelik geliştirilmiş bir ölçeğin Türkçeye uyarlanması ve psikometrik özelliklerinin incelenmesi sürecini kapsamaktadır. Ölçeğin özgün formu Wang vd. (2025) tarafından geliştirilmiş olup, bu çalışmada Türkçe formun dil eşdeğerliği, kapsam geçerliği, yapı geçerliği ve güvenirliğinin incelenmesi amaçlanmıştır. Araştırma, nicel araştırma yöntemlerinden betimsel tarama modeli kapsamında yürütülmüştür. Bu desen, mevcut bir durumu olduğu gibi, sistematik biçimde betimlemeyi amaçlamaktadır (Karasar, 2015).

B. Katılımcılar

Araştırmanın örneklemini, Türkiye'nin farklı illerinde görev yapan toplam 209 İngilizce öğretmeni oluşturmaktadır. Katılımcıların yaş ortalaması 36.00 olup, yaş aralığı 22–61 arasında değişmektedir (SS = 8.55). Katılımcıların %75.6'sı kadın (n = 158), %24.4'ü erkek (n = 51) öğretmenlerden oluşmaktadır. Katılımcıların tamamı aktif olarak devlet veya özel okullarda İngilizce öğretmeni olarak görev yapmaktadır.

C. Ölçek Uyarlama Süreci

Uyarlama süreci, Beaton vd. (2000) ve Hambleton & De Jong (2003) tarafından önerilen aşamalar izlenerek gerçekleştirilmiştir. Bu kapsamda:

Çeviri (Forward Translation):

Ölçeğin özgün İngilizce formu, yapay zekâ ve eğitim teknolojileri alanında uzman iki akademisyen tarafından bağımsız olarak Türkçeye çevrilmiştir. Her iki çeviri, anlam ve kavramsal eşdeğerlik açısından karşılaştırılmıştır.

Uzman Değerlendirmesi (Expert Panel Review):

Oluşturulan Türkçe taslak form, beş uzmandan (üç eğitim teknolojisi, bir ölçme-değerlendirme, bir dilbilim uzmanı) oluşan kurul tarafından incelenmiştir. Uzmanlar, her maddeyi “anlam uygunluğu”, “dil akıcılığı” ve “kültürel geçerlik” ölçütlerine göre değerlendirmiştir. Uzman görüşleri doğrultusunda üç maddede küçük dilsel uyarlamalar yapılmıştır.

Geri Çeviri (Back Translation):

Revize edilen Türkçe form, ana dili İngilizce olan iki dil uzmanı tarafından yeniden İngilizceye çevrilmiştir. Bu çeviriler, özgün ölçekle karşılaştırılarak anlamsal tutarlılığı doğrulanmıştır.

Ön Uygulama (Pilot Test):

Nihai Türkçe form, 25 İngilizce öğretmenine ön deneme olarak uygulanmıştır. Katılımcılardan alınan geri bildirimler doğrultusunda, madde ifadelerinde anlam kaybına neden olabilecek hiçbir unsur bulunmamıştır. Bu nedenle ölçek formu, esas uygulamaya hazır hale getirilmiştir.

D. Veri Toplama Aracı

Üretken Yapay Zekâ Okuryazarlığı Ölçeği (Generative Artificial Intelligence Literacy Scale)”, Wang vd. (2025) tarafından geliştirilmiş olup, öğretmenlerin üretken yapay zekâ teknolojilerine yönelik bilgi (8 madde), kullanım (9 madde), tasarım (6 madde), değerlendirme (5 madde) ve etik (4 madde) yeterliklerini ölçmeyi amaçlamaktadır. Toplam 32 maddeden ve beş faktörden oluşan ölçek, 5’li Likert tipi (1 = Kesinlikle Katılmıyorum, 5 = Kesinlikle Katılıyorum) bir derecelendirmeye sahiptir. Tüm maddeler olumlu ifadelerden oluşmakta, ters madde içermemektedir.

Ölçeğin orijinal formundaki bileşik güvenirlik (CR) katsayıları .83 ile .95 arasında değişmektedir. Bu bulgu, alt boyutların yüksek iç tutarlılığa sahip olduğunu göstermektedir. Türkçe formun geçerlik ve güvenirlik analizleri bu çalışmada yeniden incelenmiştir.

E. Veri Toplama Süreci

Veriler, çevrim içi form aracılığıyla gönüllü katılımcılardan toplanmıştır. Katılımcılara araştırmanın amacı, gizlilik ilkeleri ve gönüllülük esasları açıklanmıştır. Ölçek uygulaması ortalama 8–10 dakika sürmüştür. Veri setinde eksik veya uç değer bulunmadığı için herhangi bir müdahale yapılmamıştır.

F. Veri Analizi

Verilerin analizinde Jamovi 2.4 istatistik yazılımı kullanılmıştır. Ölçeğin Türkçe formunun yapı geçerliğini sınamak amacıyla Doğrulamalı Faktör Analizi (DFA) uygulanmıştır. DFA’da modelin uyum düzeyi aşağıdaki indekslerle değerlendirilmiştir: χ^2/df , RMSEA, CFI, TLI ve SRMR (Hu & Bentler, 1999). Ayrıca, alt boyutların iç tutarlılığını değerlendirmek için Cronbach’s α ve McDonald’s ω güvenirlik katsayıları hesaplanmıştır.

Ön varsayımlar (çoklu normallik, aykırı değer, çoklu doğrusal ilişki) kontrol edilmiştir. Gerekli durumlarda robust (sağlam) analiz teknikleri tercih edilmiştir. DFA sonucunda elde edilen model uyum indeksleri, ölçeğin Türkçe formunun yapı geçerliğini desteklemiştir.

III. BULGULAR

A. Doğrulamalı Faktör Analizi (DFA) Sonuçları

Uyarlanan Üretken Yapay Zekâ (ÜYZ) Okuryazarlığı Ölçeği’nin beş faktörlü modeline ilişkin Doğrulamalı Faktör Analizi (DFA) sonuçları, modelin iyi düzeyde uyum gösterdiğini ortaya koymuştur. Modelin genel uyum indeksleri aşağıda sunulmuştur:

χ^2 (df = 449) = 1091, $p < .001$; χ^2/df = 2.43; CFI = .926; TLI = .919; RMSEA = .083 [90% CI: .076–.089]; SRMR = .066; GFI = .873; AGFI = .842.

Bu değerler, Hu & Bentler (1999) ve Kline (2016) tarafından önerilen ölçütlerle karşılaştırıldığında, modelin kabul edilebilir düzeyde uyum gösterdiğini göstermektedir (CFI ve TLI $\geq .90$, SRMR $\leq .08$, RMSEA $\leq .08$).

Ayrıca, Hoelter kritik örneklem büyüklüğü (CN = 97) modelin mevcut örneklem büyüklüğü ($n = 209$) için yeterli olduğunu göstermektedir. Bu bulgular, beş faktörlü modelin Türk öğretmen örnekleminde istatistiksel olarak anlamlı ve kuramsal olarak tutarlı olduğunu ortaya koymaktadır.

Tablo 1. ÜYZ Okuryazarlığı Ölçeğinin Uyum İndeksleri

Uyum İndeksi	Değer	Kabul Edilebilir Aralık*
CFI	0.926	≥ 0.90
TLI	0.919	≥ 0.90
RMSEA	0.083 [0.076–0.089]	≤ 0.08 (sınırdaki iyi)
SRMR	0.066	≤ 0.08
GFI	0.873	≥ 0.85
AGFI	0.842	≥ 0.80

B. Faktör Yükleri ve Madde Geçerliliği

Her bir maddeye ilişkin standartlaştırılmış faktör yükleri (β), .57 ile .95 arasında değişmiştir ve tüm yükler $p < .001$ düzeyinde anlamlı bulunmuştur. Bu durum, ölçek maddelerinin kendi faktörlerini güçlü biçimde temsil ettiğini göstermektedir.

Tablo 2. ÜYZ Okuryazarlığı Ölçeği Türkçe Formuna Ait Faktör Yükleri

Faktör	Madde Kodu	β	p	Açıklama
Bilgi	B1–B8	.57 – .95	<.001	Tüm yükler anlamlı, özellikle B3–B5 > .90
Kullanım	K1–K9	.82 – .92	<.001	Uygulama yeterliği yüksek, β ort. = .88
Tasarım	T1–T6	.79 – .92	<.001	Pedagojik tasarım becerileri güçlü
Değerlendirme	D1–D5	.91 – .95	<.001	En yüksek yükler bu boyutta
Etik	E1–E4	.91 – .95	<.001	Yüksek etik farkındalık gösteriyor

Faktör yükleri incelendiğinde, özellikle Etik (.91–.95) ve Değerlendirme (.91–.95) alt boyutlarında çok güçlü ilişkiler olduğu görülmektedir. Bu sonuç, öğretmenlerin üretken yapay zekâ teknolojilerine yönelik etik ve değerlendirme temelli farkındalıklarının belirgin olduğunu göstermektedir.

C. Faktörler Arası Korelasyonlar

Beş faktör arasındaki korelasyonlar yüksek ve anlamlı düzeyde bulunmuştur. En yüksek korelasyon Bilgi–Kullanım ($r = .82$) arasında, en düşük korelasyon ise Tasarım–Etik ($r = .26$) arasında gözlenmiştir.

Tablo 3. Faktörler Arası Korelasyon Matrisi

Faktörler	1	2	3	4	5
1. Bilgi	1	.82	.55	.74	.58
2. Kullanım	—	1	.62	.73	.59
3. Tasarım	—	—	1	.53	.26
4. Değerlendirme	—	—	—	1	.73
5. Etik	—	—	—	—	1

Tüm korelasyonlar $p < .001$ düzeyinde anlamlıdır. Bu sonuçlar, faktörlerin birbirini destekleyen ama ayırt edilebilir yapılar olduğunu göstermektedir. Özellikle Bilgi–Kullanım ve Değerlendirme–Etik boyutları arasındaki yüksek ilişkiler, öğretmenlerin ÜYZ teknolojilerini hem pedagojik hem de etik çerçevede bütüncül biçimde değerlendirdiğini göstermektedir.

D. Güvenirlilik ve Yakınsak Geçerlik Bulguları

Alt boyutlara ilişkin Cronbach's α , McDonald's ω ve Ortalama Açıklanan Varyans (AVE) değerleri Tablo 3'te sunulmuştur.

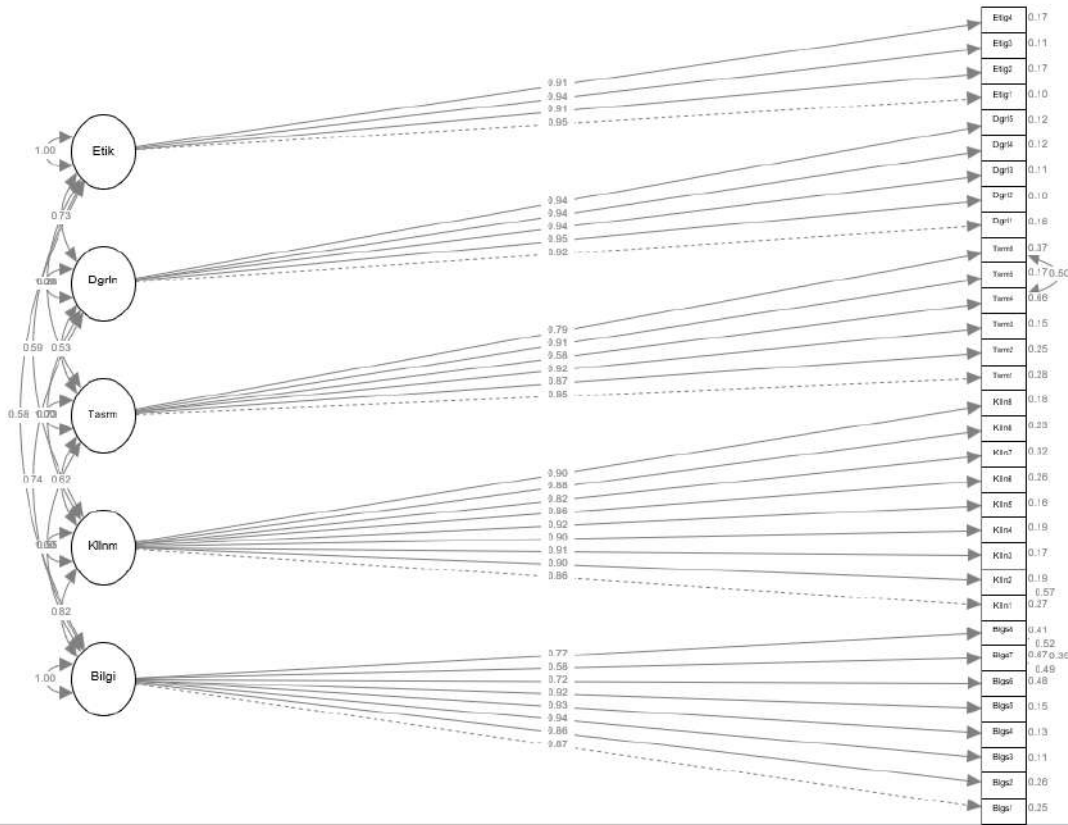
Tablo 4. ÜYZ Okuryazarlığı Ölçeği Türkçe Formu Güvenirlilik Göstergeleri

Boyut	Cronbach's α	McDonald's ω	AVE	Açıklama
Bilgi	.950	.919	.699	Yüksek iç tutarlılık
Kullanım	.970	.966	.778	Çok yüksek güvenilirlik
Tasarım	.924	.902	.669	Kabul edilebilir düzeyde yüksek
Değerlendirme	.973	.973	.878	Mükemmel iç tutarlılık
Etik	.961	.962	.862	Mükemmel iç tutarlılık

Tüm alt boyutlarda α ve $\omega > .90$, AVE $> .50$ değerleri sağlanmıştır. Bu bulgular ölçeğin yüksek iç tutarlılığa ve yakınsak geçerliğe sahip olduğunu göstermektedir (Fornell & Larcker, 1981). En yüksek AVE değerinin “Değerlendirme” boyutunda görülmesi, öğretmenlerin ÜYZ araçlarını pedagojik etkinlik, doğruluk ve güvenilirlik açısından değerlendirme becerilerinin belirgin olduğunu göstermektedir.

E. Modifikasyon Önerileri ve Modelin Son Durumu

DFA çıktısındaki modifikasyon indeksleri incelendiğinde, bazı madde çiftleri arasında anlamlı hata kovaryansları önerilmiştir (örneğin, Kullanım8–Kullanım9, Tasarım1–Tasarım2, Etik2–Etik4). Bu öneriler teorik olarak tutarlı bulunmuş ve sınırlı sayıda hata kovaryansı modele eklenmiştir. Bu eklemeler modelin genel uyum indekslerini iyileştirmiştir (CFI'nin .912'den .926'ya, TLI'nin .905'ten .919'a yükselmesi).



Şekil 1. ÜYZ Okuryazarlığı Ölçeği Beş Faktörlü DFA Modeli

IV. TARTIŞMA

Bu çalışmanın amacı, Wang vd. (2025) tarafından geliştirilen Üretken Yapay Zekâ (ÜYZ) Okuryazarlığı Ölçeği'nin Türkçeye uyarlanması ve geçerlik-güvenirlilik özelliklerinin İngilizce öğretmenleri örnekleminde incelenmesidir. Elde edilen bulgular, ölçeğin beş faktörlü yapısının Türkçe formda da korunduğunu ve modelin iyi düzeyde uyum sağladığını göstermiştir. DFA sonuçlarında elde edilen CFI = .926, TLI = .919, RMSEA = .083 ve SRMR = .066 değerleri, modelin istatistiksel olarak kabul edilebilir uyum düzeyinde olduğunu ortaya koymaktadır. Bu sonuçlar, beş faktörlü yapının teorik temellerle uyumlu ve kültürel olarak geçerli olduğunu desteklemektedir.

Yüksek düzeyde gözlenen iç tutarlılık değerleri (Cronbach's α = .924-.973; McDonald's ω = .902-.973), ölçeğin alt boyutlarının güvenilir ölçümler sunduğunu göstermektedir. Bu bulgu, orijinal çalışmada Wang vd. (2025) tarafından raporlanan .83-.95 aralığındaki güvenilirlik değerleriyle tutarlıdır. Ayrıca AVE değerlerinin .66-.87 arasında değişmesi, ölçeğin her bir boyutunun ilgili yapıyı yüksek oranda temsil ettiğini, yani yakınsak geçerliğin sağlandığını göstermektedir (Fornell & Larcker, 1981).

Beş faktör arasındaki anlamlı korelasyonlar (örneğin, Bilgi-Kullanım r = .82, Değerlendirme-Etik r = .73) ÜYZ okuryazarlığının çok boyutlu ama birbirine bağlı bir yapı olduğunu ortaya koymaktadır. Bu durum, öğretmenlerin üretken yapay zekâyı yalnızca teknik bilgi olarak değil, aynı zamanda pedagojik, etik ve tasarımsal bir süreç olarak ele aldıklarını göstermektedir. Bu bulgu, Venkatesh ve Bala'nın (2008) teknoloji kabul modelinde vurgulanan "algılanan yararlılık" ve "kullanım kolaylığı" değişkenlerinin öğretmenlerin pedagojik inançlarıyla yakından ilişkili olduğu sonucunu desteklemektedir.

Literatürdeki benzer uyarlama çalışmalarında da (ör. Balıkçı & Yıldız Durak, 2025a; Balıkçı & Alpsülün, 2025) öğretmenlerin yapay zekâ teknolojilerine yönelik farkındalıklarının ve etik

duyarlılıklarının, teknoloji entegrasyonunun niteliğini doğrudan etkilediği belirtilmiştir. Bu bağlamda, elde edilen sonuçlar, Türk öğretmen örnekleminde ÜYZ'nin pedagojik ve etik yönlerinin, kullanım boyutuyla birlikte güçlü bir biçimde yapılandığını göstermektedir. Özellikle “etik” boyutunda elde edilen yüksek faktör yükleri (.91–.95) öğretmenlerin yapay zekâ uygulamalarına ilişkin mahremiyet, adalet ve doğruluk gibi değerler konusundaki farkındalıklarının belirgin olduğunu göstermektedir. Bu durum, UNESCO'nun (2025) GenAI for Education kılavuzunda vurgulanan “insan merkezli ve güvenli entegrasyon” ilkesiyle örtüşmektedir.

Ayrıca, tasarım boyutuna ilişkin yüklerin yüksek çıkması ($\beta = .79-.92$), öğretmenlerin yapay zekâyı yalnızca bir araç olarak değil, öğrenme ortamlarının tasarım sürecine entegre edilen pedagojik bir bileşen olarak değerlendirdiklerini göstermektedir. Bu bulgu, Oh ve Ahn'ın (2024) ÜYZ'nin öğretmen rolünü “bilgi aktarıcıdan öğrenme tasarımcısına dönüştürdüğü” yönündeki sonucuyla uyumludur.

Bu bağlamda, ÜYZ okuryazarlığı ölçeğinin Türkçe formu, öğretmenlerin bilgi, uygulama ve etik boyutlardaki farkındalıklarını bütüncül biçimde değerlendirmek için kullanılabilecek geçerli bir araç olarak öne çıkmaktadır. Bulgular, öğretmen eğitimi programlarında ÜYZ yeterliklerinin sistematik biçimde izlenmesi ve geliştirilmesi gerektiğine dair güçlü kanıtlar sunmaktadır.

V. SONUÇLAR

Bu çalışmada, İngilizce Öğretmenleri için Üretken Yapay Zekâ Okuryazarlığı Ölçeği'nin Türkçe uyarlaması gerçekleştirilmiş ve ölçeğin psikometrik özellikleri incelenmiştir. Analizler sonucunda ölçeğin beş faktörlü yapısının korunduğu, model uyum indekslerinin kabul edilebilir düzeyde olduğu ve alt boyutların yüksek iç tutarlılığa sahip olduğu belirlenmiştir. Bu sonuçlar, ölçeğin Türk öğretmen örnekleminde geçerli ve güvenilir bir ölçme aracı olduğunu göstermektedir.

Araştırmanın bulgularına göre, öğretmenlerin ÜYZ okuryazarlığı çok boyutlu bir yapı sergilemekte; bilgi, kullanım, tasarım, değerlendirme ve etik yeterlikleri birbirini tamamlayan bileşenler olarak ortaya çıkmaktadır. Özellikle etik farkındalık ve pedagojik tasarım yeterlikleri, öğretmenlerin teknolojiyi daha bilinçli, eleştirel ve öğrenme odaklı biçimde kullanmalarını desteklemektedir. Bu durum, yapay zekâ temelli araçların eğitimde sorumlu ve sürdürülebilir biçimde entegrasyonu için önemli bir dayanak oluşturmaktadır.

Uygulamalı Öneriler

1. Öğretmen yetiştirme programlarında, ÜYZ okuryazarlığına yönelik içeriklerin ders programlarına sistematik biçimde entegre edilmesi önerilmektedir.
2. Mesleki gelişim seminerlerinde, öğretmenlere üretken yapay zekâ araçlarının etik, pedagojik ve tasarımsal boyutlarını tanıtan uygulamalı eğitimler düzenlenmelidir.
3. Politika düzeyinde, MEB ve yükseköğretim kurumları tarafından ÜYZ okuryazarlığına ilişkin ulusal standartlar ve etik yönergeler geliştirilmelidir.
4. Gelecek araştırmalarda, ölçeğin farklı branşlardaki öğretmen gruplarında veya öğretmen adaylarında geçerlik–güvenirlik analizlerinin yinelenmesi önerilmektedir. Ayrıca, yapay zekâ deneyimi veya yaş gibi demografik değişkenler açısından ölçme değişmezliği analizleri yapılabilir.

Sonuç Olarak

Bu çalışma, öğretmenlerin üretken yapay zekâ yeterliklerinin ölçülmesine yönelik Türkçe alanyazına önemli bir katkı sunmaktadır. ÜYZ okuryazarlığı, yalnızca teknolojiyi kullanma becerisi değil; aynı zamanda bilgi, etik, eleştirel düşünme ve pedagojik tasarım boyutlarını bütüncül olarak içeren bir yeterliktir. Dolayısıyla, bu ölçek eğitimde yapay zekâ entegrasyonuna yönelik hem akademik araştırmalarda hem de öğretmen eğitiminde güvenilir bir değerlendirme aracı olarak kullanılabilir.

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MİGREN VE OKSİDATİF STRES ARASINDAKİ İLİŞKİ

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Özet - Migren, günümüzde yaygın olan hastalıklarından biri olarak bilinmektedir. Nörovasküler bir hastalık olarak nitelendirilebilir. Yani sinir sinyallerini geçici olarak etkileyen anormal beyin aktivitesi ve kan damarlarının daralması sonucunda başın bir noktasında oluşan ve ataklar şeklinde tekrarlayan baş ağrısı olarak tanımlandığı görülmektedir. Dolayısıyla stress, hormonal değişim, anksiyete, genetik yatkınlık, çevresel tetikleyiciler ve nöroinflamatuvar süreçler bu bozukluğun temel bileşenlerini oluşturmaktadır. Bu temel bileşenlerin dışında son yıllarda yapılan çok sayıdaki çalışmaya bakıldığında, migrenin patogenezinde oksidatif stresin belirgin bir rol oynadığı ortaya konmuştur. Oksidatif stress ise, reaktif oksijen türleri (ROS) ile antioksidan savunma mekanizmaları arasındaki dengenin bozulması sonucu hücrel hasarın oluşması şeklinde tanımlanmaktadır. Yapılan araştırmanın oksidatif stresin nasıl oluştuğu ve bunun yaygın hastalıklardan biri olan migren hastalığı üzerindeki etkisinin nasıl olduğuna yönelik bilgilendirme yapması yönüyle önem taşıdığı düşünülmektedir. Sonuç olarak yapılan çalışmada migrenin ortaya çıkışında hangi faktörlerin etkili olduğunun belirlenmesi, oksidatif stresin bunun neresinde olduğu ile ilgili bilgiler ifade edilmektedir. Ayrıca elde edilen bu bilgilere ilave olarak oksidatif stresin migren üzerinde doğrudan etkili olduğuna ilişkin bir takım araştırma sonuçlarına, çalışmalarda oksidatif stresin migren üzerinde doğrudan etkili olduğuna dair yapılan analizlere ve sonuçlarının yorumlarına yer verilmektedir. Literatürdeki bu araştırma sonuçlarından hareketle özellikle oksidatif stresin migren patofizyolojisindeki rolüne, klinik bulgulara, biyobelirteçlere ve tedavi ile antioksidan yaklaşımlara değinilmektedir.

Anahtar Kelimeler: Migren, Antioksidanlar, oksidatif stress, Periodontitis, Reaktif oksijen türü.

GİRİŞ

Migrenin, geçmişten günümüze neredeyse herkesçe bir şikâyet konusu edilen yaygın bir hastalık olduğu söylenebilir. Bu bakımdan tek ya da çift taraflı, zonklayıcı, şiddetli baş ağrıları, çoğunlukla da tek taraflı, mide bulantısı, kusma, fotofobi ve fonofobi gibi otonom sinir sistemi fonksiyonlarını bozan semptomlarla tekrarlayan kronik bir nörovasküler hastalık olarak ortaya çıkmaktadır (Steiner ve Stovner, 2023). Birçok hastanın bu durumdayken sosyal yaşamındaki normal veya iş aktivitelerini gerçekleştiremediği bilinmektedir. Migrenin görülme sıklığına bakıldığında 2019 küresel hastalık yükü çalışmasına göre çoğunlukla 25-49 yaş arası kişilerde olduğu ifade edilmektedir (Vos vd., 2020). Dolayısıyla yapılan diğer çalışmalar da migren vakalarının genelde orta yaş kadınlarda görüldüğünü, kent sakinlerinin, otuz yaş üstü kişilerin ve kadınların migren için olası risk faktörleri olduğunu ifade etmektedirler (Yu vd., 2011, 2012, 2013).

Migren ile yakından ilişkili olan iki durumdan söz edilebilir. Bunlar, oksidatif stres ve nörojenik inflamasyonlardır. Ancak burada daha çok oksidatif stres üzerinde durulmaya çalışılacaktır. Bu bakımdan migrenin bu iki durumdan kaynaklı çok faktörlü bir hastalık olduğu ifade edilmektedir. Oksidatif stres, reaktif oksijen türlerinin (ROS) aşırı birikiminin neden olduğu vücutta ya da hücrelerde oksidatif hasar sürecine verilen isimdir. Bu stres oluştuğunda, vücuttaki proinflamatuvar faktörleri aktive eder ve bu da nörojenik inflamasyonu tetikler. Dolayısıyla migrenin bir tedavisinin olmadığı, kullanılan mevcut ilaçların sadece semptomatik rahatlama sağladığı ve tüm hastalar için de uygun olmadığı ifade edilmektedir (Yamanaka vd., 2021). Bu bakımdan hazırlanan bu çalışmada, migrenin tetikleyici faktörlerine, oksidatif stres ve nörojenik inflamasyon arasındaki ilişkisine, Migren ve oksidatif stres arasındaki ilişkiye, oksidatif stres belirteçlerine ve bir antioksidan olarak topiramata değinilmiştir. Yapılan çalışmanın bazı literatürlerle desteklenerek migren ve buna bağlı olarak oksidatif stres ile bağlantılı sebeplerin ortaya konması ve aralarındaki ilişkinin somut gerçeklerle açıklanması bakımından, ayrıca farkındalık oluşturmaya nedeniyle önem taşıdığı düşünülmektedir.

Migrenin ortaya çıkış nedenleri (etiyojisi) ve tetikleyicileri

Migren, farklı birçok sebepten ötürü ortaya çıkan kompleks bir hastalıktır. Ayrıca farklı tetikleyicilerden kaynaklı çeşitli migren türleri görülebilmektedir. Sadece tek bir tetikleyicinin bile birden fazla migren atağına yol açabileceği ifade edilmektedir. Yapılan bir araştırmada (Zhang ve ark., 2023) bu hastaların yaklaşık %44'ünün akut tedavi sonrasında yetersiz semptom rahatlama yaşadıkları belirtilmiştir. Bu nedenle, migrenlerin spesifik nedenlerini ve tetikleyicilerini doğru bir şekilde belirlemek ve tedavilerini buna göre uyarlamak, semptomların giderilmesini hızlandırmak ve hastanın acısını azaltmak için son derece önemli görülmektedir. Migrenin önemli bir genetik bileşeninin olduğu ve bunun da yaklaşık olarak %50 ila %80 arasında değiştiği ifade edilmektedir (Yeh vd., 2024 ; Khan vd., 2021). Genetik faktörler migrenlerin daha erken başlangıç yaşı, erkek hastalarda daha yüksek sıklıkta görülmesi ve artan ilaç kullanımı gibi temel klinik özelliklerini etkilemektedir (Pelzer vd., 2019). Yapılan son çalışmalarda da migrenle ilintili 100' den fazla genetik lokusun (konum) olduğu ortaya konulmuştur.

Tetikleyici faktörler açısından bakıldığında, uyku bozuklukları migren atakları için önemli tetikleyici faktörler olarak gösterilebilir. Dolayısıyla beyin sapı-korteks ağı migren yolunda kritik bir rol oynamakta ve uykusuzluk, obstrüktif uyku apnesi, uykuya ilişkili hareket bozuklukları ve REM uyku bozuklukları gibi durumların migren başlangıcıyla yakından ilişkili olduğu ifade edilmektedir (Vgontzas ve Pavlović, 2018). Bunun yanında stres bir diğer önemli tetikleyicidir; stres bir bireyin başa çıkma kapasitesini aştığında, migrenler otonom sinir sisteminin, özellikle hipotalamus-hipofiz-adrenal ekseninin aktivasyonu yoluyla tetiklenebilmektedir. Bu aktivasyon, migren ataklarını başlatabilen veya şiddetlendirebilen kortizol ve diğer stres hormonlarının salınımına yol açmaktadır (Stubberud ve ark., 2021). Diyet bileşenleri de migren oluşumuyla yakından bağlantılıdır. Örneğin, vücutta nitrik okside (NO) dönüşen nitrat ve nitrit içeren işlenmiş etlerin tüketilmesi vazodilatasyona (kas gevşemesi) neden olabilir, bu da potansiyel olarak beyin kan akışını değiştirir ve migrenleri tetikler (Gonzalez vd., 2016). Cinsiyet farklılığı da migreni tetiklemektedir. Şöyle ki, endokrin faktörlerin migren patogenezi (hastalığına) önemli ölçüde katkıda bulunduğu ve kadınların daha sık etkilendiği belirtilmektedir. Östrojen seviyelerindeki dalgalanma, özellikle adet başlangıcından itibaren, kadınlarda migren riskini erkeklere kıyasla yaklaşık üç kat daha arttırmaktadır (Jacome, 2001).

Migrenin, Oksidatif Stres İle Nörojenik İnflamasyon Arasındaki İlişkisi

Yukarıdaki başlıklarda ifade edildiği üzere, migren tetikleyicilerinin çoğunun vücutta oksidatif strese neden olma yeteneğine sahip olduğu söylenebilir. Örneğin, alkol kısmen alkol dehidrogenaz, kısmen de migrenle bağlantılı bir diyet faktörü olan sitokrom P450-2E1 tarafından metabolize edilir. Bu bakımdan oksidatif stres, ilkinde süperoksit iyonları ve hidrojen peroksit üretimiyle tetiklenmektedir (Valencia-Olvera vd., 2014). Yüksek alkol tüketimi de mikrogliayı aktive etmekte ve ROS (reaktif oksidatif stres)

üretimini önemli ölçüde artırmaktadır (Qin ve Crews, 2012). Dolayısıyla, migrene neden olan faktörlerin oksidatif stresi artırma konusunda benzer bir kapasiteye sahip olduğu ve bunun da migren başlangıcını kolaylaştırdığı düşünülmektedir.

Nörojenik inflamasyona baktığımızda ise, migren patofizyolojisi açısından migren başlangıcının en doğrudan mekanizmalarından biri olarak kabul edildiği görülmektedir. Bunun yanında, hücre içi ve hücre dışı iyon konsantrasyonlarındaki değişikliklerle ortaya çıkabilir ve bu da kısa süreli oksidatif strese ve nörojenik inflamatuvar faktörlerin salınımına neden olabilir (Kissoon ve Cutrer, 2017). Dolayısıyla, migrenler arasında oksidatif stres ve nörojenik inflamasyon arasında karmaşık bir bağlantı olduğuna inanılmaktadır. Migren, oksidatif stres ve nörojenik inflamasyonla ilgili klinik kanıtlar, topiramatin antioksidan ve anti-inflamatuvar etkilerine dair deneysel kanıtlarla birlikte, topiramatin oksidatif stres ve nörojenik inflamasyon yollarını bloke ederek migreni tedavi edebileceği fikrini destekleyen güçlü bir varsayımsal destek sağladığı söylenebilir.

Oksidatif Stres Belirteçleri

Migren hastalarında *malondialdehit (MDA)* düzeyleri, özellikle auralı migren vakalarında, artan lipid peroksidasyonunu ve oksidatif stres hasarını yansıtacak şekilde belirgin olarak yükseldiği görülmüştür (Aytaç vd., 2014 ; Bernecker vd., 2011 ; Gupta vd., 2009 ; Tuncel vd., 2008). Ayrıca, 4-hidroksinonenal (4-HNE) düzeyi migren hastalarında kontrollerle karşılaştırıldığında net bir şekilde daha yüksek çıkmakta ve oksidatif stresin varlığını daha da belirginleştirmektedir (Bernecker vd., 2011 ; Tablo 1). Migren hastalarında antioksidan enzim düzeylerinin belirgin olarak azaldığı ifade edilebilir. Kontrollerle karşılaştırıldığında migren grubunda katalaz (CAT) ve süperoksit dismutaz (SOD) düzeyleri anlamlı derecede düşük olduğu görülmektedir (Aytaç vd., 2014). Auralı migren hastalarında SOD aktivitesi aurasız migren hastalarına göre anlamlı derecede yüksek olmakla birlikte, SOD aktivitesi ile migren ataklarının süresi arasında anlamlı bir korelasyon olmadığı görülmektedir (Tuncel vd., 2008 ; Tablo 1).

50 migren hastası ve 30 sağlıklı gönüllüden alınan plazma örneklerini inceleyen bir çalışmada, 8-hidroksi-2'-deoksiguanozin plazma düzeylerinin migren hastalarında kontrol grubuna göre anlamlı derecede yüksek olduğu bulunmuş ve bu durum migren ile oksidatif stresle ilişkili DNA hasarı arasında bir bağlantı olduğunu göstermiştir (Geyik vd., 2016 ; Tablo 1).

Tablo 1. Migrenli hastalarda oksidatif stres

Oksidatif stres belirteci	Yöntem	Örneklem büyüklüğü (hasta/kontrol)	Sonuçlar	Kaynak
TAS TOS TAC	Vaka-kontrol	75/65	Migren hastalarında daha düşük TAS düzeyleri ve daha yüksek TOS düzeyleri ile oksidatif stres indeksi (OSI) gözlemlendi.	Jornayvaz ve Shulman, 2010
TAS TOS TAC	Vaka-kontrol	141/70	TAS, TOS ve OSI açısından hasta ve kontrol grupları arasında istatistiksel olarak anlamlı fark bulunmadı.	Eren ve ark., 2015
TAS TOS TAC	Vaka-kontrol	50/40	TAS, TOS ve OSI açısından anlamlı fark saptanmadı.	Tripathi ve ark., 2018
TAC	Ön test-son test karşılaştırması	120/30	Transkraniyal manyetik stimülasyon ve amitriptilin	Tripathi ve ark., 2018

			tedavisi sonrası TAC düzeyleri arttı.	
TAC	Kohort	32/14	Serum TAC düzeyleri hastaların %37,5'inde yükselmiş bulundu.	Gross ve ark., 2012
SOD MDA 4-HNE CAT	Vaka-kontrol	56/25	Migren hastalarında MDA düzeyleri anlamlı derecede yüksekti. SOD aktivitesi, auralı migren hastalarında aurasızlara göre anlamlı derecede yüksekti. Baş ağrısı süresiyle anlamlı ilişki yoktu.	Tuncel ve ark., 2008
SOD MDA 4-HNE CAT	Vaka-kontrol	50/50	Migren hastalarında MDA düzeyleri ve 'plazma demir indirgeme kapasitesi' kontrol grubuna göre daha yüksekti.	Aytaç ve ark., 2014
SOD MDA 4-HNE CAT	Vaka-kontrol	48/48	Migren ve kontrol grupları arasında MDA farkı istatistiksel olarak anlamlı değildi. 4-HNE, migren grubunda anlamlı derecede yüksekti.	Bernecker ve ark., 2011
SOD MDA 4-HNE CAT	Vaka-kontrol	31/30	Serum MDA düzeyleri migren hastalarında anlamlı derecede daha yüksekti.	Aytaç ve ark., 2014
SOD MDA 4-HNE CAT	Vaka-kontrol	32/14	CAT düzeyi migren grubunda anlamlı derecede düşük bulundu.	Aytaç ve ark., 2014
SOD MDA 4-HNE CAT	Kohort vaka analizi	32	Serum peroksit düzeyleri hastaların %46,9'unda yükselmiş bulundu.	Aytaç ve ark., 2014
8-OH8G	Vaka-kontrol	50/50	Migren hastalarında plazma 8-OH8G düzeyleri artmış bulundu.	Geyik ve ark., 2016

CAT: Katalaz; **SOD:** Süperoksit dismutaz; **TOS:** Toplam oksidatif durum; **TAS:** Toplam antioksidan durum; **TAC:** Toplam antioksidan kapasite; **OSI:** Oksidatif stres indeksi; **MDA:** Malondialdehit; **4-HNE:** 4-hidroksinonenal; **8-OH8G:** 8-hidroksi-2'-deoksiguanozin.

Oksidatif stres belirteçleri

Migren hastalarında *malondialdehit (MDA) düzeyleri*, özellikle auralı migren vakalarında, artmış lipid peroksidasyonunu ve oksidatif stres hasarını yansıtabilecek şekilde belirgin olarak yükseldiği belirlenmiştir (Aytaç vd., 2014 ; Bernecker vd., 2011 ; Gupta vd., 2009 ; Tuncel vd., 2008). Ayrıca, 4-hidroksinonenal (4-HNE) düzeyi migren hastalarında kontrollerle karşılaştırıldığında belirgin olarak daha yüksek olduğu ve oksidatif stresin varlığını daha da desteklediği görülmektedir (Bernecker vd., 2011 ; Tablo 1). Migren hastalarında antioksidan enzim düzeylerinin belirgin olarak azaldığı gözlemlenmiştir. Kontrollerle karşılaştırıldığında migren grubunda katalaz (CAT) ve süperoksit dismutaz (SOD) düzeyleri anlamlı derecede düşük çıkmıştır (Aytaç vd., 2014). Auralı migren hastalarında SOD aktivitesi aurasız migren hastalarına göre anlamlı derecede yüksek olmakla birlikte, SOD aktivitesi ile

migren ataklarının süresi arasında anlamlı bir korelasyonun olmadığı ortaya çıkmıştır (Tuncel vd., 2008 ; Tablo 1).

Antioksidan olarak topiramate

Topiramate, oksidatif stres üzerinde karmaşık bir etki göstermektedir. Diyabetli bir fare modelinde, topiramate, 4-HNE düzeylerini azaltarak ve glutatyon (GSH) düzeylerini artırarak beyni diyabet kaynaklı hasardan etkili bir şekilde korumuştur (Price vd., 2015). Benzer şekilde, plastik ve rekonstrüktif cerrahi sonrası flep nekrozunun önlenmesi üzerine yapılan bir çalışmada ise topiramatin MDA düzeylerini düşürdüğü ve GSH düzeylerini artırdığı gözlenmiştir (Ahmadzadeh vd., 2022). Ancak, topiramatin erkek farelerin karaciğer ve böbrekleri üzerindeki potansiyel toksik etkileri üzerine yapılan bir çalışmada, topiramatin antioksidan enzimler SOD ve CAT'ın aktivitelerini önemli ölçüde azalttığı, MDA ve NO seviyelerini ise artırdığı belirlenmiştir (El Makawy vd., 2022).

Bu bulgulardan hareketle, topiramatin oksidatif stres üzerinde ikili etki gösterebileceğini, belirli durumlarda nöroproteksiyon (nöron korunması) sağlarken farklı koşullar ve dozajlarda oksidatif stresi artırabileceğini gösterdiği söylenebilir.

SONUÇLAR

Bu çalışmanın, migrenin nedenlerini, özellikle oksidatif stres ve nörojenik inflamasyonun rollerine vurgu yaptığı görülmektedir. Topiramatin migren yönetimindeki antioksidan ve antiinflamatuvar özelliklerinin vurgulandığı görülmüştür. Hem nörojenik inflamasyonun hem de oksidatif stresin migren gelişiminde kilit faktörler olduğu ve topiramatin antiinflamatuvar ve antioksidatif etkileri aracılığıyla nöroprotektif potansiyele sahip olduğu ortaya konmuştur. Ayrıca, topiramatin bu yolları nasıl düzenlediği ve migren tedavisindeki etkinliğini doğrulamak için daha fazla deneysel çalışmaya ihtiyacın olduğu belirtilmiştir.

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DİŞ ETİ İLTİHABI İLE OKSİDATİF STRES ARASINDAKİ İLİŞKİ

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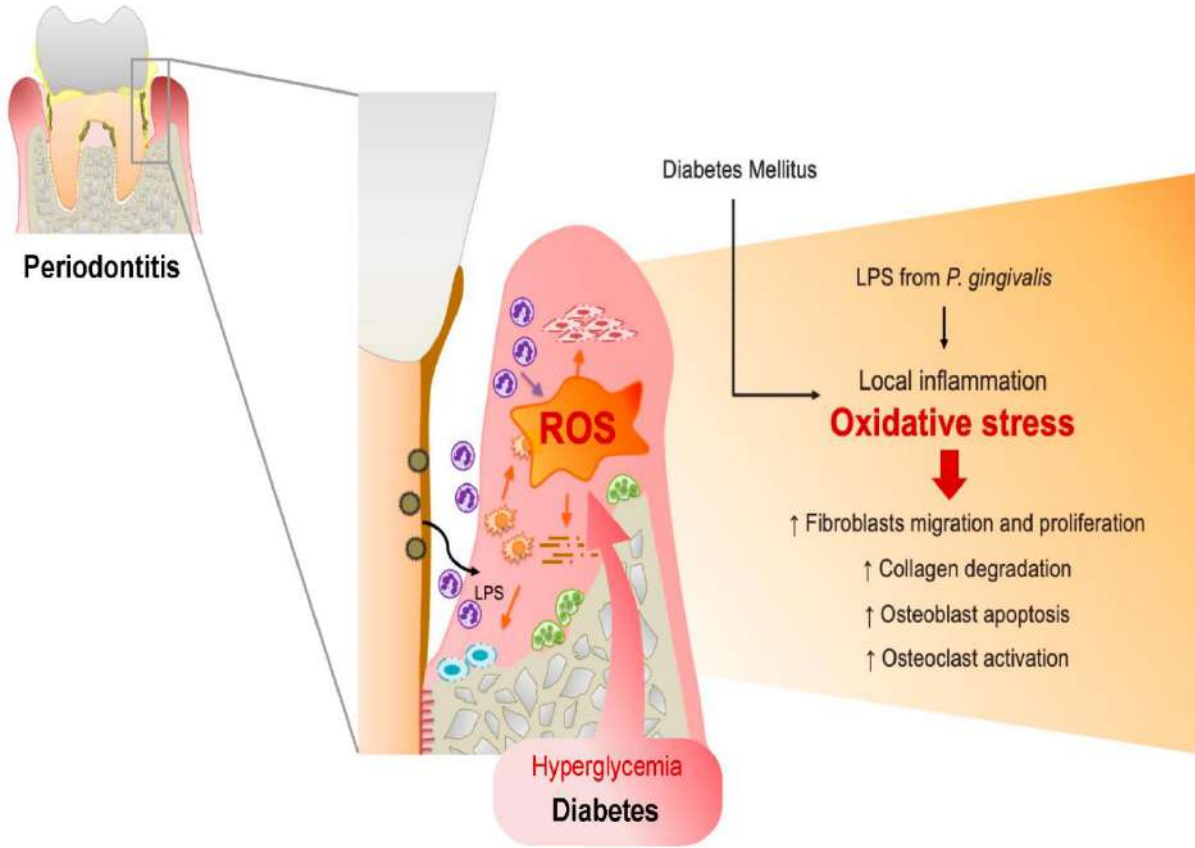
Özet - Genel anlamda diş eti iltihabı, diş etlerinde enfeksiyon ya da iltihap kaynaklı gelişen bir diş hastalığı olarak bilinmektedir. Genellikle dişlerde plak, tartar ve bakteri birikimi sonucu diş etinin dış kısmında kızarıklık, şişme ve sızlama ile kendisini hissettirmeye başlar. Dolayısıyla tıbbi adı gingivitis olan diş etinde enfeksiyon veya iltihaba bağlı tahriş, kızarıklık, şişme veya kanamaya neden olabilen erken aşama bu diş eti hastalığı tedavi edilmediği takdirde periodontitise neden olmaktadır. Son yıllarda yapılan araştırmalar, bu hastalıkların patogenezinde oksidatif stresin önemli bir rol oynadığını göstermektedir. Oksidatif stres, reaktif oksijen türlerinin (ROS) üretimi ile antioksidan savunma sistemleri arasındaki denge bozulduğunda ortaya çıkmakta ve hücrel hasara yol açmaktadır. Periodontal hastalıkların gelişiminde bakteriyel plak birincil etken olmakla birlikte, bağışıklık sisteminin bu mikroorganizmalara verdiği yanıt da doku hasarına katkı sağlamaktadır. Oksidatif stres, nötrofillerin bakterilere karşı oluşturduğu reaktif oksijen türlerinin aşırı üretimi sonucunda artmakta ve periodontal dokularda kollajen yıkımı ile kemik rezorpsiyonuna neden olmaktadır. Bu durumun, inflamasyonun kronikleşmesine ve periodontal bağ dokusunun yıkımına yol açtığı ifade edilebilir. Bu bakımdan yapılan araştırmada oksidatif strese bağlı olarak meydana gelen diş eti iltihabı arasındaki ilişkiyi sebepleriyle birlikte belirlemek, temel nedenlerini ortaya koymak ve antioksidan savunma sistemlerinin oksidatif stresin buna benzer zararlı etkilerini nasıl dengede tuttuğu ayrıntılı bir şekilde ele alınmıştır. Ayrıca antioksidan savunma sistemlerinin bu dengeyi sağlamada hangi enzimlerin rol aldığı hakkında da bilgilendirme yapılmıştır.

Anahtar Kelimeler: Antioksidanlar, Diş eti iltihabı, oksidatif stress, Periodontitis, Reaktif oksijen türü.

GİRİŞ

Halk arasında diş eti iltihabı olarak bilinen, tıp dilindeki karşılığı ise gingivitis olan, periodontal dokuların inflamatuvar bir cevabı olarak ortaya çıkan, geri dönüşümlü bir periodontal hastalık türüdür. Bu iltihabın patogenezinde mikrobiyal dental plak birikimi kadar, konak yanıtı ve buna bağlı oksidatif stres mekanizmalarının da önemli rol oynadığı söylenebilir. Bu bakımdan oksidatif stres, reaktif oksijen türleri (ROS) ile antioksidan savunma sistemleri arasındaki dengenin bozulması şeklinde tanımlanmaktadır

(Halliwell & Gutteridge, 2015). Son dönemlerde yapılan çalışmalara bakıldığında, periodontal dokulardaki inflamatuvar sürecin oksidatif stresle yakın bir ilişki içerisinde olduğu ortaya çıkmaktadır (Canakci et al., 2005; Akalin et al., 2007). Dolayısıyla hazırlanan bu çalışmada güncel literatür desteğiyle özellikle diş ile ilgili bu tür iltihap vakalarında oksidatif stresin biyolojik temellerine, antioksidan savunma sistemleri ve denge kontrolüne, bu hastalığa ait klinik bulgulara, oksidatif stresin buna yönelik tedaviye etkisine ve klinik önemine değinilmektedir. Bu bakımdan hazırlanan ve literatür bulguları ve sonuçları ile desteklenen diş eti iltihabı konusunun oksidatif stres ile arasındaki ilişkinin neler olduğuna yönelik kısaca özlü bilgilerin sunulması okuyucularda, araştırmacılarda farkındalık oluşturmaları açısından önem taşıdığı ifade edilebilir.



Şekil 1. Mikroorganizma/LPS uyarımı → ROS üretimi → fibroblast, osteoklast aktivasyonu ve kollajen yıkımı gibi periodontal dokudaki patofizyolojik mekanizmaları gösteren şekil.

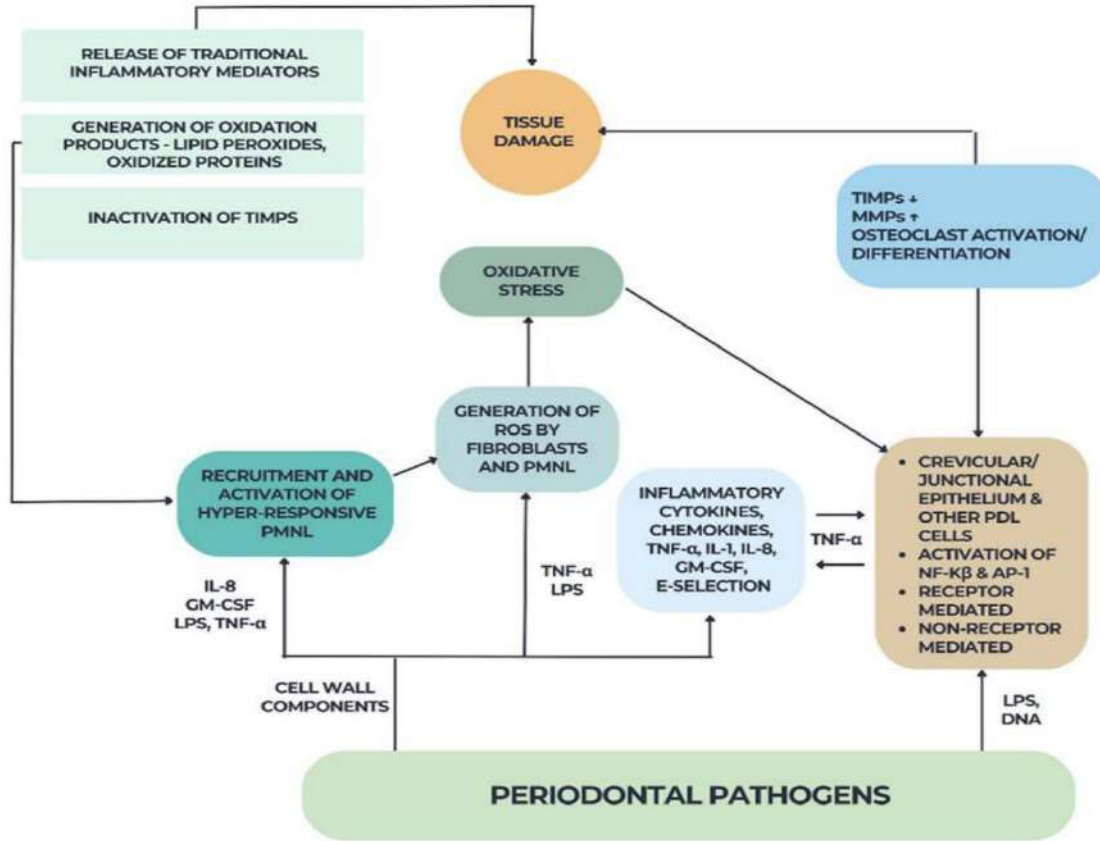
(Kaynak: Langley-Evans et al., 2020)

Diş Eti İltihabında Oksidatif Stresin Biyolojik Temelleri

Diş etindeki bu durum esnasında bakteri plağında bulunan mikroorganizmalar konak dokularda inflamatuvar yanıtı tetiklemektedirler. Bu durumda nötrofiller ve makrofajlar bakterileri yok etmek için reaktif oksidatif stres (ROS) üretirler. Her ne kadar ROS' un fizyolojik düzeylerde antimikrobiyal etkisi yararlı olarak görülse de, aşırı üretim durumunda periodontal dokularda hücre membran lipidlerinin peroksidasyonu, protein oksidasyonu ve DNA hasarı meydana gelmektedir (Battino et al., 2002; Chapple & Matthews, 2007). Yapılan farklı bir çalışmada ise (Cherian et al., 2019), gingivitisli bireylerin diş eti oluşu sıvılarında malondialdehit (MDA) düzeylerinin sağlıklı bireylere göre anlamlı derecede yüksek olduğu ortaya konmuştur.

Antioksidan Savunma Sistemleri ve Denge Bozulması

İnsan vücudunda ROS' un zararlı etkilerini dengeleyen enzimatik (süperoksit dismutaz, katalaz, glutatyon peroksidaz) ve enzimatik olmayan (C vitamini, E vitamini, glutatyon) antioksidan bir savunma sisteminin olduğu bilinmektedir (Scandalios, 2005). Gingivitis sırasında oksidan üretiminin artmasıyla bu antioksidan sistemler güçlük çekmeye başlayarak, zamanla oksidan/antioksidan dengenin bozulmasına neden olmaktadır. Yine bu durumu destekler nitelikte bir çalışmaya (Buduneli ve ark., 2006) bakıldığında, gingivitisli bireylerin tükürüğünde toplam antioksidan kapasitenin sağlıklı bireylere göre anlamlı derecede düşük olduğu sonucunun ortaya çıktığı görülmektedir. Bir şekil üzerinde meydana gelen hasar ve denge bozulması aşağıdaki gibi özetlenebilir.



Şekil 2. Periodontal hastalıklarda oksidatif stresin doku hasarı, ROS üretimi ve sistemik etkilerle olan ilişkisini gösteren şematik diyagram.

(Kaynak: Influence of Reactive Oxygen Species on Wound Healing, 2021)

Klinik Bulgular ve Biyobelirteçler

Gingivitis üzerindeki oksidatif stresin etkileri klinik olarak da değerlendirilebilmektedir. Yapılan klinik bulgu çalışmalarının sonuçlarına bakıldığında kanama indeksi, plak indeksi ve gingival indeks gibi parametrelerdeki artışla birlikte oksidatif stres belirteçlerinde (*MDA*, *8-OHdG*, *nitrit/nitrat*) yükselmelerin olduğu ortaya konmaktadır (Sculley & Langley-Evans, 2003). Diğer bir çalışmada (Dede, Özden, & Avcı, 2012) ise, gingivitisli bireylerde diş eti oluşu sıvısında (DOS-Leptin ve Sitokin) *8-OHdG* düzeylerinde artışın olduğu, tedavi sonrası bu düzeylerin anlamlı derecede azaldığı belirtilmektedir.

Oksidatif Stresin Tedaviye Etkisi ve Klinik Önemi

Diş eti iltihabı (Gingivitis) tedavisinde temel yaklaşım olarak, plak kontrolü ve profesyonel diş temizliği sıralanmaktadır. Bunun yanında antioksidan destekli tedavi yaklaşımları da gündeme gelmektedir. Yapılan bir araştırma (Chapple et al., 2013), topikal ve sistemik antioksidan uygulamalarının gingival inflamasyonu azaltabileceğini ileri sürmektedir. Farklı bir çalışmada (Buzatu, Luca, & Bumbu, 2024) ise, gingivitisli bireylere uygulanan C vitamini takviyesinin, klinik indekslerde iyileşme ve oksidatif stres belirteçlerinde azalmaya neden olduğu belirtilmektedir.

SONUÇLAR

Çalışmada literatür desteği ile elde edilen sonuçlara bakıldığında diş eti iltihabı ile oksidatif stres arasında çift yönlü bir ilişkinin olduğu görülmektedir. Yani, inflamasyon oksidatif stres üretimini tetiklerken, artan oksidatif stres de periodontal dokulardaki hasarı derinleştirmektedir. Dolayısıyla gingivitisin değerlendirilmesinde ve tedavisinde oksidatif stres parametrelerinin göz önünde bulundurulması, klinik seyri anlamada ve yeni tedavi stratejileri geliştirmede son derece önemli katkılarda bulunduğu ifade edilebilir.

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