

TOKYO SUMMIT

**TOKYO 11 TH INTERNATIONAL INNOVATIVE
STUDIES & CONTEMPORARY SCIENTIFIC RESEARCH
CONGRESS**

April 6-7 2026 / Tokyo - Japan

EDITORS

Dr. Duong To Quoc THAI

Dr. Esra KOÇAK

ISBN:979-8-89695-407-1

PROCEEDINGS BOOK



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Water Street Corridor New York, NY 10038

www.libertyacademicbooks.com

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adapted by Mariam Rasulan

ISBN: 979-8-89695-407-1

Publication Date: 10.05.2026

CONGRESS ID

CONGRESS TITLE

TOKYO 11 TH INTERNATIONAL INNOVATIVE STUDIES & CONTEMPORARY SCIENTIFIC RESEARCH
CONGRESS

DATE and PLACE

APRIL 6-7, 2026 / TOKYO- JAPAN

ORGANIZATION

IKSAD-Institute of Economic Development and Social Research, Türkiye
London Sovereign School, United Kingdom

NUMBER of ACCEPTED PAPERS-120 (*Türkiye- 52, Other Countries- 68*)

NUMBER of REJECTED PAPERS-15

PARTICIPANTS COUNTRY

Türkiye, Algeria, Nigeria, Morocco, United States, India, Indonesia, Vietnam, Romania,
Azerbaijan, Pakistan, Poland, Albania

PRESENTATION

Oral & Poster presentation

EVALUATION PROCESS

All applications have undergone a double-blind peer review process

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Observer hall-1

FORMAL EĞİTİMİN SONUNU GETİREN İNFORMAL ve SOSYAL MEDYA ile YAPAY ZEKÂ UYGULAMALARINA İLİŞKİN ÖĞRENCİ GÖRÜŞLERİ

STUDENT VIEWS ON INFORMAL EDUCATION AND SOCIAL MEDIA AND ARTIFICIAL INTELLIGENCE APPLICATIONS THAT BRING THE END OF FORMAL EDUCATION

Prof. Dr. Mehmet ÖZBAŞ
Erzincan Binali Yıldırım Üniversitesi

Observer hall-1

FORMAL EĞİTİMİN SONUNU GETİREN İNFORMAL ve SOSYAL MEDYA ile YAPAY ZEKÂ UYGULAMALARINA İLİŞKİN ÖĞRENCİ GÖRÜŞLERİ

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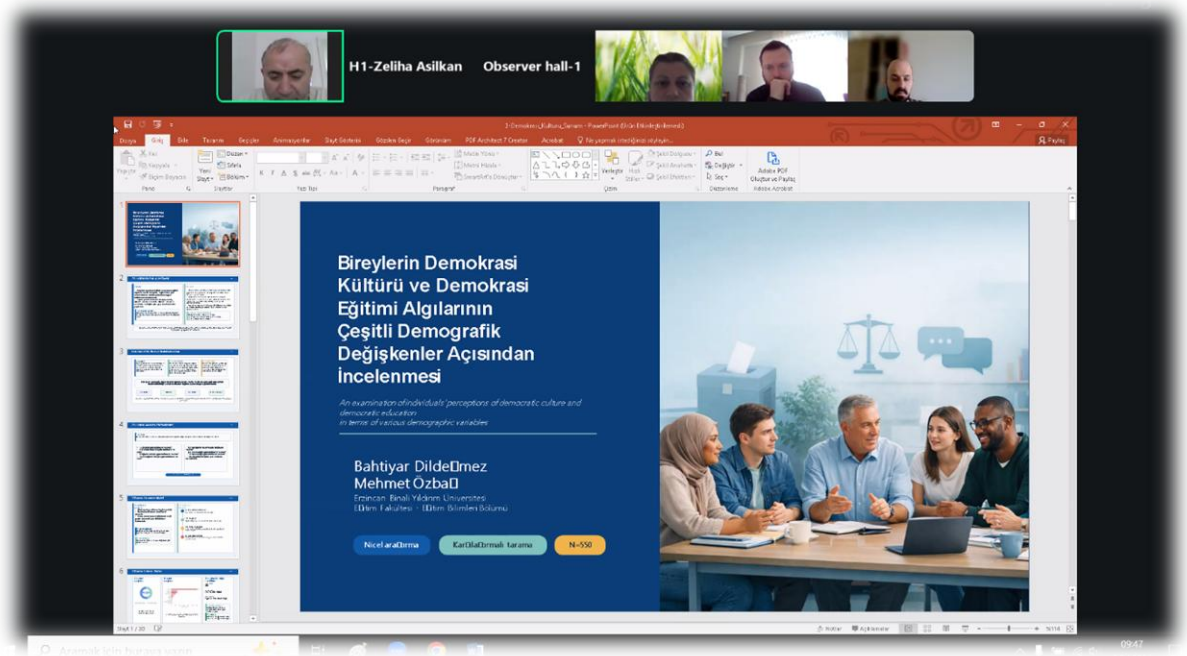
Observer hall-1

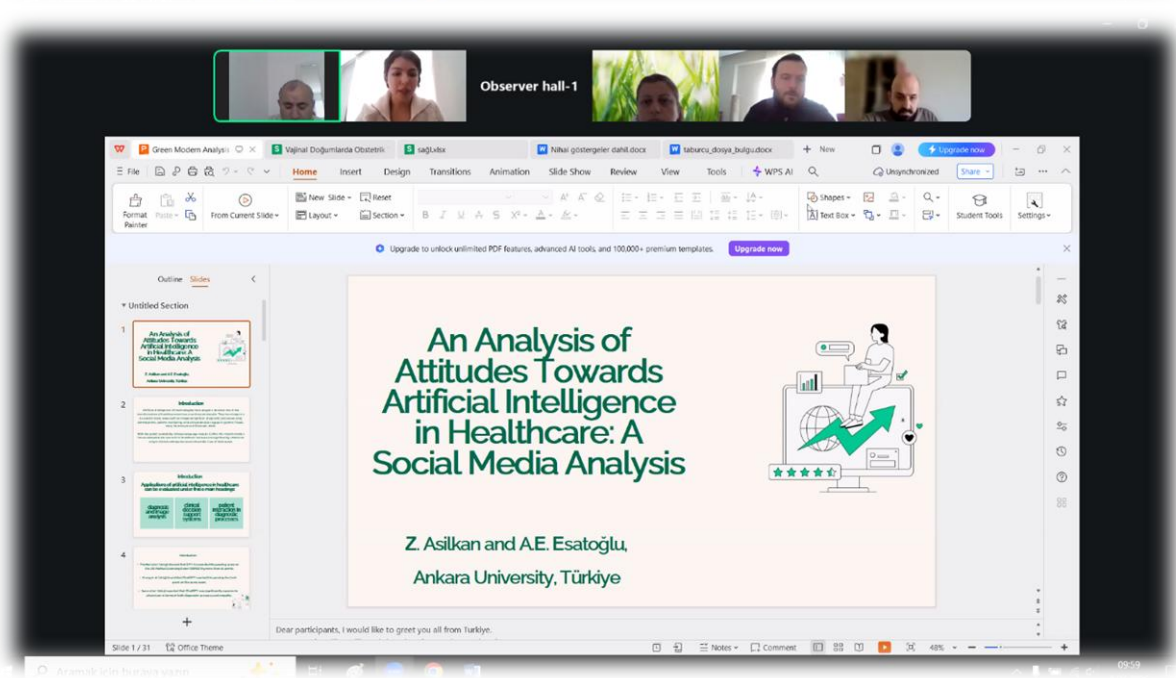
KONYA TEKNİK ÜNİVERSİTESİ

YOLOv8 ile ARMUT YAPRAKLARINDAN ARMUT ÇEŞİTLERİNİN SINIFLANDIRILMASI

EMİNE BAŞ
FATİH BAL

Konya Teknik Üniversitesi





Observer hall-1

H-1 irem_aksoy

BAL ARISI VE ARI ÜRÜNLERİNDE MİKROPLASTİKLERİN VARLIĞININ ARAŞTIRILMASI

Investigating the Presence of Microplastics in Honeybees and Bee Products

Dr. Mehmet Emin HACIYUSUFOĞLU
Bağımsız Araştırmacı | Independent Researcher

Tokyo Summit - XI 11TH INTERNATIONAL INNOVATIVE STUDIES & CONTEMPORARY SCIENTIFIC RESEARCH CONGRESS
April 6-7, 2026 / Tokyo - Japan

2026

Observer hall-2

H-2, Kamil Arif Kırık

H-2, Nermin Er Aydemir

HALL-2, MIKOTA KARENGA

Hall-2 Fidan Balkaya

H-2, Sıla Ezgi Şentürk

Esra Koçak

H-2, Müberra Sarı

Rukuye Aylaz

Esra Koçak

H-2, Müberra Sarı

Ses

Video

Kabine

Sohbet

Tepki ver

Paylaş

Oturum sahibi araçları

Kaydet

Daha fazla

Odadın

Sickit: düşecek

09:00

8.04.2026

Observer Hall-5

Prof. Dr. Alparslan Dilsiz

Observer Hall-5

Serhat Toptanur

Zeynep Tekin

Shahrazad AMIZADEH

Unal Öztürk

dinleyici

Abdullah Yavuz...

dinleyici

Abdullah Yavuz Özmen

12:05

workplace

Observer Hall-4

Hall-4, Ahmet Niyazi Özker

Observer Hall-4

Hall4 Güvenç Kural

HALL-4, BİROL ALTUN

Meryem Gül-Hall 4

Hall-4, Timur KÖSE

Ayıl KASAPOĞLU

Emine ÖRS hall-4

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Ses Video

Katılımcılar Sohbet Tepki ver Paylaş Oturma sahibi araçları Ara odalar Daha fazla

Odadan çık

Observer hall-1

**RUMİNANT YETİŞTİRİCİLİĞİNİN
METAN EMİSYONUNA ETKİLERİ**

**EFFECTS OF RUMINANT BREEDING
ON METHANE EMISSIONS**

Dr. Erdiç ALTINÇEKİÇ
Gıda ve Yem Kontrol Merkez Araştırma Enstitüsü, Bursa, Türkiye

Öğr. Üye. Dr. Sevil ÇALIŞKAN ELEREN
Bursa Uludağ Üniversitesi, Mühendislik Fakültesi, Çevre Mühendisliği Bölümü, Türkiye

Doç. Dr. Şeniz ÖZİŞ ALTINÇEKİÇ
Bursa Uludağ Üniversitesi, Ziraat Fakültesi, Zootekni Bölümü, Türkiye

11. Uluslararası Yenilikçi Çalışmalar ve Modern Bilimsel Araştırmalar Kongresi
(6-7 Nisan 2026, Tokyo)

Bursa Uludağ Üniversitesi

Observer hall-1

**KINIK OFİYOLİTİNDEKİ
TÜKENMİŞ HARZBURGİTLERİN
JEOKİMYASAL ÖZELLİKLERİ**

Tokyo Summit - XI
11TH INTERNATIONAL INNOVATIVE STUDIES &
POLYTECHNICAL RESEARCH SYMPOSIUM

İrem Aksoy¹, Tijen Üner²

1 Department of Geological Engineering, Kutahya
Dumlupınar University, Türkiye

2 Department of Geological Engineering, Van Yüzüncü Yıl
University, Türkiye

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Tokyo Summit - XI

11TH INTERNATIONAL INNOVATIVE STUDIES & CONTEMPORARY SCIENTIFIC RESEARCH CONGRESS

April 6-7, 2026 / Tokyo - Japan

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1



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ONLINE / 06.04.2026 / HALL-1 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: **Prof. Dr. Mehmet ÖZBAŞ**

AUTHORS	AFFILIATION	TOPIC TITLE
Assoc. Prof. Emine BAS Muhammet Fatih SEKER	Konya Technical University	BINARY CUCKOO CATFISH OPTIMIZER FOR UFLP PROBLEMS
Assoc. Prof. Emine BAS Res. Asst. Fatih BAL	Konya Technical University	CLASSIFICATION OF PEAR VARIETIES USING PEAR LEAVES WITH YOLOV8
Asst. Prof. Dr. Hüseyin BODUR	Duzce University	A LIGHTWEIGHT QR-ASSISTED ZERO-KNOWLEDGE IDENTIFICATION PROTOCOL FOR SECURE AUTHENTICATION
Prof. Dr. Mehmet ÖZBAŞ	Erzincan Binali Yildirim University	STUDENT VIEWS ON INFORMAL AND SOCIAL MEDIA AND ARTIFICIAL INTELLIGENCE APPLICATIONS THAT BRING THE END OF FORMAL EDUCATION
Res. Asst. Bahtiyar DILDEGMEZ Prof. Dr. Mehmet ÖZBAŞ	Erzincan Binali Yildirim University	AN EXAMINATION OF INDIVIDUALS' PERCEPTIONS OF DEMOCRATIC CULTURE AND DEMOCRATIC EDUCATION IN TERMS OF VARIOUS DEMOGRAPHIC VARIABLES
Lecturer Zeliha ASILKAN Prof. Dr. Afsun Ezel ESATOGLU	Ankara University	AN EXAMINATION OF ATTITUDES TOWARDS ARTIFICIAL INTELLIGENCE IN HEALTHCARE SERVICES USING SOCIAL MEDIA ANALYSIS
Assoc. Prof. Dr. Burak BAŞKAN	Erzurum Technical University	POLITICAL COMMUNICATION AND CAMPAIGNING IN THE AGE OF ALGORITHMS AND ARTIFICIAL INTELLIGENCE
Prof. Dr. Cem Harun MEYDAN İklim Nur EROĞLU Asst. Prof. M. Alper AKDEMİR	Ankara Science University	ORGANIZATIONAL SILENCE IN THE CONTEXT OF ARTIFICIAL INTELLIGENCE: THE ROLE OF ALGORITHMIC AUTHORITY IN SILENCE MECHANISMS

ONLINE / 06.04.2026 / HALL-2 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: **Prof. Dr. Rukuye AYLAZ**

AUTHORS	AFFILIATION	TOPIC TITLE
Asst. Prof. Dr. Nermin ER AYDEMİR Sıla Ezgi ŞENTÜRK	Alanya Alaaddin Keykubat University	AN EXAMINATION OF THE 6TH GRADE TURKISH TEXTBOOK FROM THE PERSPECTIVE OF MULTIPLE INTELLIGENCE THEORY
Prof. Dr. Rukuye AYLAZ MSc Fidan BALKAYA	Inonu University	INVESTIGATING THE EFFECTS OF PSYCHODRAMA AND VIRTUAL REALITY-SUPPORTED PSYCHOEDUCATION ON PSYCHOLOGICAL WELL-BEING AND ANXIETY LEVELS IN EARTHQUAKE SURVIVORS
MSc Fidan BALKAYA Prof. Dr. Rukuye AYLAZ	Inonu University	MOBILE HEALTH APPLICATIONS IN CHRONIC DISEASE MANAGEMENT: A REVIEW OF THE LITERATURE FROM THE LAST FIVE YEARS (2020–2025)
Assoc. Prof. Dr. Kamil Arif KIRKIC Müberra SARI	Istanbul Sabahattin Zaim University Ministry of National Education	CONFIRMATORY FACTOR ANALYSIS OF THE TURKISH VERSION OF THE SECOND LANGUAGE LEARNING GRIT (L2-GRIT) SCALE
Ayhan DALLI Assoc. Prof. Dr. Kamil Arif KIRKIC	Ministry of National Education Istanbul Sabahattin Zaim University	MIDDLE AND HIGH SCHOOL TEACHERS' CURRICULUM LITERACY AND TEACHER SELF-REGULATION
Mikota Abedi KARENGA Prof. Dr. Osman Ferda BEYTEKIN	Ege University	A RESEARCH ON PERSPECTIVES OF PRIMARY SCHOOL TEACHERS ON DIGITAL INCLUSION IN EDUCATION IN DAR ES SALAAM, TANZANIA

ONLINE / 06.04.2026 / HALL-3 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: **Prof. Dr. Harun SAHIN**

AUTHORS	AFFILIATION	TOPIC TITLE
Sila KALE Dr. Birsen ACIKEL Dr. Tarik GUNES	Nisantasi University Eskisehir Technical University Iskenderun Technical University	STRATEGIC APPROACHES TO SUSTAINABLE AVIATION EDUCATION: A THEORETICAL ANALYSIS OF GLOBAL POLICY FRAMEWORKS
Sila KALE Dr. Birsen ACIKEL Dr. Tarik GUNES	Nisantasi University Eskisehir Technical University Iskenderun Technical University	EMERGENCY MANAGEMENT IN AIRPORTS IN RELATION TO AIR TRAFFIC CONTROL: A HUMAN FACTORS-BASED ASSESSMENT
Prof. Dr. Harun SAHIN Buse Basak TURAN	Akdeniz University	A NEW DIMENSION OF THE HIDDEN CURRICULUM IN SOCIAL STRUCTURING: EDUCATION AND SOCIAL MEDIA VIDEOS IN THE AGE OF DIGITALIZATION
Elnura GULIYEVA	Military Institute named after H. Aliyev	ENHANCING SPEAKING PROFICIENCY THROUGH INTEGRATED INNOVATIVE PEDAGOGIES IN MILITARY EFL EDUCATION: A QUASI- EXPERIMENTAL STUDY
Asst. Prof. Dr. Merve SAMIOGLU	Istanbul University	INTERACTIVE APPLETS IN UNDERSTANDING DESCRIPTIVE STATISTICS
Asst. Prof. Dr. Merve SAMIOGLU	Istanbul University	CLASSIFYING COGNITIVE BIASES: THE PROBLEM OF NORMATIVE REFERENCE POINTS

ONLINE / 06.04.2026 / HALL-4 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: **Assoc. Prof. Dr. Anna KOPICZKO**

AUTHORS	AFFILIATION	TOPIC TITLE
Dr. Rajmonda MILLOSHI Dr. Aida ZOTAJ	University of Medicine Tirana Aleksander Moisiu University Durrës	QUANTITATIVE ANALYSIS OF THE LEARNING CLIMATE AND COGNITIVE LOAD IN NURSING LABORATORY PRACTICES: A CROSS-SECTIONAL STUDY
Lina Marsella Saury RODRÍGUEZ	Universidad Juarez Autonoma de Tabasco	INCLUSION OF MENTAL HEALTH IN EDUCATION
Cristian-Romeo SPĂTARU Cristian Constantin POPESCU	"Alexandru Ioan Cuza" University of Iasi	DETERMINANTS OF CORRUPTION IN EMERGING AND DEVELOPED ECONOMIES: A PANEL DATA ANALYSIS WITH DYNAMIC FIXED EFFECTS
Dr. Jai Gopal GUPTA	National Institute of Technology Sikkim	EVOLUTION AND INNOVATION IN INDIAN RAILWAY TRAIN COACHES
Raf Raf Shakil ANSARI	Sharda University	EXPLORING POETICS OF RESISTANCE IN JAVED AKHTAR'S A NEW DECREE
Assoc. Prof. Dr. Anna KOPICZKO Wiktoria PIETRZAK Jakub BALDYKA Dr. Patrycja WIDLAK Dr. Joanna CIEPLINSKA	Jozef Pilsudski University of Physical Education in Warsaw	DETERMINANTS OF SKELETAL MINERALIZATION IN ADOLESCENT MALES: THE ROLE OF SPORT TYPE, BODY COMPOSITION, AND DIET
Dr. Anisa POTKA Prof. Dr. Numila KUNESHKA	Mother Teresa University Hospital Centre	DANON DISEASE PRESENTING AS HYPERTROPHIC CARDIOMYOPATHY: A CASE REPORT
Irina-Ana DROBOT	Technical University of Civil Engineering Bucharest	HAIKU POEMS AND ALLUSIONS TO CONTEXTS
Marigona RIZANI-SHABANI	University of Prishtina	ASSESSMENT OF NURSING STUDENTS' KNOWLEDGE AND ATTITUDES IN KOSOVO TOWARD MEDICATION ADMINISTRATION ERRORS

ONLINE / 06.04.2026 / HALL-5 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: **Bogdan-Catalin SERBAN**

AUTHORS	AFFILIATION	TOPIC TITLE
Vlad DIACONESCU Bogdan-Catalin SERBAN Matei-Gabriel URSACHESCU Caterina ZETU Maria Ruxandra SALAGEAN Diana DUMITRASCU Octavian BUIU Marius BUMBAC	University of Medicine and Pharmacy "Carol Davila" National Institute for Research and Development in Microtechnologies – IMT Bucharest National College "B. P. Hasdeu" International Theoretical High School of Computer Science National College "Saint Sava" Valahia University of Targoviste	RIVAROXABAN: A TARGETED FACTOR XA INHIBITOR IN MODERN ANTICOAGULANT THERAPY
Vlad DIACONESCU Bogdan-Catalin SERBAN Matei-Gabriel URSACHESCU Caterina ZETU Maria Ruxandra SALAGEAN Diana DUMITRASCU Octavian BUIU Marius BUMBAC	University of Medicine and Pharmacy "Carol Davila" National Institute for Research and Development in Microtechnologies – IMT Bucharest National College "B. P. Hasdeu" International Theoretical High School of Computer Science National College "Saint Sava" National Institute for Research and Valahia University of Targoviste	OMEPRAZOLE – FROM ACID-TRIGGERED ACTIVATION TO THE NEW ERA OF GASTRIC ACID SUPPRESSION
Asst. Prof. Nelya NOVOTORZHINA Asst. Prof. Mehpara SAFAROVA Asst. Prof. Gariba GAHRAMANOVA Asst. Prof. Malahat ABBASOVA Shafa KAZIMZADEH Gunay MUSTAFAYEVA Irada HAJIYEVA	Institute of Chemistry; Azerbaijan University of Architecture and Construction	BACTERICIDAL ADDITIVE FOR CUTTING FLUIDS
Bogdan-Catalin SERBAN Matei-Gabriel URSACHESCU Vlad DIACONESCU Caterina ZETU Maria Ruxandra SALAGEAN Diana DUMITRASCU Octavian BUIU Marius BUMBAC	National Institute for Research and Development in Microtechnologies – IMT Bucharest National College "B. P. Hasdeu" University of Medicine and Pharmacy "Carol Davila" International Theoretical High School of Computer Science National College "Saint Sava" National Institute for Research and Development in Microtechnologies – IMT Bucharest Valahia University of Targoviste	CARAMELIZATION: CURRENT PERSPECTIVES ON A VERSATILE BUT POORLY UNDERSTOOD CHEMICAL PROCESS
Bogdan-Catalin SERBAN Matei-Gabriel URSACHESCU Vlad DIACONESCU Caterina ZETU Maria Ruxandra SALAGEAN Diana DUMITRASCU Octavian BUIU Marius BUMBAC	National Institute for Research and Development in Microtechnologies – IMT Bucharest National College "B. P. Hasdeu" University of Medicine and Pharmacy "Carol Davila" International Theoretical High School of Computer Science National College "Saint Sava" National Institute for Research and Development in Microtechnologies – IMT Bucharest Valahia University of Targoviste	POLYSACCHARIDES USED IN THE PHARMACEUTICAL AND NATURAL SUPPLEMENTS INDUSTRIES: PROPERTIES, APPLICATIONS, AND PERSPECTIVES
Vlad DIACONESCU Bogdan-Catalin SERBAN Matei-Gabriel URSACHESCU Caterina ZETU Maria Ruxandra SALAGEAN Diana DUMITRASCU Octavian BUIU Marius BUMBAC	University of Medicine and Pharmacy "Carol Davila" National Institute for Research and Development in Microtechnologies – IMT Bucharest National College "B. P. Hasdeu" International Theoretical High School of Computer Science National College "Saint Sava" National Institute for Research and Valahia University of Targoviste	OLIGOSACCHARIDES AND POLYSACCHARIDES IN COSMETICS: PROPERTIES, APPLICATIONS, AND FUTURE PERSPECTIVES
Matei-Gabriel URSACHESCU Matei-Gabriel URSACHESCU Bogdan-Catalin SERBAN Vlad DIACONESCU Caterina ZETU Maria Ruxandra SALAGEAN Diana DUMITRASCU Octavian BUIU Marius BUMBAC	National College "B. P. Hasdeu" National Institute for Research and Development in Microtechnologies – IMT Bucharest University of Medicine and Pharmacy "Carol Davila" International Theoretical High School of Computer Science National College "Saint Sava" National Institute for Research and Valahia University of Targoviste	CYCLODEXTRINS: FROM SUPRAMOLECULAR HOST-GUEST CHEMISTRY TO DRUG DELIVERY APPLICATIONS

ONLINE / 06.04.2026 / HALL-1 / SESSION-2



TOKYO LOCAL TIME



17³⁰ : 19³⁰



ANKARA LOCAL TIME



11³⁰ : 13³⁰

HEAD OF SESSION: **Dr. Mehmet Emin HACIYUSUFOGLU**

AUTHORS	AFFILIATION	TOPIC TITLE
Dr. Mehmet Emin HACIYUSUFOGLU	Independent Researcher	DETECTION OF AMITRAZ AND FLUMETHRIN RESIDUES IN PROPOLIS
Dr. Mehmet Emin HACIYUSUFOGLU	Independent Researcher	INVESTIGATION OF THE PRESENCE OF MICROPLASTICS IN HONEY BEE AND BEE PRODUCTS
Dr. Selda BULUT Dr. Hakan ERDOĞAN Hamza ÖMER	Firat University Independent (Ankara) Firat University	DIGITALIZATION AND ITS CLIMATE COST: THE OVERLOOKED ECOLOGICAL FOOTPRINT OF THE TWIN TRANSITION
Dr. Erdinç ALTINÇEKİÇ Asst. Prof. Dr. Sevil ÇALIŞKAN ELEREN Assoc. Prof. Dr. Şeniz ÖZİŞ ALTINÇEKİÇ	Food and Feed Control Central Research Institute Bursa Uludag University Bursa Uludag University	EFFECTS OF RUMINANT BREEDING ON METHANE EMISSIONS
Asst. Prof. Dr. Irem AKSOY Assoc. Prof. Dr. Tijen UNER	Kutahya Dumlupinar University Van Yuzuncu Yil University	GEOCHEMISTRY OF DEPLETED HARZBURGITES FROM THE KINIK OPHIOLITE, WESTERN ANATOLIA, TURKIYE
Kubra ARANCI Aylin BAYRAM Nizami SHAMIYEV Dr. Sevgi GULYUZ Asst. Prof. Kerem BURAN Dr. Ozgur YILMAZ	Marmara University Health Sciences University Eskisehir Technical University TUBITAK University of Health Sciences Istanbul Cerrahpasa University	DEVELOPMENT OF MULTIFUNCTIONAL CARBOXYMETHYLATED KAPPA-CARRAGEENAN PLATFORMS FOR HEMOSTATIC AND TISSUE ENGINEERING APPLICATIONS
Yusuf BOZOKLU Nilgun SECILMIS Petek BALCI Prof. Dr. Ali KARA	Texco Textile Dyehouse Bursa Technical University Bursa Uludag University Bursa Uludag University	EFFECT OF pH ON THE REMOVAL OF REACTIVE BLUE 221 FROM AQUEOUS SOLUTIONS VIA A MAGNETIC PHOTOCATALYTIC ADSORBENT
Yusuf BOZOKLU Nilgun SECILMIS Petek BALCI Prof. Dr. Ali KARA	Texco Textile Dyehouse Bursa Technical University Bursa Uludag University Bursa Uludag University	INVESTIGATION OF THE CONCENTRATION EFFECT ON THE REMOVAL OF REACTIVE BLUE 221 FROM AQUEOUS SOLUTIONS USING A MAGNETIC PHOTOCATALYTIC ADSORBENT

ONLINE / 06.04.2026 / HALL-2 / SESSION-2



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17³⁰ : 19³⁰



ANKARA LOCAL TIME



11³⁰ : 13³⁰

HEAD OF SESSION: **Assoc. Prof. Dr. Taner YILMAZ**

AUTHORS	AFFILIATION	TOPIC TITLE
Asst. Prof. Dr. Kenan ASLANOV	Azerbaijan State University of Economics	THE RELATIONSHIP BETWEEN PSYCHOLOGICAL RESILIENCE AND JOB STRESS AMONG HEALTHCARE WORKERS: EVIDENCE FROM ISTANBUL
Assoc. Prof. Dr. Taner YILMAZ Ali Burak KELEBEK	Usak University	FITNESS-ORIENTED SOCIAL MEDIA AND BODY IMAGE: A NARRATIVE REVIEW OF RISK MECHANISMS, PROTECTIVE FACTORS, AND FINDINGS FROM TÜRKİYE AMONG UNIVERSITY STUDENTS
Kardelen DUDULAR CİNALİ	Beykoz University, Faculty of Social Sciences, Department of Psychology	THE RELATIONSHIP OF PERCEIVED SOCIAL SUPPORT, INTERNALIZED STIGMA, AND EXPERIENTIAL AVOIDANCE WITH THE SEVERITY OF ALCOHOL USE DISORDER IN INDIVIDUALS WITH ALCOHOL USE DISORDER
Kardelen DUDULAR CINALI Prof. Dr. Sait ULUC	Beykoz University Hacettepe University	THE INFLUENCE OF DATING VIOLENCE ATTITUDE AND DEPRESSION LEVEL ON DEMAND-WITHDRAW COMMUNICATION PATTERNS
Kamala MAMMAZAZADA	Azerbaijan State Oil and Industry University	ANFIS-BASED MODELING OF A WASTEWATER TREATMENT BIOREACTOR: EFFECT OF RULE NUMBER ON MODEL ACCURACY
Etibar VAZIROV Mehrin MUSTAFAZADE Ayan GOYLAROVA	ADA University Independent Researcher Independent Researcher	MULTIMODAL ARTIFICIAL INTELLIGENCE FRAMEWORK FOR STRESS PREDICTION USING PHYSIOLOGICAL SIGNALS AND TEXTUAL EMOTIONAL ANALYSIS
Etibar VAZIROV Banu JABIYEVA Adika MAMMADOVA	ADA University Independent Researcher Independent Researcher	LEARNING TEMPORAL PATTERNS IN RENEWABLE ENERGY OUTPUT USING DEEP TIME-SERIES MODELS AND METEOROLOGICAL SIGNALS

ONLINE / 06.04.2026 / HALL-3 / SESSION-2



TOKYO LOCAL TIME



17³⁰ : 19³⁰



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11³⁰ : 13³⁰

HEAD OF SESSION: Dr. Duong To Quoc THAI

AUTHORS	AFFILIATION	TOPIC TITLE
Latafat Beybutova ALASGAR	"Genocide Memorial Complex", Guba City	QUBA - RICH IN HISTORICAL SITES AND MONUMENTS
Dr. Duong To Quoc THAI	Dong Thap University	AN OVERVIEW OF THE BANQUE DE L'INDOCHINE'S OPERATIONS IN VIETNAM DURING THE VOLATILE YEARS (1940–1945)
Dr. Duong To Quoc THAI	Dong Thap University	THE PRESENCE OF BANQUE DE L'INDOCHINE BRANCHES IN VIETNAM (1940–1945): FOOTPRINTS AND INTERACTIONS
Togrul HALILOV Resul BAGIROV	Nakhchivan State University	TYPOLGY AND ARTISTIC CHARACTERISTICS OF MEDIEVAL CERAMIC ARTIFACTS OF NAKHCHIVAN
Gabriela IVANOVSKA	Istanbul University / Ss. Cyril and Methodius University in Skopje	ON THE FRINGES OF HUMANITY: AFFIRMATIVE ETHICS AND POSTHUMANIST KINSHIP IN HELEN MCDONALD'S H IS FOR HAWK
Dr. Zekirja SHABANI	Institute of Albanology	THE POSITION OF WOMEN IN THE KOSOVO VILAYET DURING THE LATE OTTOMAN PERIOD
Benjamin Olumide BAMIDELE Moses Adeolu AGOI* Emmanuel Taiwo AGOI Oluwanifemi Opeyemi AGOI	Lagos State University of Education Lagos State University of Education Loughborough University Obafemi Awolowo University	ARCHITECTURAL SOUND AS DATA: COMPUTATIONAL MODELS FOR MUSIC-DRIVEN SPATIAL DESIGN
Soukaina EL BOURACHDI Soukaina EL BOURACHDI Ali Raza AYUB Yassine RAKCHO Lekbira EL MERSLY Mahdi LECHHEB José Alberto HERRERA-MELIÁN Amal LAHKIMI	Sidi Mohamed Ben Abdellah University Ibn Tofail University; Moulay Ismail University; Universidad de Las Palmas de Gran Canaria Cadi Ayyad University Mohammed VI Polytechnic University	PHOTOCATALYTIC DEGRADATION OF ORGANIC CONTAMINANTS USING GREEN-SYNTHESIZED TiO ₂ NANOPARTICLES FROM GINGER ROOT POWDER IMMOBILIZED IN CHITOSAN BEADS: A COMBINED EXPERIMENTAL AND THEORETICAL INVESTIGATION FOR SUSTAINABLE WATER PURIFICATION

ONLINE / 06.04.2026 / HALL-4 / SESSION-2



TOKYO LOCAL TIME



17³⁰ : 19³⁰



ANKARA LOCAL TIME



11³⁰ : 13³⁰

HEAD OF SESSION: **Prof. Dr. Ahmet Niyazi OZKER**

AUTHORS	AFFILIATION	TOPIC TITLE
Assit. Prof. Dr. Meryem GÜL	Osmaniye Korkut Ata University	THE EFFECT OF CULTURAL INTELLIGENCE ON ENTREPRENEURSHIP ORIENTATION
Emine ÖRS Prof. Dr. Dilek SÜREKÇİ YAMAÇLI	Izmir Democracy University	THE RELATIONSHIP BETWEEN FINANCIAL DEVELOPMENT AND ECONOMIC GROWTH: A STUDY WITHIN THE FRAMEWORK OF THEORETICAL APPROACHES
Dr. Birol ALTUN	Independent Researcher	POST-PANDEMIC RETURN TO THE OFFICE DEBATES: MANAGERS INSIST, EMPLOYEES RESIST
Assoc. Prof. Dr. Kerem TOKER Res. Asst. Timur KÖSE	Bezmialem Vakıf University	EXAMINING THE RELATIONSHIP BETWEEN NATIONAL INVESTMENTS IN ARTIFICIAL INTELLIGENCE AND HEALTH EXPENDITURES
Prof. Dr. Ayül KASAPOĞLU	Baskent University	A RELATIONAL SOCIOLOGICAL ANALYSIS OF RETIREMENT POVERTY IN TURKEY
Assoc. Prof. Dr. Hasan Selcuk ETİ Guvenc KURUL	Tekirdag Namik Kemal University	A CONCEPTUAL ANALYSIS ON THE ROLE OF VIRTUAL INFLUENCERS IN MARKETING COMMUNICATION, TRUST DYNAMICS, AND THEORETICAL LIMITS
Assoc. Prof. Dr. Hasan Selcuk ETİ	Tekirdag Namik Kemal University	A REVIEW ON THE ROLE OF USER-GENERATED CONTENT (UGC) IN MARKETING COMMUNICATIONS AND TRUST DYNAMICS
Prof. Dr. Ahmet Niyazi OZKER	Bandirma Onyedi Eylül University	CONTRIBUTIONS TO GDP GROWTH IN RECENT YEARS IN TURKIYE: THE ROLE OF A FUNCTIONING MARKET ECONOMY

ONLINE / 06.04.2026 / HALL-5 / SESSION-2



TOKYO LOCAL TIME



17³⁰ : 19³⁰



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11³⁰ : 13³⁰

HEAD OF SESSION: Prof. Dr. Alparslan DILSIZ

AUTHORS	AFFILIATION	TOPIC TITLE
Prof. Dr. Alparslan DILSIZ Shahrazad AMIZADEH Aysegul TURKSOY	Ataturk University	MANAGEMENT OF GINGIVAL RECESSON DUE TO OVER AGGRESSIVE BRUSHING WITH SUBEPITHELIAL CONNECTIVE TISSUE GRAFTS: A CASE REPORT
Prof. Dr. Alparslan DILSIZ Serhat TOPTAMUR Zeynep TEKIN	Ataturk University	CERVICAL FRACTURES OF DENTAL IMPLANTS AND MANAGEMENT: CASE REPORT AND LITERATURE REVIEW
Prof. Dr. Alparslan DILSIZ Zeynep TEKIN Abdullah Yavuz OZMEN	Ataturk University	SURGICAL PERIODONTAL TREATMENT OF ORAL PREGNANCY TUMOR: CASE REPORT WITH FOLLOW-UP
Rojda TANRIVERDI Hakan UYAR Assoc. Prof. Dr. Senay Balci FIDANCI Prof. Dr. Lulifer TAMER	Mersin University	THE RELATIONSHIP BETWEEN SALIVARY ALPHA-DEFENSIN (HNP 1-3) LEVELS AND DENTAL CARIES
Rojda TANRIVERDI Ali NEBIOGLU Assoc. Prof. Dr. Senay Balci FIDANCI Prof. Dr. Murat BOZLU Prof. Dr. Lulifer TAMER	Mersin University	INVESTIGATION OF GALECTIN-1, GALECTIN-3, AND GALECTIN-9 LEVELS IN PATIENTS WITH BLADDER CANCER
Unal OZTURK Ergul Belge KURUTAS	Sutcu Imam University	THE PROTECTIVE ROLE OF Equisetum arvense L. IN A CARDIAC ISCHEMIA-REPERFUSION INJURY MODEL INDUCED IN RATS: A BIOCHEMICAL STUDY

ONLINE / 07.04.2026 / HALL-1 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: **Lect. Busra Tansu CEYLAN**

AUTHORS	AFFILIATION	TOPIC TITLE
Öğr. Emircan GÜMÜŞ Prof. Dr. Asim OLGUN Araş. Gör. Dr. Şahin ÖZEL	Bursa Uludag University	MELAMINE-REINFORCED PGMA/POLY-GMS ADHESIVES FOR ENHANCED COPPER ADHESION
Assoc. Prof. Tahira HUSEYNOVA Gunel AMANULLAYEVA Gunel ASLANOVA	Azerbaijan State Oil and Industry University	OXIDATION OF 1-METHYL CYCLOHEPTANE WITH THE PARTICIPATION OF CROWN ETHERS
Zeynep KIYMAZ	Epsan Plastik	CHARACTERIZATION OF GLASS FIBER REINFORCED CHEMICALLY AND MECHANICALLY RECYCLED PA66 COMPOSITES
Dr. Raziye BOZKURT Prof. Dr. Bilal SENOL	Aksaray University	ANALYSIS OF SOFTWARE-ASSISTED LIQUEFACTION POTENTIAL USING SPT AND CPT PARAMETERS AND COMPARISON OF THE RESULTING SAFETY FACTOR
Dr. Raziye BOZKURT Prof. Dr. Bilal SENOL	Aksaray University	CALCULATING LIQUEFACTION POTENTIAL NUMERICALLY USING A SOFTWARE-BASED APPROACH WITH SPT DATA
Samet LAFKA Assoc. Prof. Dr. Dogan SIMSEK Prof. Dr. Hande GULER OZGUL	Bursa Uludag University	MECHANICAL AND CORROSION PROPERTIES OF AL-DP SHEETS IN RESISTANCE SPOT WELDING APPLICATIONS
Lect. Busra Tansu CEYLAN Burak GUL Prof. Dr. Rukiye ERTAN	Bursa Uludag University / Mudanya University	INFLUENCE OF CORE THICKNESS AND TEMPERATURE ON THE MECHANICAL PROPERTIES OF NOMEX HONEYCOMB-CORE CARBON FIBER/EPOXY SANDWICH COMPOSITES
Unal YILMAZ Prof. Dr. Figen BALO	Firat University	SURVEILLANCE PERFORMANCE ANALYSIS OF MINI UNMANNED AERIAL VEHICLES USING THE ANALYTICAL HIERARCHY PROCESS
Unal YILMAZ Prof. Dr. Figen BALO	Firat University	LOCKING MECHANISM SELECTION IN UNMANNED AERIAL VEHICLES: RELIABILITY AND COST-ORIENTED DECISION-MAKING APPLICATION

ONLINE / 07.04.2026 / HALL-2 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: **Res. Asst. Gulsum Ecem DEMIRDAG**

AUTHORS	AFFILIATION	TOPIC TITLE
Asst. Prof. Dr. Mahsa HAKKI Asst. Prof. Dr. Hüseyin ZÜLFİKAR	Istanbul Sabahattin Zaim University	MORPHOLOGICAL TRANSFORMATION OF HISTORICAL MOTIFS: A RESEARCH-BASED DESIGN ATTEMPT THROUGH THE ISTANBUL ARCHAEOLOGICAL MUSEUM AND TOPKAPI PALACE
Res. Asst. Gulsum Ecem DEMIRDAG	Mersin University	POST-EARTHQUAKE URBAN DAMAGE DETECTION USING THE NORMALIZED DIFFERENCE BUILT-UP INDEX (NDBI) AND SENTINEL-2 IMAGERY: THE CASE OF ISKENDERUN, TURKIYE
Res. Asst. Dr. Aysecan Hazal AK YILDIRIM	Istanbul University	NEOLIBERAL GOVERNANCE AND THE LIMITS OF AI INTEGRATION IN ISTANBUL'S MULTIMODAL TRANSPORT SYSTEM
Res. Asst. Dr. Aysecan Hazal AK YILDIRIM	Istanbul University	SOCIAL EQUITY AND MOBILITY IN PROXIMITY-BASED URBANISM: A BIBLIOMETRIC ANALYSIS AND CRITICAL PERSPECTIVE OF THE 15-MINUTE CITY LITERATURE
Prof. Dr. Mihalıs KUYUCU	Istanbul Galata University	THE DEVELOPMENT AND FUTURE OF PODCASTING IN TURKEY: CAN PODCASTING BECOME AN ALTERNATIVE TO RADIO?
Burcu KELES Asst. Prof. Mehmet ASLAN	Van Yuzuncu Yıl University	THE IDEOLOGY OF ENGLISH SUPERIORITY AND ITS ROLE IN CONTEMPORARY LINGUISTIC EXPLOITATION
Amina GASIMOVA Fatima SEYFULLAYEVA Dr. Kenan ASLANOV	Azerbaijan State University of Economics	THE IMPACT OF FINTECH ON CASHLESS PAYMENTS: THE ROLE OF "PASHA PAY" (M10) AND "E-MANAT" IN FINANCIAL INCLUSION
Elshan GULUZADA Dr. Kenan ASLANOV	Azerbaijan State University of Economics	THE IMPACT OF PERCEIVED VALUE OF HEALTH AND THERMAL TOURISM PRODUCTS ON VISIT INTENTION
Govher YAZDURDYEVA	Alanya Alaaddin Keykubat University	9TH GRADE SPEAKING SKILLS IN THE TURKIYE CENTURY MAARIF MODEL: A QUALITATIVE DOCUMENT ANALYSIS

ONLINE / 07.04.2026 / HALL-3 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: Assoc. Prof. Dr. Pham Duc THUAN

AUTHORS	AFFILIATION	TOPIC TITLE
Ephesus O. FATUNMBI Mukail A. AKINDE Olubisi L. AAKO	Federal Polytechnic Ilaro	ENTROPY DYNAMICS IN FINANCIAL SYSTEMS: A THERMOFLUID FRAMEWORK FOR RISK, UNCERTAINTY, AND MARKET INEFFICIENCY
C.U. IZUOGU E.U. UCHE M.O. OLAOLU L.C. NJOKU N.E. UMEH S. IBRAHIM-OLE SIN G.D. AGOU J.E. ORJI Chinemerem Nkechinyere NWOKEAFOR	Alex Ekwueme Federal University	PERCEPTION OF ORANGE-FLESHED SWEET POTATOES AMONG FARMERS IN AFIKPO ZONE EBONYI STATE NIGERIA
Dr. Phan Thi YEN Dr. Dang VINH	University of Danang Korea University of Information and Communication Technology	DEVELOPING A MULTIDIMENSIONAL RESEARCH COMPETENCE FRAMEWORK FOR UNDERGRADUATE STUDENTS
Assoc. Prof. Dr. Pham Duc THUAN	Can Tho University	MARINE AND ISLAND ECONOMIC DEVELOPMENT POLICIES IN VIETNAM (1986–2020)
Nguyen Chien THANG Le Nguyen Doan KHOI	Institute for European and Americas Studies Can Tho University	THE IMPACT OF CORPORATE SOCIAL RESPONSIBILITY ON BUSINESS PERFORMANCE THROUGH CORPORATE REPUTATION IN THE CONTEXT OF NEW-GENERATION FREE TRADE AGREEMENTS: A CASE STUDY OF THE SEAFOOD INDUSTRY IN THE MEKONG DELTA
Dr. Cat Duyen HUYNH	Nha Trang University	TOURIST SATISFACTION WITH OCOP-CERTIFIED AQUACULTURE PRODUCTS: IMPLICATIONS FOR SUSTAINABLE TOURISM AND LOCAL VALUE CHAINS IN COASTAL VIETNAM
Solomon Akinwale OJEDELE Dr. Timilehin Olayinka OMONIYI Busayo Bose ADELEKE	University of Ibadan, Faculty of Education	ASSESSMENT OF CORE 21ST CENTURY SKILLS AMONG SECONDARY SCHOOL STUDENTS IN IBADAN

ONLINE / 07.04.2026 / HALL-4 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: **Assoc. Prof. Dr. Saimah KHAN**

AUTHORS	AFFILIATION	TOPIC TITLE
Zineb ELABOUDI Samira EL AOUIDI Radouan SAADI Azzouz BENKADAD Zineb EL MOURIDI Abdelmourhit LAISSAOUI Abdelaziz MADINZI Salah SOUABI	University of Hassan II Casablanca National Energy Center for Nuclear Science and Technology National Institute for Agricultural Research University of Hassan II Casablanca	RADIONUCLIDE MOBILITY AND TRANSFER DYNAMICS IN SEMI-ARID MOROCCAN AGROECOSYSTEMS
Faisal NAZIR	The University of Agriculture Faisalabad	PRODUCTION AND CHARACTERIZATION OF CARBON NANOTUBES FROM BIOCHAR UNDER MICROWAVE IRRADIATION
Asst. Prof. Anita PANDEY	Kirodimal Govt. Arts and Science College	COMMUNITY COMPOSITION AND GUILD STRUCTURE OF SPIDER ASSEMBLAGES IN RELATION TO THE DRY DECIDUOUS FOREST OF BARMKELA, CHHATTISGARH, INDIA
Assoc. Prof. Dr. Saimah KHAN	Integral University	PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS) IN COSMETICS: OCCURRENCE, EXPOSURE PATHWAYS, HEALTH CONCERNS AND EMERGING REGULATORY RESPONSES
Sabrina SUHAIMI	Polytechnic Tun Syed Nasir Syed Ismail	SEED OIL FOR MAKING OIL BASED PAINT
Aurel NURO Bledar MYRTAJ Elvin COMO Albana HASIMI Gazmir CELA	University of Tirana Polytechnic University of Tirana	EVALUATION OF WATER QUALITY FOR LANA RIVER, ALBANIA/LAYER
Amir DJELLOULI Yamina BERREDJEM Mohamed YAGOUB Hadjer GUESMIA	CRSTRA, Biskra + University Badji Mokhtar, Annaba University Badji Mokhtar, Annaba Mohamed Khider University, Biskra CRSTRA, Biskra	BATCH NITROPHENOL ADSORPTION EMPLOYING LOW-COST ACTIVATED CARBON AND FIXED-BED COLUMNS

ONLINE / 07.04.2026 / HALL-5 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: **Dr. Ochuko ORAKPOGHENOR**

AUTHORS	AFFILIATION	TOPIC TITLE
Dr. K.R. PADMA	Sri Padmavati Mahila Visvavidyalayam	THERAPEUTIC AND IMMUNOMODULATORY POTENTIAL OF ALLIUM SATIVUM AND ALLIUM CEPA IN THE MANAGEMENT OF MALARIA: PHYTOCHEMICAL MECHANISMS AND FUTURE PERSPECTIVES
Huma IKRAM Rumaisa ZAKIR Darakhshan J. HALEEM	University of Karachi	PRENATAL STRESS INCREASES SUSCEPTIBILITY TO APOMORPHINE ADDICTION AND MODIFIES THE RESPONSIVENESS OF 5HT-1A RECEPTORS IN ADULT RATS
Dr. Ochuko ORAKPOGHENOR	Abubakar Tafawa Balewa University Bauchi	ENHANCING REPRODUCIBILITY IN VETERINARY PATHOLOGY THROUGH STRUCTURED LESION GRADING SYSTEMS
Rachida ELBARGHMI Mostapha ABOURRICH	Abdelmalek Essaadi University	ASSESSMENT OF MEDICAL AND PHARMACEUTICAL WASTE MANAGEMENT PRACTICES IN PRIMARY HEALTHCARE FACILITIES
Nesrine BENKHAIRA Saad Ibnsouda KORAICHI Kawtar Fikri-Benbrahim	Sidi Mohamed Ben Abdellah University	LIMONENE AS A NATURAL SOLUTION TO ANTIMICROBIAL RESISTANCE
Dr. Monika STOJANOVA Prof. Dr. Marina S.T. STOJANOVA Acad. Prof. Dr. Dragutin A. DJUKIC Milos RABRENOVIC	Association for Scientific-research, Educational and Cultural Activities "Open Science" University of Ss. Cyril and Methodius, Faculty of Agricultural Sciences and Food University of Kragujevac, Faculty of Agronomy Association for Scientific-research, Educational and Cultural Activities "Open Science"	ANTIMICROBIAL AND SENSORY PROPERTIES OF BIO-SOUPS ENRICHED WITH FUSCOPORIA TORULOSA EXTRACTS
Vjollca BERISHA Sevdije GOVORI	University of Prishtina, Faculty of Mathematical and Natural Sciences, Department of Chemistry	SYNTHESIS, SPECTROSCOPIC CHARACTERIZATION, AND BIOLOGICAL ACTIVITY OF NOVEL HETEROCYCLIC SCHIFF BASE LIGANDS AND THEIR CO(II), NI(II), TI(III) AND TI(IV) COMPLEXES

ONLINE / 07.04.2026 / HALL-6 / SESSION-1



TOKYO LOCAL TIME



15⁰⁰ : 17⁰⁰



ANKARA LOCAL TIME



09⁰⁰ : 11⁰⁰

HEAD OF SESSION: **Rajesh J.H. NAVASINGH**

AUTHORS	AFFILIATION	TOPIC TITLE
Jebasingh Jeremiah Rajesh Jesudoss HYNES Rajesh J.H. NAVASINGH	Opole University of Technology	ARTIFICIAL INTELLIGENCE POWERED CLIMATE CHANGE MODELLING
A. O. IDOWU	Federal Polytechnic Ilaro	COPULA-BASED MULTIVARIATE CONTROL CHARTS FOR MONITORING DEPENDENT COUNT PROCESSES: APPLICATION TO CARDIOMETABOLIC DISEASES
Sofia EL MARJANY Yassine EL ALLOUCHE Abdellah ELAISOUCQ Hicham ZAITAN Fouad KHALIL	Sidi Mohamed Ben Abdellah University	COMPUTATIONAL DEVELOPMENT OF NOVEL TRIM24-TARGETED AGENTS FOR PROSTATE CANCER THERAPY
Ghina EL ZEIN	Saint Joseph University of Beirut	BRIDGING THE PEDAGOGICAL GAP: AN AI-BASED SUBJECT IMPROVEMENT PLAN (AI-SIP) FOR REMEDICATION OF GENETICS MISCONCEPTIONS IN BEIRUT PUBLIC SCHOOLS
Abdelali LAID Abed ZOULIKHA Aced Mohamed REDA	University Djillali Liabes of Sidi Bel Abbes	TEMPERATURE-DEPENDENT NUMERICAL SIMULATION OF CIGS SOLAR CELLS INCORPORATING A ZNS INSULATION LAYER
Afshan NASEEM Irfan BASHIR Raheela JAVAID	University of Management and Technology, Lahore, Pakistan	ARTIFICIAL INTELLIGENCE AND ACADEMIC INTEGRITY IN HIGHER EDUCATION: POLICY READINESS AND CHALLENGES IN LAHORE UNIVERSITIES
Balasubramani G. L. Rinky RAJPUT Manish GUPTA Pradeep DAHIYA Jitendra K THAKUR Rakesh BHATNAGAR Abhinav GROVER	Jawaharlal Nehru University National Institute of Plant Genome Research Banaras Hindu University Jawaharlal Nehru University	STRUCTURE-BASED DRUG REPURPOSING TO INHIBIT THE DNA GYRASE OF MYCOBACTERIUM TUBERCULOSIS

ABSTRACTS		
<i>Lecturer Zeliha ASILKAN Prof. Dr. Afsun Ezel ESATOGLU</i>	<i>AN EXAMINATION OF ATTITUDES TOWARDS ARTIFICIAL INTELLIGENCE IN HEALTHCARE SERVICES USING SOCIAL MEDIA ANALYSIS</i>	<i>1</i>
<i>Asst. Prof. Dr. Nermin ER AYDEMİR Sıla Ezgi ŞENTÜRK</i>	<i>AN EXAMINATION OF THE 6TH GRADE TURKISH TEXTBOOK FROM THE PERSPECTIVE OF MULTIPLE INTELLIGENCE THEORY</i>	<i>2</i>
<i>Mikota Abedi KARENGA Prof. Dr. Osman Ferda BEYTEKIN</i>	<i>A RESEARCH ON PERSPECTIVES OF PRIMARY SCHOOL TEACHERS ON DIGITAL INCLUSION IN EDUCATION IN DAR ES SALAAM, TANZANIA</i>	<i>3</i>
<i>Prof. Dr. Harun SAHIN Buse Basak TURAN</i>	<i>A NEW DIMENSION OF THE HIDDEN CURRICULUM IN SOCIAL STRUCTURING: EDUCATION AND SOCIAL MEDIA VIDEOS IN THE AGE OF DIGITALIZATION</i>	<i>4</i>
<i>Asst. Prof. Dr. Merve SAMIOGLU</i>	<i>INTERACTIVE APPLETS IN UNDERSTANDING DESCRIPTIVE STATISTICS</i>	<i>6</i>
<i>Asst. Prof. Dr. Merve SAMIOGLU</i>	<i>CLASSIFYING COGNITIVE BIASES: THE PROBLEM OF NORMATIVE REFERENCE POINTS</i>	<i>7</i>
<i>Lina Marsella Saury RODRÍGUEZ</i>	<i>INCLUSION OF MENTAL HEALTH IN EDUCATION</i>	<i>8</i>
<i>Raf Raf Shakil ANSARI</i>	<i>EXPLORING POETICS OF RESISTANCE IN JAVED AKHTAR'S A NEW DECREE</i>	<i>9</i>
<i>Assoc. Prof. Dr. Anna KOPICZKO Wiktoria PIETRZAK Jakub BALDYKA Dr. Patrycja WIDLAK Dr. Joanna CIEPLINSKA</i>	<i>DETERMINANTS OF SKELETAL MINERALIZATION IN ADOLESCENT MALES: THE ROLE OF SPORT TYPE, BODY COMPOSITION, AND DIET</i>	<i>10</i>
<i>Dr. Anisa POTKA Prof. Dr. Numila KUNESHKA</i>	<i>DANON DISEASE PRESENTING AS HYPERTROPHIC CARDIOMYOPATHY: A CASE REPORT</i>	<i>11</i>
<i>Marigona RIZANI-SHABANI</i>	<i>ASSESSMENT OF NURSING STUDENTS' KNOWLEDGE AND ATTITUDES IN KOSOVO TOWARD MEDICATION ADMINISTRATION ERRORS</i>	<i>12</i>
<i>Vlad DIACONESCU Bogdan-Catalin SERBAN Matei-Gabriel URSACHESCU Caterina ZETU Maria Ruxandra SALAGEAN Diana DUMITRASCU Octavian BUIU Marius BUMBAC</i>	<i>RIVAROXABAN – MOLECULAR PRECISION IN THE DIRECT INHIBITION OF COAGULATION FACTOR Xa</i>	<i>13</i>
<i>Vlad DIACONESCU Bogdan-Catalin SERBAN Matei-Gabriel URSACHESCU Caterina ZETU Maria Ruxandra SALAGEAN Diana DUMITRASCU Octavian BUIU Marius BUMBAC</i>	<i>OMEPRazole – FROM ACID-TRIGGERED ACTIVATION TO THE NEW ERA OF GASTRIC ACID SUPPRESSION</i>	<i>15</i>

<i>Asst. Prof. Nelya NOVOTORZHINA</i> <i>Asst. Prof. Mehpara SAFAROVA</i> <i>Asst. Prof. Gariba GAHRAMANOVA</i> <i>Asst. Prof. Malahat ABBASOVA</i> <i>Shafa KAZIMZADEH</i> <i>Gunay MUSTAFAYEVA</i> <i>Irada HAJIYEVA</i>	<i>BACTERICIDAL ADDITIVE FOR CUTTING FLUIDS</i>	17
<i>Bogdan-Catalin SERBAN</i> <i>Matei-Gabriel URSACHESCU</i> <i>Vlad DIACONESCU</i> <i>Caterina ZETU</i> <i>Maria Ruxandra SALAGEAN</i> <i>Diana DUMITRASCU</i> <i>Octavian BUIU</i> <i>Marius BUMBAC</i>	<i>CARAMELIZATION: CURRENT PERSPECTIVES ON A VERSATILE BUT POORLY UNDERSTOOD CHEMICAL PROCESS</i>	18
<i>Bogdan-Catalin SERBAN</i> <i>Matei-Gabriel URSACHESCU</i> <i>Vlad DIACONESCU</i> <i>Caterina ZETU</i> <i>Maria Ruxandra SALAGEAN</i> <i>Diana DUMITRASCU</i> <i>Octavian BUIU</i> <i>Marius BUMBAC</i>	<i>POLYSACCHARIDES USED IN THE PHARMACEUTICAL AND NATURAL SUPPLEMENTS INDUSTRIES: PROPERTIES, APPLICATIONS, AND PERSPECTIVES</i>	19
<i>Vlad DIACONESCU</i> <i>Bogdan-Catalin SERBAN</i> <i>Matei-Gabriel URSACHESCU</i> <i>Caterina ZETU</i> <i>Maria Ruxandra SALAGEAN</i> <i>Diana DUMITRASCU</i> <i>Octavian BUIU</i> <i>Marius BUMBAC</i>	<i>OLIGOSACCHARIDES AND POLYSACCHARIDES IN COSMETICS: PROPERTIES, APPLICATIONS, AND FUTURE PERSPECTIVES</i>	21
<i>Matei-Gabriel URSACHESCU</i> <i>Bogdan-Catalin SERBAN</i> <i>Vlad DIACONESCU</i> <i>Caterina ZETU</i> <i>Maria Ruxandra SALAGEAN</i> <i>Diana DUMITRASCU</i> <i>Octavian BUIU</i> <i>Marius BUMBAC</i>	<i>CYCLODEXTRINS: FROM SUPRAMOLECULAR HOST-GUEST CHEMISTRY TO DRUG DELIVERY APPLICATIONS</i>	23
<i>Dr. Mehmet Emin HACIYUSUFOGLU</i>	<i>DETECTION OF AMITRAZ AND FLUMETHRIN RESIDUES IN PROPOLIS</i>	24
<i>Dr. Mehmet Emin HACIYUSUFOGLU</i>	<i>INVESTIGATION OF THE PRESENCE OF MICROPLASTICS IN HONEY BEE AND BEE PRODUCTS</i>	26
<i>Dr. Selda BULUT</i> <i>Dr. Hakan ERDOĞAN</i> <i>Hamza ÖMER</i>	<i>DIGITALIZATION AND ITS CLIMATE COST: THE OVERLOOKED ECOLOGICAL FOOTPRINT OF THE TWIN TRANSITION</i>	28
<i>Asst. Prof. Dr. İrem AKSOY</i> <i>Assoc. Prof. Dr. Tijen UNER</i>	<i>GEOCHEMISTRY OF DEPLETED HARZBURGITES FROM THE KINIK OPHIOLITE, WESTERN ANATOLIA, TURKIYE</i>	30

<i>Yusuf BOZOKLU Nilgun SECILMIS Petek BALCI Prof. Dr. Ali KARA</i>	<i>EFFECT OF pH ON THE REMOVAL OF REACTIVE BLUE 221 FROM AQUEOUS SOLUTIONS VIA A MAGNETIC PHOTOCATALYTIC ADSORBENT</i>	<i>31</i>
<i>Yusuf BOZOKLU Nilgun SECILMIS Petek BALCI Prof. Dr. Ali KARA</i>	<i>INVESTIGATION OF THE CONCENTRATION EFFECT ON THE REMOVAL OF REACTIVE BLUE 221 FROM AQUEOUS SOLUTIONS USING A MAGNETIC PHOTOCATALYTIC ADSORBENT</i>	<i>33</i>
<i>Kubra ARANCI Aylin BAYRAM Nizami SHAMIYEV Dr. Sevgi GULYUZ Asst. Prof. Kerem BURAN Dr. Ozgur YILMAZ</i>	<i>DEVELOPMENT OF MULTIFUNCTIONAL CARBOXYMETHYLATED KAPPA- CARRAGEENAN PLATFORMS FOR HEMOSTATIC AND TISSUE ENGINEERING APPLICATIONS</i>	<i>34</i>
<i>Asst. Prof. Dr. Kenan ASLANOV</i>	<i>THE RELATIONSHIP BETWEEN PSYCHOLOGICAL RESILIENCE AND JOB STRESS AMONG HEALTHCARE WORKERS: EVIDENCE FROM ISTANBUL</i>	<i>35</i>
<i>Kardelen DUDULAR CİNALI Arif Haldun SOYGÜR</i>	<i>THE RELATIONSHIP OF PERCEIVED SOCIAL SUPPORT, INTERNALIZED STIGMA, AND EXPERIENTIAL AVOIDANCE WITH THE SEVERITY OF ALCOHOL USE DISORDER IN INDIVIDUALS WITH ALCOHOL USE DISORDER</i>	<i>36</i>
<i>Kardelen DUDULAR CİNALI Prof. Dr. Sait ULUC</i>	<i>THE INFLUENCE OF DATING VIOLENCE ATTITUDE AND DEPRESSION LEVEL ON DEMAND-WITHDRAW COMMUNICATION PATTERNS</i>	<i>37</i>
<i>Gabriela IVANOVSKA</i>	<i>ON THE FRINGES OF HUMANITY: AFFIRMATIVE ETHICS AND POSTHUMANIST KINSHIP IN HELEN MCDONALD'S H IS FOR HAWK</i>	<i>38</i>
<i>Dr. Zekirja SHABANI</i>	<i>THE POSITION OF WOMEN IN THE KOSOVO VILAYET DURING THE LATE OTTOMAN PERIOD</i>	<i>39</i>
<i>Soukaina EL BOURACHDI Soukaina EL BOURACHDI Ali Raza AYUB Yassine RAKCHO Lekbira EL MERSLY Mahdi LECHHEB José Alberto HERRERA- MELIÁN Amal LAHKIMI</i>	<i>PHOTOCATALYTIC DEGRADATION OF ORGANIC CONTAMINANTS USING GREEN- SYNTHESIZED TiO₂ NANOPARTICLES FROM GINGER ROOT POWDER IMMOBILIZED IN CHITOSAN BEADS: A COMBINED EXPERIMENTAL AND THEORETICAL INVESTIGATION FOR SUSTAINABLE WATER PURIFICATION</i>	<i>40</i>
<i>Dr. Birol ALTUN</i>	<i>POST-PANDEMIC RETURN TO THE OFFICE DEBATES: MANAGERS INSIST, EMPLOYEES RESIST</i>	<i>42</i>
<i>Assoc. Prof. Dr. Kerem TOKER Res. Asst. Timur KÖSE</i>	<i>EXAMINING THE RELATIONSHIP BETWEEN NATIONAL INVESTMENTS IN ARTIFICIAL INTELLIGENCE AND HEALTH EXPENDITURES</i>	<i>44</i>
<i>Prof. Dr. Aytul KASAPOGLU</i>	<i>A RELATIONAL SOCIOLOGICAL ANALYSIS OF RETIREMENT POVERTY IN TURKEY</i>	<i>46</i>

<i>Prof. Dr. Alparslan DILSIZ Shahrzad AMIZADEH Aysegul TURKSOY</i>	<i>MANAGEMENT OF GINGIVAL RECESSON DUE TO OVER AGGRESSIVE BRUSHING WITH SUBEPITHELIAL CONNECTIVE TISSUE GRAFTS: A CASE REPORT</i>	47
<i>Rojda TANRIVERDI Hakan UYAR Assoc. Prof. Dr. Senay Balci FIDANCI Prof. Dr. Lulufer TAMER</i>	<i>THE RELATIONSHIP BETWEEN SALIVARY ALPHA-DEFENSIN (HNP 1–3) LEVELS AND DENTAL CARIES</i>	48
<i>Rojda TANRIVERDI Ali NEBIOGLU Assoc. Prof. Dr. Senay Balci FIDANCI Prof. Dr. Murat BOZLU Prof. Dr. Lulufer TAMER</i>	<i>INVESTIGATION OF GALECTIN-1, GALECTIN-3, AND GALECTIN-9 LEVELS IN PATIENTS WITH BLADDER CANCER</i>	50
<i>Zeynep KIYMAZ</i>	<i>CHARACTERIZATION OF GLASS FIBER REINFORCED CHEMICALLY AND MECHANICALLY RECYCLED PA66 COMPOSITES</i>	52
<i>Samet LAFKA Assoc. Prof. Dr. Dogan SIMSEK Prof. Dr. Hande GULER OZGUL</i>	<i>MECHANICAL AND CORROSION PROPERTIES OF AL-DP SHEETS IN RESISTANCE SPOT WELDING APPLICATIONS</i>	54
<i>Asst. Prof. Dr. Mahsa HAKKI Asst. Prof. Dr. Hüseyin ZÜLFİKAR</i>	<i>MORPHOLOGICAL TRANSFORMATION OF HISTORICAL MOTIFS: A RESEARCH-BASED DESIGN ATTEMPT THROUGH THE ISTANBUL ARCHAEOLOGICAL MUSEUM AND TOPKAPI PALACE</i>	55
<i>Res. Asst. Gulsum Ecem DEMIRDAG</i>	<i>POST-EARTHQUAKE URBAN DAMAGE DETECTION USING THE NORMALIZED DIFFERENCE BUILT-UP INDEX (NDBI) AND SENTINEL-2 IMAGERY: THE CASE OF ISKENDERUN, TURKIYE</i>	57
<i>Res. Asst. Dr. Aysecan Hazal AK YILDIRIM</i>	<i>NEOLIBERAL GOVERNANCE AND THE LIMITS OF AI INTEGRATION IN ISTANBUL'S MULTIMODAL TRANSPORT SYSTEM</i>	58
<i>Res. Asst. Dr. Aysecan Hazal AK YILDIRIM</i>	<i>SOCIAL EQUITY AND MOBILITY IN PROXIMITY- BASED URBANISM: A BIBLIOMETRIC ANALYSIS AND CRITICAL PERSPECTIVE OF THE 15- MINUTE CITY LITERATURE</i>	59
<i>Burcu KELES Asst. Prof. Mehmet ASLAN</i>	<i>THE IDEOLOGY OF ENGLISH SUPERIORITY AND ITS ROLE IN CONTEMPORARY LINGUISTIC EXPLOITATION</i>	60
<i>Amina GASIMOVA Fatima SEYFULLAYEVA Dr. Kenan ASLANOV</i>	<i>THE IMPACT OF FINTECH ON CASHLESS PAYMENTS: THE ROLE OF "PASHA PAY" (M10) AND "E-MANAT" IN FINANCIAL INCLUSION</i>	61
<i>Elshan GULUZADA Dr. Kenan ASLANOV</i>	<i>THE IMPACT OF PERCEIVED VALUE OF HEALTH AND THERMAL TOURISM PRODUCTS ON VISIT INTENTION</i>	62
<i>Govher YAZDURDYEVA</i>	<i>9TH GRADE SPEAKING SKILLS IN THE TURKIYE CENTURY MAARIF MODEL: A QUALITATIVE DOCUMENT ANALYSIS</i>	63

<i>Ephesus O. FATUNMBI Mukail A. AKINDE Olubisi L. AAKO</i>	<i>ENTROPY DYNAMICS IN FINANCIAL SYSTEMS: A THERMOFLUID FRAMEWORK FOR RISK, UNCERTAINTY, AND MARKET INEFFICIENCY</i>	<i>64</i>
<i>C.U. IZUOGU E.U. UCHE M.O. OLAOLU L.C. NJOKU N.E. UMEH S. IBRAHIM-OLE SIN G.D. AGOU J.E. ORJI Chinemerem Nkechinyere NWOKEAFOR</i>	<i>PERCEPTION OF ORANGE-FLESHED SWEET POTATOES AMONG FARMERS IN AFIKPO ZONE EBONYI STATE NIGERIA</i>	<i>65</i>
<i>Assoc. Prof. Dr. Pham Duc THUAN</i>	<i>MARINE AND ISLAND ECONOMIC DEVELOPMENT POLICIES IN VIETNAM (1986– 2020)</i>	<i>66</i>
<i>Nguyen Chien THANG Le Nguyen Doan KHOI</i>	<i>THE IMPACT OF CORPORATE SOCIAL RESPONSIBILITY ON BUSINESS PERFORMANCE THROUGH CORPORATE REPUTATION IN THE CONTEXT OF NEW-GENERATION FREE TRADE AGREEMENTS: A CASE STUDY OF THE SEAFOOD INDUSTRY IN THE MEKONG DELTA</i>	<i>67</i>
<i>Dr. Cat Duyen HUYNH</i>	<i>TOURIST SATISFACTION WITH OCOP- CERTIFIED AQUACULTURE PRODUCTS: IMPLICATIONS FOR SUSTAINABLE TOURISM AND LOCAL VALUE CHAINS IN COASTAL VIETNAM</i>	<i>68</i>
<i>Solomon Akinwale OJEDELE Dr. Timilehin Olayinka OMONIYI Busayo Bose ADELEKE</i>	<i>ASSESSMENT OF CORE 21ST CENTURY SKILLS AMONG SECONDARY SCHOOL STUDENTS IN IBADAN</i>	<i>69</i>
<i>Zineb ELABOUDI Samira EL AOUIDI Radouan SAADI Azzouz BENKADAD Zineb EL MOURIDI Abdelmourhit LAISSAOUI Abdelaziz MADINZI Salah SOUABI</i>	<i>RADIONUCLIDE MOBILITY AND TRANSFER DYNAMICS IN SEMI-ARID MOROCCAN AGROECOSYSTEMS</i>	<i>70</i>
<i>Faisal NAZIR</i>	<i>PRODUCTION AND CHARACTERIZATION OF CARBON NANOTUBES FROM BIOCHAR UNDER MICROWAVE IRRADIATION</i>	<i>71</i>
<i>Sabrina SUHAIMI</i>	<i>SEED OIL FOR MAKING OIL BASED PAINT</i>	<i>72</i>
<i>Amir DJELLOULI Yamina BERREDJEM Mohamed YAGOUB Hadjer GUESMIA</i>	<i>BATCH NITROPHENOL ADSORPTION EMPLOYING LOW-COST ACTIVATED CARBON AND FIXED-BED COLUMNS</i>	<i>73</i>
<i>Dr. K.R. PADMA</i>	<i>THERAPEUTIC AND IMMUNOMODULATORY POTENTIAL OF ALLIUM SATIVUM AND ALLIUM CEPA IN THE MANAGEMENT OF MALARIA: PHYTOCHEMICAL MECHANISMS AND FUTURE PERSPECTIVES</i>	<i>74</i>
<i>Huma IKRAM Rumaisa ZAKIR</i>	<i>PRENATAL STRESS INCREASES SUSCEPTIBILITY TO APOMORPHINE</i>	<i>75</i>

<i>Darakhshan J. HALEEM</i>	<i>ADDICTION AND MODIFIES THE RESPONSIVENESS OF 5HT-1A RECEPTORS IN ADULT RATS</i>	
<i>Dr. Ochuko ORAKPOGHENOR</i>	<i>ENHANCING REPRODUCIBILITY IN VETERINARY PATHOLOGY THROUGH STRUCTURED LESION GRADING SYSTEMS</i>	76
<i>Rachida ELBARGHMI Mostapha ABOURRICH</i>	<i>ASSESSMENT OF MEDICAL AND PHARMACEUTICAL WASTE MANAGEMENT PRACTICES IN PRIMARY HEALTHCARE FACILITIES</i>	77
<i>Nesrine BENKHAIRA Saad Ibnsouda KORAICHI Kawtar Fikri-Benbrahim</i>	<i>LIMONENE AS A NATURAL SOLUTION TO ANTIMICROBIAL RESISTANCE</i>	78
<i>Dr. Monika STOJANOVA Prof. Dr. Marina S.T. STOJANOVA Acad. Prof. Dr. Dragutin A. DJUKIC Milos RABRENOVIC</i>	<i>ANTIMICROBIAL AND SENSORY PROPERTIES OF BIO-SOUPS ENRICHED WITH FUSCOPORIA TORULOSA EXTRACTS</i>	79
<i>Vjollca BERISHA Sevdije GOVORI</i>	<i>SYNTHESIS, SPECTROSCOPIC CHARACTERIZATION, AND BIOLOGICAL ACTIVITY OF NOVEL HETEROCYCLIC SCHIFF BASE LIGANDS AND THEIR CO(II), NI(II), TI(III) AND TI(IV) COMPLEXES</i>	80
<i>A. O. IDOWU B. Alabi N. O. C. Aako O. L. D. Sokenu, M. R</i>	<i>COPULA-BASED MULTIVARIATE CONTROL CHARTS FOR MONITORING DEPENDENT COUNT PROCESSES: APPLICATION TO CARDIOMETABOLIC DISEASES</i>	81
<i>Sofia EL MARJANY Yassine EL ALLOUCHE Abdellah ELAISSOUQ Hicham ZAITAN Fouad KHALIL</i>	<i>COMPUTATIONAL DEVELOPMENT OF NOVEL TRIM24-TARGETED AGENTS FOR PROSTATE CANCER THERAPY</i>	82
<i>Ghina EL ZEIN</i>	<i>BRIDGING THE PEDAGOGICAL GAP: AN AI-BASED SUBJECT IMPROVEMENT PLAN (AI-SIP) FOR REMEDIATION OF GENETICS MISCONCEPTIONS IN BEIRUT PUBLIC SCHOOLS</i>	83
<i>Abdelali LAID Abed ZOULIKHA Aced Mohamed REDA</i>	<i>TEMPERATURE-DEPENDENT NUMERICAL SIMULATION OF CIGS SOLAR CELLS INCORPORATING A ZNS INSULATION LAYER</i>	84
<i>Afshan NASEEM Irfan BASHIR Raheela JAVAID</i>	<i>ARTIFICIAL INTELLIGENCE AND ACADEMIC INTEGRITY IN HIGHER EDUCATION: POLICY READINESS AND CHALLENGES IN LAHORE UNIVERSITIES</i>	85
<i>Balasubramani G. L. Rinky RAJPUT Manish GUPTA Pradeep DAHIYA Jitendra K THAKUR Rakesh BHATNAGAR Abhinav GROVER</i>	<i>STRUCTURE-BASED DRUG REPURPOSING TO INHIBIT THE DNA GYRASE OF MYCOBACTERIUM TUBERCULOSIS</i>	86

FUL TEXTS		
<i>Assoc. Prof. Emine BAS Muhammet Fatih SEKER</i>	<i>BINARY CUCKOO CATFISH OPTIMIZER FOR UFLP PROBLEMS</i>	87
<i>Assoc. Prof. Emine BAS Res. Asst. Fatih BAL</i>	<i>CLASSIFICATION OF PEAR VARIETIES USING PEAR LEAVES WITH YOLOV8</i>	105
<i>Asst. Prof. Dr. Hüseyin BODUR</i>	<i>A LIGHTWEIGHT QR-ASSISTED ZERO- KNOWLEDGE IDENTIFICATION PROTOCOL FOR SECURE AUTHENTICATION</i>	112
<i>Prof. Dr. Mehmet ÖZBAŞ</i>	<i>STUDENT VIEWS ON INFORMAL AND SOCIAL MEDIA AND ARTIFICIAL INTELLIGENCE APPLICATIONS THAT BRING THE END OF FORMAL EDUCATION</i>	119
<i>Res. Asst. Bahtiyar DILDEGMEZ Prof. Dr. Mehmet ÖZBAŞ</i>	<i>AN EXAMINATION OF INDIVIDUALS' PERCEPTIONS OF DEMOCRATIC CULTURE AND DEMOCRATIC EDUCATION IN TERMS OF VARIOUS DEMOGRAPHIC VARIABLES</i>	130
<i>Assoc. Prof. Dr. Burak BAŞKAN</i>	<i>POLITICAL COMMUNICATION AND CAMPAIGNING IN THE AGE OF ALGORITHMS AND ARTIFICIAL INTELLIGENCE</i>	143
<i>Prof. Dr. Cem Harun MEYDAN İklim Nur EROĞLU Asst. Prof. M. Alper AKDEMİR</i>	<i>ORGANIZATIONAL SILENCE IN THE CONTEXT OF ARTIFICIAL INTELLIGENCE: THE ROLE OF ALGORITHMIC AUTHORITY IN SILENCE MECHANISMS</i>	149
<i>Prof. Dr. Rukuye AYLAZ MSc Fidan BALKAYA</i>	<i>EXAMINING THE EFFECTIVENESS OF VIRTUAL REALITY-ASSISTED PSYCHOEDUCATION ON ANXIETY IN EARTHQUAKE SURVIVORS: A QUALITATIVE STUDY</i>	160
<i>MSc Fidan BALKAYA Prof. Dr. Rukuye AYLAZ</i>	<i>MOBILE HEALTH APPLICATIONS IN CHRONIC DISEASE MANAGEMENT: A REVIEW OF THE LITERATURE FROM THE LAST FIVE YEARS (2020–2025)</i>	168
<i>Assoc. Prof. Dr. Kamil Arif KIRKIC Müberra SARI</i>	<i>CONFIRMATORY FACTOR ANALYSIS OF THE TURKISH VERSION OF THE SECOND LANGUAGE LEARNING GRIT (L2-GRIT) SCALE</i>	173
<i>Ayhan DALLI Assoc. Prof. Dr. Kamil Arif KIRKIC</i>	<i>MIDDLE AND HIGH SCHOOL TEACHERS' CURRICULUM LITERACY AND TEACHER SELF- REGULATION</i>	184
<i>Sila KALE Dr. Birsan ACIKEL Dr. Tarik GUNES</i>	<i>STRATEGIC APPROACHES TO SUSTAINABLE AVIATION EDUCATION: A THEORETICAL ANALYSIS OF GLOBAL POLICY FRAMEWORKS</i>	193
<i>Sila KALE Dr. Birsan ACIKEL Dr. Tarik GUNES</i>	<i>EMERGENCY MANAGEMENT IN AIRPORTS IN RELATION TO AIR TRAFFIC CONTROL: A HUMAN FACTORS-BASED ASSESSMENT</i>	203
<i>Elnura GULIYEVA</i>	<i>ENHANCING SPEAKING PROFICIENCY THROUGH INTEGRATED INNOVATIVE PEDAGOGIES IN MILITARY EFL EDUCATION: A QUASI-EXPERIMENTAL STUDY</i>	216
<i>Dr. Rajmonda MILLOSHI Dr. Aida ZOTAJ</i>	<i>QUANTITATIVE ANALYSIS OF THE LEARNING CLIMATE AND COGNITIVE LOAD IN NURSING LABORATORY PRACTICES: A CROSS- SECTIONAL STUDY</i>	223

<i>Cristian-Romeo SPĂȚARU Cristian Constantin POPESCU</i>	<i>DETERMINANTS OF CORRUPTION IN EMERGING AND DEVELOPED ECONOMIES: A PANEL DATA ANALYSIS WITH DYNAMIC FIXED EFFECTS</i>	231
<i>Dr. Jai Gopal GUPTA</i>	<i>EVOLUTION AND INNOVATION IN INDIAN RAILWAY TRAIN COACHES</i>	245
<i>Irina-Ana DROBOT</i>	<i>HAIKU POEMS AND ALLUSIONS TO CONTEXTS</i>	254
<i>Dr. Erdinç ALTINÇEKİÇ Asst. Prof. Dr. Sevil ÇALIŞKAN ELEREN Assoc. Prof. Dr. Şeniz ÖZİŞ ALTINÇEKİÇ</i>	<i>EFFECTS OF RUMINANT BREEDING ON METHANE EMISSIONS</i>	260
<i>Asst. Prof. Dr. İrem AKSOY Assoc. Prof. Dr. Tijen UNER</i>	<i>GEOCHEMISTRY OF DEPLETED HARZBURGITES FROM THE KINIK OPHIOLITE, WESTERN ANATOLIA, TURKIYE</i>	272
<i>Assoc. Prof. Dr. Taner YILMAZ Ali Burak KELEBEK</i>	<i>FITNESS-ORIENTED SOCIAL MEDIA AND BODY IMAGE: A NARRATIVE REVIEW OF RISK MECHANISMS, PROTECTIVE FACTORS, AND FINDINGS FROM TÜRKİYE AMONG UNIVERSITY STUDENTS</i>	280
<i>Kamala MAMMADZADA</i>	<i>ANFIS-BASED MODELING OF A WASTEWATER TREATMENT BIOREACTOR: EFFECT OF RULE NUMBER ON MODEL ACCURACY</i>	287
<i>Etibar VAZIROV Mehrin MUSTAFAZADE Ayan GOYLAROVA</i>	<i>MULTIMODAL ARTIFICIAL INTELLIGENCE FRAMEWORK FOR STRESS PREDICTION USING PHYSIOLOGICAL SIGNALS AND TEXTUAL EMOTIONAL ANALYSIS</i>	293
<i>Etibar VAZIROV Banu JABIYEVA Adika MAMMADOVA</i>	<i>LEARNING TEMPORAL PATTERNS IN RENEWABLE ENERGY OUTPUT USING DEEP TIME-SERIES MODELS AND METEOROLOGICAL SIGNALS</i>	302
<i>Latafat Beybutova ALASGAR</i>	<i>QUBA - RICH IN HISTORICAL SITES AND MONUMENTS</i>	310
<i>Dr. Duong To Quoc THAI</i>	<i>AN OVERVIEW OF THE BANQUE DE L'INDOCHINE'S OPERATIONS IN VIETNAM DURING THE VOLATILE YEARS (1940–1945)</i>	314
<i>Dr. Duong To Quoc THAI</i>	<i>THE PRESENCE OF BANQUE DE L'INDOCHINE BRANCHES IN VIETNAM (1940–1945): FOOTPRINTS AND INTERACTIONS</i>	324
<i>Togrul HALILOV Resul BAGIROV</i>	<i>TPOLOGY AND ARTISTIC CHARACTERISTICS OF MEDIEVAL CERAMIC ARTIFACTS OF NAKHCHIVAN</i>	335
<i>Benjamin Olumide BAMIDELE Moses Adeolu AGOI* Emmanuel Taiwo AGOI Oluwanifemi Opeyemi AGOI</i>	<i>ARCHITECTURAL SOUND AS DATA: COMPUTATIONAL MODELS FOR MUSIC- DRIVEN SPATIAL DESIGN</i>	341
<i>Assit. Prof. Dr. Meryem GÜL</i>	<i>THE EFFECT OF CULTURAL INTELLIGENCE ON ENTREPRENEURSHIP ORIENTATION</i>	353
<i>Emine ÖRS Prof. Dr. Dilek SÜREKÇİ YAMAÇLI</i>	<i>THE RELATIONSHIP BETWEEN FINANCIAL DEVELOPMENT AND ECONOMIC GROWTH: A STUDY WITHIN THE FRAMEWORK OF THEORETICAL APPROACHES</i>	364

<i>Assoc. Prof. Dr. Hasan Selcuk ETI Guvenc KURUL</i>	<i>A CONCEPTUAL ANALYSIS ON THE ROLE OF VIRTUAL INFLUENCERS IN MARKETING COMMUNICATION, TRUST DYNAMICS, AND THEORETICAL LIMITS</i>	374
<i>Assoc. Prof. Dr. Hasan Selcuk ETI</i>	<i>A REVIEW ON THE ROLE OF USER-GENERATED CONTENT (UGC) IN MARKETING COMMUNICATIONS AND TRUST DYNAMICS</i>	379
<i>Prof. Dr. Ahmet Niyazi OZKER</i>	<i>CONTRIBUTIONS TO GDP GROWTH IN RECENT YEARS IN TURKIYE: THE ROLE OF A FUNCTIONING MARKET ECONOMY</i>	389
<i>Prof. Dr. Alparslan DILSIZ Serhat TOPTAMUR Zeynep TEKIN</i>	<i>CERVICAL FRACTURES OF DENTAL IMPLANTS AND MANAGEMENT: CASE REPORT AND LITERATURE REVIEW</i>	398
<i>Prof. Dr. Alparslan DILSIZ Zeynep TEKIN Abdullah Yavuz OZMEN</i>	<i>SURGICAL PERIODONTAL TREATMENT OF ORAL PREGNANCY TUMOR: CASE REPORT WITH FOLLOW-UP</i>	404
<i>Unal OZTURK Ergul Belge KURUTAS</i>	<i>THE PROTECTIVE ROLE OF EQUISETUM ARVENSE L. IN A CARDIAC ISCHEMIA- REPERFUSION INJURY MODEL INDUCED IN RATS: A BIOCHEMICAL STUDY</i>	412
<i>Öğr. Emircan GÜMÜŞ Prof. Dr. Asim OLGUN Araş. Gör. Dr. Şahin ÖZEL</i>	<i>MELAMINE-REINFORCED PGMA/POLY-GMS ADHESIVES FOR ENHANCED COPPER ADHESION</i>	419
<i>Assoc. Prof. Tahira HUSEYNOVA Gunel AMANULLAYEVA Gunel ASLANOVA</i>	<i>OXIDATION OF 1-METHYL CYCLOHEPTANE WITH THE PARTICIPATION OF CROWN ETHERS</i>	428
<i>Dr. Raziye BOZKURT Prof. Dr. Bilal SENOL</i>	<i>ANALYSIS OF SOFTWARE-ASSISTED LIQUEFACTION POTENTIAL USING SPT AND CPT PARAMETERS AND COMPARISON OF THE RESULTING SAFETY FACTOR</i>	434
<i>Dr. Raziye BOZKURT Prof. Dr. Bilal SENOL</i>	<i>CALCULATING LIQUEFACTION POTENTIAL NUMERICALLY USING A SOFTWARE-BASED APPROACH WITH SPT DATA</i>	440
<i>Lect. Busra Tansu CEYLAN Burak GUL Prof. Dr. Rukiye ERTAN</i>	<i>INFLUENCE OF CORE THICKNESS AND TEMPERATURE ON THE MECHANICAL PROPERTIES OF NOMEX HONEYCOMB-CORE CARBON FIBER/EPOXY SANDWICH COMPOSITES</i>	449
<i>Unal YILMAZ Prof. Dr. Figen BALO</i>	<i>SURVEILLANCE PERFORMANCE ANALYSIS OF MINI UNMANNED AERIAL VEHICLES USING THE ANALYTICAL HIERARCHY PROCESS</i>	465
<i>Unal YILMAZ Prof. Dr. Figen BALO</i>	<i>LOCKING MECHANISM SELECTION IN UNMANNED AERIAL VEHICLES: RELIABILITY AND COST-ORIENTED DECISION-MAKING APPLICATION</i>	474
<i>Prof. Dr. Mihalıs KUYUCU</i>	<i>THE DEVELOPMENT AND FUTURE OF PODCASTING IN TURKEY: CAN PODCASTING BECOME AN ALTERNATIVE TO RADIO?</i>	482
<i>Dr. Phan Thi YEN Dr. Dang VINH</i>	<i>DEVELOPING A MULTIDIMENSIONAL RESEARCH COMPETENCE FRAMEWORK FOR UNDERGRADUATE STUDENTS</i>	496
<i>Asst. Prof. Anita PANDEY</i>	<i>COMMUNITY COMPOSITION AND GUILD STRUCTURE OF SPIDER ASSEMBLAGES IN</i>	504

	<i>RELATION TO THE DRY DECIDUOUS FOREST OF BARMKELA, CHHATTISGARH, INDIA</i>	
<i>Assoc. Prof. Dr. Saimah KHAN</i>	<i>PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS) IN COSMETICS: OCCURRENCE, EXPOSURE PATHWAYS, HEALTH CONCERNS AND EMERGING REGULATORY RESPONSES</i>	<i>511</i>
<i>Aurel NURO Bledar MYRTAJ Elvin COMO Albana HASIMI Gazmir CELA</i>	<i>EVALUATION OF WATER QUALITY FOR LANA RIVER, ALBANIALAYER</i>	<i>517</i>
<i>Jebasingh Jeremiah Rajesh Jesudoss HYNES Rajesh J.H. NAVASINGH</i>	<i>ARTIFICIAL INTELLIGENCE POWERED CLIMATE CHANGE MODELLING</i>	<i>521</i>

**AN EXAMINATION OF ATTITUDES TOWARDS ARTIFICIAL INTELLIGENCE IN
HEALTHCARE SERVICES USING SOCIAL MEDIA ANALYSIS**

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ABSTRACT

The integration of artificial intelligence technologies into the healthcare sector has become increasingly prominent in recent years. AI can be used in healthcare services in areas such as diagnostic support systems, image interpretation and patient monitoring, while healthcare service users employ it for consultation on health issues, pre-doctoral diagnosis, support during treatment, and similar purposes. Day by day, new and varied attitudes and reactions towards artificial intelligence are emerging among healthcare professionals and the general public. Social media platforms, particularly X (formerly Twitter), have become an important data source for researchers as they reflect individuals' reactions in their daily lives in an instant and unfiltered manner. The aim of this study is to analyse public attitudes towards the use of artificial intelligence in healthcare services through X (Twitter) posts. Data was collected by compiling X posts within specific time frames using predefined keywords, and then analysed using MAXQDA. The results showed that positive attitudes towards artificial intelligence in healthcare were more prevalent than negative assessments. Users frequently highlighted artificial intelligence's capacity for speed, consistency, and accuracy in diagnostic processes. The most prominent concern was found to be that doctors' professional positions were threatened by AI. The research results revealed the importance of raising awareness that artificial intelligence in healthcare is not a “replacement for doctors” but rather a “complementary and supportive” technology that increases efficiency in diagnosis and treatment processes, and that developing individuals' digital health literacy in this direction is crucial.

Keywords: Artificial intelligence, Healthcare, Sentiment analysis, social media analysis

**SAĞLIK HİZMETLERİNDE YAPAY ZEKÂYA YÖNELİK TUTUMLARIN SOSYAL MEDYA
ANALİZİ İLE İNCELENMESİ**

ÖZET

Yapay zekâ teknolojilerinin sağlık alanına entegrasyonu son yıllarda oldukça belirgin hale gelmiştir. Sağlık kurumlarında tanı destek sistemleri, görüntü yorumlama, hasta takibi gibi alanlarda yer alan AI, sağlık hizmeti kullanıcıları tarafında ise sağlık sorunlarında danışmanlık, hekim öncesi tanı alma, tedavi sürecinde destek vb. alanlarda kullanılmaktadır. Gün geçtükçe yapay zekâya sağlık profesyonelleri ve toplum genelinde yeni ve çeşitli tutum ve tepkiler oluşmaktadır. Sosyal medya platformları, özellikle X (eski adıyla Twitter) bireylerin gündelik yaşamda verdikleri tepkileri anlık ve filtresiz biçimde yansıtmaları bakımından araştırmacılar için önemli bir veri kaynağı haline gelmiştir. Bu çalışmanın amacı, sağlık hizmetlerinde yapay zekâ kullanımına ilişkin kamuoyu tutumunun X (Twitter) paylaşımları üzerinden analiz edilmesidir. Önceden belirlenen anahtar kelimeler aracılığıyla belirli tarih aralıklarında X paylaşımları derlenerek veriler toplanmış ve MAXQDA'ya aktarılarak analiz edilmiştir. Sonuçlar, sağlık alanında yapay zekâya yönelik olumlu tutumların olumsuz değerlendirmelere kıyasla daha baskın olduğunu göstermiştir. Kullanıcılar, yapay zekânın tanı süreçlerindeki hızı, tutarlılığı ve doğruluğu kapasitesini sıklıkla ön plana çıkarmıştır. En belirgin kaygının, hekimlerin mesleki konumunun AI ile tehdit altında olması yönünde olduğu bulunmuştur. Araştırma sonuçları, sağlık hizmetlerinde yapay zekanın 'hekimin alternatifi' değil, teşhis ve tedavi süreçlerinde verimliliği artıran 'tamamlayıcı ve destekleyici' bir teknoloji” olduğu konusunda farkındalık oluşturulması ve bu doğrultuda bireylerin dijital sağlık okuryazarlığının geliştirilmesinin önemli olduğunu ortaya koymuştur.

Anahtar Kelimeler: Yapay zeka, Sağlık hizmetleri, Duygu analizi, Sosyal medya analizi

AN EXAMINATION OF THE 6TH GRADE TURKISH TEXTBOOK FROM THE PERSPECTIVE OF MULTIPLE INTELLIGENCE THEORY

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ABSTRACT

The Theory of Multiple Intelligences, proposed by Howard Gardner, argues that individuals possess different areas of intelligence and that the educational process should be organized in a way that takes these differences into account. The purpose of this study is to examine the inclusion of activities based on the theory of multiple intelligences in textbooks and to determine the distribution of these activities according to different areas of intelligence, thereby revealing the extent to which each type of intelligence is addressed. In this context, the material for the study consists of the 6th Grade Turkish Textbook (Volumes 1 and 2) for Middle School and Imam Hatip Middle School published by the Ministry of National Education in 2025. Free reading texts and listening/viewing texts were not included in the scope of this study. The study was conducted using the document review method, one of the qualitative research methods, and the data obtained were analyzed using descriptive analysis techniques. The activities examined were classified and evaluated based on the eight fundamental intelligence areas outlined in Garner's Multiple Intelligence Theory (verbal-linguistic, logical-mathematical, visual-spatial, musical-rhythmic, bodily-kinesthetic, interpersonal, intrapersonal, and naturalistic intelligence). In conclusion, this study is important in terms of determining the extent to which the Multiple Intelligences Theory, which takes into account the different learning styles of students, is reflected in textbooks and evaluating the current situation. In this regard, it is recommended that the activities included in textbooks be diversified to cover different intelligence areas and that activities supporting each intelligence area be included.

Keywords: Turkish Textbook, Multiple Intelligences Theory, Reading Texts, Activities.

TÜRKÇE 6. SINIF DERS KİTABININ ÇOKLU ZEKÂ KURAMI AÇISINDAN İNCELENMESİ

ÖZET

Howard Gardner tarafından ortaya konulan Çoklu Zekâ Kuramı, bireylerin farklı zekâ alanlarına sahip olduğunu ve eğitim sürecinin bu farklılıkları dikkate alacak biçimde düzenlenmesi gerektiğini savunmaktadır. Bu araştırmanın amacı, ders kitaplarında çoklu zekâ kuramına dayalı etkinliklerin yer alma durumunu incelemek ve bu etkinliklerin farklı zekâ alanlarına göre dağılımını belirleyerek hangi zekâ türlerine ne ölçüde yer verildiğini ortaya koymaktır. Bu bağlamda çalışmanın materyalini, Millî Eğitim Bakanlığı tarafından 2025 yılında yayınlanan Ortaokul ve İmam Hatip Ortaokulu Türkçe 6. Sınıf Ders Kitabı (1. ve 2. Kitap) oluşturmaktadır. Bu çalışmada serbest okuma metinleri ve dinleme/izleme metinleri çalışma kapsamına alınmamıştır. Çalışmada nitel araştırma yöntemlerinden biri olan doküman incelemesi yöntemi kullanılarak gerçekleştirilmiş olup elde edilen veriler betimsel analiz tekniğiyle analiz edilmiştir. İncelenen etkinlikler Garner'ın Çoklu Zekâ Kuramında belirttiği sekiz temel zekâ alanı (sözel–dilsel, mantıksal–matematiksel, görsel–uzamsal, müzikal–ritmik, bedensel–kinestetik, kişiler arası–sosyal, bireysel içsel–öze dönük ve doğacı zekâ) temel alınarak sınıflandırılmış ve değerlendirilmiştir. Sonuç olarak bu çalışma, öğrencilerin sahip olduğu farklı öğrenme biçimlerini dikkate alan Çoklu Zekâ Kuramı'nın ders kitaplarına ne ölçüde yansıtıldığını belirlemek ve mevcut durumu değerlendirmek açısından önem taşımaktadır. Bu doğrultuda, ders kitaplarında yer verilen etkinliklerin farklı zekâ alanlarını kapsayacak biçimde çeşitlendirilmesi ve her bir zekâ alanını destekleyen etkinliklere yer verilmesi önerilmektedir.

Anahtar Kelimeler: Türkçe Ders Kitabı, Çoklu Zekâ Kuramı, Okuma Metinleri, Etkinlikler.

A RESEARCH ON PERSPECTIVES OF PRIMARY SCHOOL TEACHERS OF DIGITAL INCLUSION IN EDUCATION IN DAR ES SALAAM TANZANIA.

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ABSTRACT

The main goal of this study was to assess primary school teachers' experience, perceptions, attitudes, available opportunities, challenges and suggestions on the digital inclusion in education practices in the Dar es Salaam region, Tanzania. The research adopted a qualitative research approach. To explore in-depth lived experience and perception of teachers, phenomenological research design was employed. The study group consisted of 21 primary school teachers from different public and private primary schools allocated in Dar es Salaam Tanzania. The respondents were purposefully selected with the intention of gathering accurate and in-depth information about digital in education practices in primary school. The data was collected through semi-structured interviews and observation and analyzed using content analysis to obtain themes and sub-themes. At the end of the analysis the findings revealed that primary school teachers use the concept of digital inclusion as a tool for enhancing teaching effectiveness, important essential component of 21st century modern education, as a tool to promote students learning outcome and as a multifaceted construct with divergent implications. The results further highlighted concerns about digital risks including safety management to the administrative data confidentiality, equity and inclusive digital risk mitigation. Although existing education policies and the curriculum strongly emphasize digital integrations a substantial gap between policy intentions and practical implementation was observed. However, challenges such as infrastructure gaps, lack of digital tools, unreliable internet and low digital literacy among teachers and students was revealed. In addition, the results, highlighted inequalities driven by social and gender differences in technology use. Basing on the situation, teachers recommended improvements in infrastructure, reliable and affordable internet, sustainable professional development, policy coherence and increased financial support from stakeholders.

Keywords: Digital inclusion, Education, Tanzania, Primary school

**A NEW DIMENSION OF THE HIDDEN CURRICULUM IN SOCIAL STRUCTURING:
EDUCATION AND SOCIAL MEDIA VIDEOS IN THE AGE OF DIGITALIZATION**

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ÖZET

Bu çalışmanın temel amacı dijitalleşme çağında sosyal medya platformlarında paylaşılan kısa formatlı videoların bireylerin öğrenmelerinde örtük etkisini incelemek; ‘başarılı öğrenci’ ve ‘ideal öğrenci’ algısını tek tipleştirme, tüketim kültürü ve toksik mükemmeliyetçilik temaları üzerinden öğrenci davranışlarına yansımalarını ortaya koymaktır. Çalışmada, nitel araştırma türünde olup, doküman incelemesi yöntemi kullanılmıştır. Verilerinin toplanması sürecinde; “ders çalışma, yks, yks2026, Ipad not, sabah rutini” gibi etiketler üzerinden küresel ve yerel, yüksek etkileşimli 12 adet kısa formatlı video; metinleri, nesneleri, mekân göstergeleri doğrultusunda analiz edilmiştir. Verilerin çözümlemesinde içerik analizi tekniği benimsenmiştir. Verilerin çözümlemesi sürecinde kodların güvenilirliğini sağlamak amacıyla, videolar araştırmacılar haricinde eğitim programları ve öğretim alanında öğrenim gören üç yüksek lisans öğrencisine izletilmiştir. Yapılan bağımsız değerlendirmeler sonucunda, belirlenen kodlar karşılaştırılarak görüş birliğine varılmıştır. Araştırma bulguları, bütüncül bir yaklaşımla ele alınarak analiz edilen videoların içeriğindeki dijitalleşme sürecinde örtük olarak verilmeye çalışılan mesajlar üç ana tema üzerinden kodlanmıştır. (1) Başarılı, ideal öğrenci algısı belli rutinlere ve birbirinin kopyası çalışma ortamlarına sıkıştırılarak ve bireysel tercihlerden ziyade trendlere uyum ön planda tutularak standartlaştırılmaktadır. (2) Eğitim süreci lüks teknolojik aletlerle standartlaştırılarak, ticarileşip, teknoloji şirketlerinin pazarlama aracı haline getirilmiştir ve ‘gösterişçi tüketim’ şeklini almıştır. (3) Motivasyon adı altında öğrencilere dayatılan mükemmeliyetçilik ve çalışma baskısı, öğrenme heyecanını yok ederek gelecek kaygısına ve tükenmişliğe sebep olabilecek bir yapıya dönüşmektedir. Sonuç olarak sosyal medya içerikleri rastgele eğlence içerikleri olmaktan çıkmış; öğrenciler arasında sahip oldukları eğitim araç-gereçlerine yönelik eşitsizliğini, gelecek kaygısını ve tükenmişliği normalleştirerek baskı yaratan dijital çağın yeni eğitim ajanı haline gelmektedir. Öğrencileri bu dijital manipülasyonlardan korumak adına eğitim programlarına ‘Algoritma Okuryazarlığı’ becerisinin entegre edilmesi; Avustralya hükümetinin yakın zamanda uygulamaya koyduğu 16 yaş altı sosyal medya kullanım yasağı gibi dijital baskıya karşı uyguladığı hamlenin, ulusal eğitim ve teknoloji politikalarına emsal teşkil edecek şekilde değerlendirilmesi düşünülebilir. Bunlara ek olarak da gelecekte, sosyal medya içeriklerinin dayattıklarının öğrenci davranışlarına etkilerini ortaya koyabilen nitel, nicel ve karma araştırma yöntemleri ile araştırmalara yer verilebilir.

Anahtar Kelimeler: Örtük Program, Sosyal Medya, Dijitalleşme

**TOPLUMSAL YAPILANMADA ÖRTÜK PROGRAMIN YENİ BOYUTU: DİJİTALLEŞME
ÇAĞINDA EĞİTİM VE SOSYAL MEDYA VİDEOLARI**

ABSTRACT

The primary objective of this study is to examine the implicit impact of short-form videos shared on social media platforms during the digitalization era on individual learning processes. It aims to reveal the reflections on student behavior through the themes of standardizing the perception of the ‘successful’ and ‘ideal’ student, consumption culture, and toxic perfectionism. The study adopts a qualitative research design and utilizes the document analysis method. In the data collection process, 12 globally and locally high-engagement short-form videos categorized under tags such as “study, yks, yks2026, Ipad notes, morning routine” were analyzed based on their texts, objects, and spatial indicators. The content analysis technique was employed for data interpretation. To ensure the reliability of the codes during the analysis process, the videos were reviewed by three graduate students in the field of Curriculum and Instruction, in addition to the researchers. Following

independent evaluations, the identified codes were compared, and a consensus was reached. The research findings, handled with a holistic approach, categorized the implicit messages conveyed through the digitalization process into three main themes: (1) The perception of the successful and ideal student is standardized by being confined to specific routines and carbon-copy study environments, prioritizing trend alignment over individual preferences. (2) The educational process has been standardized through luxury technological devices, commercialized into a marketing tool for tech companies, and has transformed into a form of 'conspicuous consumption.' (3) The perfectionism and pressure to study imposed on students under the guise of motivation transform into a structure that stifles the excitement of learning, leading to future anxiety and burnout. Consequently, social media content has transcended being mere random entertainment; it has become a new educational agent of the digital age that creates pressure by normalizing inequality regarding educational tools, future anxiety, and burnout among students. To protect students from these digital manipulations, the integration of 'Algorithm Literacy' skills into educational curricula could be considered. Furthermore, actions such as the social media ban for those under 16 recently implemented by the Australian government could be evaluated as a precedent for national education and technology policies. Additionally, future research utilizing qualitative, quantitative, and mixed methods could be conducted to further reveal the effects of social media impositions on student behavior.

Keywords: Hidden Curriculum, Social Media, Digitalization

INTERACTIVE APPLETS IN UNDERSTANDING DESCRIPTIVE STATISTICS

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ABSTRACT

Interactive applets are widely used tools in mathematics and statistics education, where dynamic visualization can make abstract concepts more accessible. By allowing learners to manipulate data and immediately observe the resulting changes, applets create opportunities for interactive exploration that are difficult to achieve through static representations. In statistics education, such tools have been used across a wide range of topics -from descriptive statistics to statistical inference, regression, and analysis of variance- allowing students to explore statistical ideas directly from data. Descriptive statistics is typically introduced early in introductory statistics courses and is often covered relatively quickly. Because the calculations involved are straightforward, students frequently perceive this topic as simple. However, classroom experience suggests that although students learn how to compute various averages, they do not always develop a clear understanding of when each measure should be used. When working with datasets that contain extreme values, for example, students may still rely on the arithmetic mean instead of considering a more robust measure such as the median. As a result, descriptive statistics can remain a set of computational procedures rather than a set of tools for summarizing data appropriately. This paper reports on the use of interactive applets in the teaching of descriptive statistics. Core topics were first presented using traditional instruction, after which applets were used in class to reinforce and illustrate key ideas. Students could manipulate datasets and observe how descriptive measures respond to changes in the data. For example, they could see how the presence of an extreme value affects different averages and how the appropriate measure of center may change as the structure of the data changes. The applets also generated random datasets and practice questions, allowing students to encounter many different problem instances and compare outcomes across multiple examples. Student feedback indicated that these activities were helpful for engaging with the material.

Keywords: Statistics Education, Descriptive Statistics, Interactive Applets, Statistical Visualization, Robustness, Outliers

CLASSIFYING COGNITIVE BIASES: THE PROBLEM OF NORMATIVE REFERENCE POINTS

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ABSTRACT

Cognitive biases are commonly defined as systematic deviations from rational judgment or optimal decision making. This definition implicitly presupposes the existence of a normative benchmark against which human judgments can be evaluated. However, while the literature on cognitive biases has expanded rapidly over the past several decades, the nature of this benchmark (or norm) is often less clear than the definition suggests. In some domains the normative standard is well established - for example, probability theory provides a clear reference point for evaluating Bayesian reasoning. In many other cases, however, the relevant normative baseline is contested, context dependent, or conceptually ambiguous. This issue becomes particularly visible when examining how cognitive biases are classified in the literature. Numerous attempts have been made to organize the growing list of biases into taxonomies or structured frameworks. For instance, Dimara et al. (2018) propose a task-based taxonomy of cognitive biases for information visualization, while Oreg and Bayazit (2009) develop a taxonomy grounded in individual motivational goals. Eppler and Muntwiler (2021) similarly review multiple classificatory approaches and highlight the fragmented nature of the bias literature across disciplines. Although these frameworks differ in their organizing principles, most implicitly assume that biases represent deviations from some normative model. Yet the nature of this reference point varies considerably across biases. In some cases, the benchmark is relatively clear. Errors in Bayesian reasoning, for example, can be evaluated against the axioms of probability theory. In other cases, however, the violated norm is less straightforward to identify. This paper highlights the role of normative reference points in thinking about cognitive bias taxonomies. Rather than proposing a new taxonomy, the study suggests that biases may also be examined in terms of the norms they violate and whether those norms are clearly defined or conceptually ambiguous. By making these reference points explicit, the paper aims to clarify an often implicit assumption underlying the classification of cognitive biases.

Keywords: Cognitive Biases, Cognitive Bias Taxonomies, Rational Decision Making, Violation of Norms, Decision Theory

INCLUSION OF MENTAL HEALTH IN EDUCATION

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ABSTRACT

Mental health is one of the human rights that today has generated increasing interest and attention, not only among international organizations and the governments of the most developed countries, but also across global society as a whole. This growing concern is largely rooted in the genuine preoccupation of younger generations regarding their mental health and the negative consequences of failing to address it. Such consequences affect, not only individual's personal lives, but also their academic and professional performance, not to mention their broader impact on society. When addressing the right to mental health, it is not enough to focus solely on treatment; it is equally essential to emphasize prevention. In this regard, the World Health Organization (WHO) has stated that many of the determinants of mental health lie outside the health sector, with education, justice, social welfare, and other sectors playing a vital role. Consequently, the WHO maintains that schools represent a significant opportunity to promote mental health and emotional well-being, prevent mental health problems, and identify and support children and adolescents experiencing emotional difficulties. For this reason, mental health and its inclusion within education must be examined in light of the State's obligation to promote, protect, and prevent harm to mental health. This approach ensures the human right to health and its convergence with the right to education, highlighting that such inclusion constitutes one of the most effective and cost-effective primary prevention interventions.

Keywords: Mental health; human right to health; human right to education; primary prevention mental health; State responsibility.

EXPLORING POETICS OF RESISTANCE IN JAVED AKHTAR'S *A NEW DECREE*

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ABSTRACT

This paper examines how Javed Akhtar constructs a powerful poetic critique of authoritarian control through the use of natural imagery and allegory. The poem dramatizes a dystopian scenario in which winds are ordered to declare their direction, waves are commanded to suppress their rebellion, and flowers are forced into uniformity. These images collectively symbolize the mechanisms through which power seeks to regulate dissent, discipline freedom, and erase plurality. Drawing upon the theoretical insights of Michel Foucault and Antonio Gramsci, the paper argues that the poem foregrounds the tension between hegemonic authority and the irrepressible forces of resistance embedded in both nature and human society. The recurring motif of "decree" functions as a metaphor for institutionalized power that attempts to normalize control by pathologizing rebellion as madness. However, the poem simultaneously destabilizes this authority by exposing its fragility through images such as "sand ramparts" and "paper palaces," suggesting that structures built on suppression are inherently unstable. Furthermore, an ecocritical perspective reveals how the disciplining of natural elements mirrors the broader socio-political attempt to regulate human agency and diversity. Ultimately, the poem asserts that resistance is not only inevitable but also intrinsic to the very fabric of life, as nature itself refuses containment. This study positions *A New Decree* as a significant poetic intervention that challenges authoritarian discourse and reaffirms the enduring power of dissent.

Keywords: Authoritarianism, Resistance, Natural Imagery

DETERMINANTS OF SKELETAL MINERALIZATION IN ADOLESCENT MALES: THE ROLE OF SPORT TYPE, BODY COMPOSITION, AND DIET

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ABSTRACT

Adolescence represents a crucial window for bone development, during which both mechanical loading and nutritional factors contribute to peak bone mass attainment. Although physical activity is known to support skeletal health, the relative contribution of different sport disciplines, particularly those varying in osteogenic stimulus, remains insufficiently defined. This study investigated the relationship between sport-specific loading patterns, dietary factors, and body composition with bone mineral density (BMD) and bone mineral content (BMC) at the femoral neck and lumbar spine in adolescent boys. This work was written with the financial support of the Ministry of Education and Science as part of the Research Project (UPB No. 14): “Determinants of bone mineral status in recreational and professional sports of different age groups”. A total of 156 Caucasian male adolescents were classified into three groups based on the osteogenic characteristics of their primary activity: high-impact disciplines (e.g., speed-power sports, combat sports, throwing events; $n = 54$), low-impact disciplines (aquatic sports; $n = 52$), and a non-training control group ($n = 50$). Bone parameters were assessed using dual-energy X-ray absorptiometry. Body composition was evaluated via bioelectrical impedance, and dietary intake was obtained from validated questionnaires. Multivariate regression models were used to identify predictors of bone outcomes. Adolescents engaged in high-impact sports exhibited superior BMD at the hip compared with both low-impact and inactive peers. Lumbar spine BMC was also greater among individuals with higher exposure to osteogenic loading. Across all analyses, physical activity level, protein intake, and consumption of dairy products emerged as consistent correlates of bone health. Femoral neck BMD was strongly predicted by fat-free mass, dietary calcium, protein intake, dairy consumption, and activity level (adj. $R^2 = 0.78$). For lumbar spine BMD, significant determinants included protein intake, dairy consumption, and physical activity (adj. $R^2 = 0.63$). Patterns for BMC were similar, although lumbar spine BMC showed a weaker association, being primarily explained by activity level alone. Engagement in sports characterized by high mechanical loading is associated with more favorable bone parameters in adolescent males. In parallel, nutritional factors, particularly protein and dairy intake, contribute meaningfully to skeletal outcomes. These findings highlight the combined importance of targeted physical activity and diet in optimizing bone development during growth.

Keywords: Adolescence; bone mineral density, mechanical loading; sport disciplines, protein intake; dairy consumption; body composition

DANON DISEASE PRESENTING AS HYPERTROPHIC CARDIOMYOPATHY: A CASE REPORT

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ABSTRACT

Background: Danon disease is a rare X-linked dominant disorder caused by mutations in the LAMP2 gene. It is characterized by the triad of cardiomyopathy, skeletal myopathy, and intellectual disability, with early and severe cardiac involvement being the main determinant of prognosis. **Case Presentation:** We report a 13-year-old female strangely presenting with no progressive dyspnea, palpitations, or proximal muscle weakness. She underwent clinical screening prior joining a volleyball team and an ECG suggested left ventricular hypertrophy, which was confirmed on echocardiogram leading to the diagnosis of hypertrophic cardiomyopathy. She reports at that time she was limited compared to her peers and able to achieve about 70% of the maximal effort. She is able to walk unlimited distances on the flat but may need to stop and rest after 3-4 flights of stairs. She reports no episodes of presyncope or syncope. She reports only occasional palpitations. Laboratory findings included elevated creatine kinase levels. Cardiac MRI confirmed myocardial hypertrophy with areas of fibrosis. Genetic testing identified a pathogenic mutation in the LAMP2 gene, confirming the diagnosis. **Management and Outcome:** The patient was started on guideline-directed medical therapy for heart failure and underwent risk stratification for sudden cardiac death, with consideration for implantable cardioverter-defibrillator (ICD) placement. Her medication at present is propranolol with a significant improvement in her symptoms. **Conclusion:** Danon disease should be considered in young patients presenting with hypertrophic cardiomyopathy and conduction abnormalities. Early diagnosis is essential for appropriate management, risk stratification, and family screening.

Keywords: Danon disease; cardiomyopathy; LAMP2 mutation; case report; genetic disorder

**ASSESSMENT OF NURSING STUDENTS' KNOWLEDGE AND ATTITUDES IN KOSOVO
TOWARD MEDICATION ADMINISTRATION ERRORS**

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ABSTRACT

Aim: This study aimed to assess nursing students' knowledge and attitudes toward medication administration errors in Kosovo. **Methods:** This descriptive study was conducted with 94 second-year students from the Department of Nursing, Faculty of Medicine, University of Prishtina "Hasan Prishtina," during November–December 2025. Data were collected using a socio-demographic questionnaire and the Nursing Students' Knowledge and Attitudes Toward Medication Errors Scale. Ethical approval and institutional permissions were obtained prior to data collection. The data were analyzed using SPSS 22.0 and presented through descriptive statistics, including frequencies, percentages, and mean values. **Results:** The findings indicate that nursing students demonstrate generally adequate knowledge and positive attitudes toward safe medication administration practices. Most students reported awareness of the importance of verifying patient identity, medication dosage, and administration routes. However, some gaps were identified in attitudes toward error reporting, with a proportion of students expressing hesitation or uncertainty about consistently reporting medication errors. **Conclusion:** While nursing students show satisfactory knowledge and generally positive attitudes toward medication administration, challenges remain in promoting a transparent and consistent error-reporting culture. Enhancing education and training on medication safety and error reporting may contribute to reducing medication errors and improving patient safety.

Keywords: Nursing students; Medication errors; Knowledge; Attitudes; Patient safety

**RIVAROXABAN – MOLECULAR PRECISION IN THE DIRECT INHIBITION OF
COAGULATION FACTOR Xa**

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ABSTRACT

Rivaroxaban is a potent, orally active oxazolidinone derivative that represents a significant advancement in anticoagulant therapy, specifically within the class of Direct Oral Anticoagulants (DOACs). Unlike indirect anticoagulants that require a cofactor, Rivaroxaban is a highly selective, small-molecule inhibitor designed to target Factor Xa, a key serine protease at the convergence of the intrinsic and extrinsic coagulation pathways. Its chemical architecture—specifically the 5-chloro-thiophene-2-carboxamide and the oxazolidinone core—enables a high-affinity, reversible binding within the *S1* and *S4* pockets of the Factor Xa active site, effectively halting the amplification of the coagulation cascade.

The aim of this paper is to review the chemical mechanism and clinical profile of Rivaroxaban, focusing on its role in preventing thromboembolic events. The molecule is a masterpiece of structure-based drug design, achieving a lock-and-key fit that prevents the conversion of prothrombin to thrombin. This targeted approach offers a predictable pharmacological response, eliminating the need for routine laboratory monitoring.

The review analyzes the following key chemical and therapeutic aspects:

- The Oxazolidinone Scaffold: Its role in providing the necessary rigidity for precise receptor docking.
- Mechanism of Action: The direct, competitive inhibition of both free and clot-bound Factor Xa, contrasting with the mechanisms of heparins.
- Pharmacokinetics: The molecule's high oral bioavailability and its balanced elimination pathways through renal and hepatic routes.
- Evolution of Therapy: A comparative look at the transition from multi-target vitamin K antagonists to single-target molecular inhibitors.

In conclusion, Rivaroxaban exemplifies the shift towards precision medicine through molecular targeting, providing a safer and more consistent anticoagulant effect. By focusing on a single point in the coagulation

cascade, this molecule demonstrates how specific chemical modifications can optimize therapeutic efficacy while minimizing systemic side effects.

Keywords: Rivaroxaban, factor Xa inhibitor, anticoagulation, thrombin generation, thrombosis

OMEPRAZOLE – FROM ACID-TRIGGERED ACTIVATION TO THE NEW ERA OF GASTRIC ACID SUPPRESSION

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ABSTRACT

Omeprazole, a substituted benzimidazole derivative, remains a cornerstone in the pharmacological management of acid-related gastrointestinal disorders, such as peptic ulcers and gastroesophageal reflux disease (GERD). From a chemical perspective, omeprazole is a sophisticated prodrug that utilizes the body's own physiological environment for site-specific activation. Its molecular structure is designed to be stable at a neutral pH, but it undergoes a rapid chemical rearrangement in the acidic environment of the gastric parietal cells. The resulting active intermediate—a reactive sulfenamide—forms a covalent, irreversible disulfide bond with the H⁺/K⁺-ATPase enzyme (the proton pump), leading to a profound and long-lasting inhibition of gastric acid secretion.

This paper aims to review the chemical and pharmacological profile of omeprazole, highlighting its unique "suicide inhibition" mechanism. Furthermore, the review explores the evolution of anti-ulcer therapy by comparing traditional Proton Pump Inhibitors (PPIs) with the latest generation of drugs: Potassium-Competitive Acid Blockers (P-CABs), such as Vonoprazan.

The following key areas are analyzed:

- **The Activation Pathway:** The pH-dependent transition from an inactive molecule to a potent sulfenamide via protonation.
- **Covalent Modification:** The chemistry of the S-S bond formation that explains the drug's long duration of action despite a short plasma half-life.
- **Pharmacokinetics and Formulation:** The necessity of enteric coating to prevent premature degradation and the impact of the drug's short plasma half-life versus its long-lasting biological effect.
- **Current Research & Innovations:** A comparative analysis with P-CABs, which provide a faster onset of action and do not require acid-triggered activation or fasting conditions.

- Clinical Relevance: The role of omeprazole in *H. pylori* eradication protocols and its interaction with the cytochrome P450 enzymatic system.

In conclusion, while omeprazole continues to be a masterpiece of rational drug design due to its targeted activation, the emergence of P-CABs marks a new frontier in gastrointestinal chemistry, offering potential advantages in rapid symptom relief and therapeutic consistency for refractory cases.

Keywords: Omeprazole, Proton Pump Inhibitors (PPIs), sulfenamide, vonoprazan, covalent inhibition

BACTERICIDAL ADDITIVE FOR CUTTING FLUIDS

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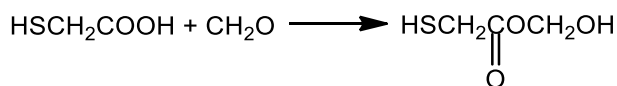
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ABSTRACT

Water-soluble cutting fluids are designed to effectively cool and lubricate metal parts during machining (grinding, cutting). Water-soluble cutting fluid offers several advantages over their oil-soluble counterparts. They are more efficient at cooling, which is crucial for high-speed metalworking, economical (due to their dilution with water), fire-safe, and versatile, as they are suitable for machining ferrous and non-ferrous metals [1, 2]. When manufacturing cutting fluids, it is advisable to use them as quickly as possible, as they can be subject to microbiological degradation during storage and transportation. For example, the authors of [3], based on their research, demonstrated that if safety precautions are not taken, the number of aerobic bacteria doubles within 20-30 minutes, and anaerobic bacteria double within 4 hours. Therefore, considerable attention is currently being paid to the development of antimicrobial additives (biocides). The authors of this study proposed hydroxymethyl ester of thioglycolic acid as a biocide. Hydroxymethyl ester of thioglycolic acid was obtained by reacting thioglycolic acid with formalin according to the following scheme:



The reaction is exothermic; after the formalin was completely added, the reaction mixture was stirred at 50°C for 4 hours. Microbiological studies of the product showed that thioglycolic acid hydroxymethyl ester exhibits remarkable bactericidal properties.

It should be noted that an advantage of the compound proposed as a biocide is the availability and affordability of commercially available starting materials, which is a significant factor.

Key Words: biocides, cutting fluid, bacteria, microbiological activity

CARAMELIZATION: CURRENT PERSPECTIVES ON A VERSATILE BUT POORLY UNDERSTOOD CHEMICAL PROCESSES

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ABSTRACT

During food processing, several chemical processes, such as the Maillard reaction (browning), protein denaturation, starch gelatinization, acid–base reactions, fermentation, emulsification, and pyrolysis, occur and contribute to changes in color, flavor, and texture. Last but not least, caramelization is the process by which sugars break down when foods are exposed to high temperatures. This thermal decomposition leads to browning and changes in aroma and taste. This communication presents an overview of the complex chemistry behind caramelization, its key roles and applications in the food industry, and perspectives related to potential health concerns. The paper points out that caramelization is a highly intricate process that involves a wide range of chemical reactions, such as enolization, sucrose inversion, condensation, dehydration, and fragmentation. The condensation of intermediate products leads to the formation of high-molecular-weight brown polymers, namely caramelan($C_{12}H_{18}O_9$), caramelen($C_{36}H_{50}O_{25}$), and caramelin($C_{125}H_{188}O_{80}$). The mechanisms involved in the formation of several compounds responsible for caramel flavor, such as diacetyl, hydroxymethylfurfural, maltol, esters, and lactones, are also presented. Several factors, such as temperature, heating rate, pH, water activity, and the nature of the sugars involved, affect caramelization and are also discussed in the paper. The importance of caramelization in the food industry for flavor development and color production is presented. Potential health concerns related to the frequency of caramel consumption, such as high caloric intake, advanced glycation end products, acrylamide, and 4-methylimidazole (4-MeI), are analysed. Even though in the last decade, several studies have demonstrated that Fructose dianhydrides, a chemical compound found in caramel, exhibit many promising properties, such as a potential prebiotic effect, the authors of this paper claim that eating caramel “for health” is not a reasonable strategy.

Keywords: Caramel, sugars, sucrose inversion, diacetyl

POLYSACCHARIDES USED IN THE PHARMACEUTICAL AND NATURAL SUPPLEMENTS INDUSTRIES: PROPERTIES, APPLICATIONS, AND PERSPECTIVES

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ABSTRACT

Polysaccharides are naturally occurring, high-molecular-weight carbohydrate polymers composed of monosaccharide units joined by O-glycosidic bonds. Due to their outstanding properties, such as biocompatibility, biodegradability, high hydrophilicity, water retention capacity, unique rheological characteristics, and the possibility of being tailored for niche applications through both covalent and non-covalent functionalization, polysaccharides are used in several fields. They play an important role in the food industry (thickening agents, gelling agents, and stabilizers), wastewater treatment (heavy metal removal), industrial applications (papermaking and textiles), soil amendment, and smart and sustainable packaging. Last but not least, polysaccharides are promising alternatives for biomedical and pharmaceutical applications.

This paper aims to provide a review of the role of polysaccharides in the pharmaceutical field, with a focus on three main areas: polysaccharides as active pharmaceutical ingredients, as dietary supplements, and as excipients in drug formulations.

The polysaccharide-based drugs that will be analyzed in this review are the following:

- heparin & low molecular weight heparins (widely used anticoagulants to treat and prevent thromboembolisms);
- acarbose, used in managing Type 2 diabetes;
- hyaluronic acid: used in treating osteoarthritis for joint lubrication and in wound healing;
- iron dextran: employed in the treatment of iron deficiency anemia;
- pentosan polysulfate: administered in the treatment of interstitial cystitis;
- sulodexide: used in the management of chronic venous ulcers.

The polysaccharide-based dietary supplements discussed are alginate and carrageenan (used in functional foods and supplements for their anti-inflammatory and potential anticarcinogenic properties), chitosan (widely marketed as a weight-loss supplement), inulin and fructans (valued for prebiotic properties), and chondroitin sulfate (often used for osteoarthritis management).

Common polysaccharide-based excipients for drug formulation include starch and its derivatives (used as fillers, binders, and disintegrants in tablets) and cellulose & derivatives.

Keywords: Heparin, hyaluronic acid, chondroitin sulfate, acarbose

OLIGOSACCHARIDES AND POLYSACCHARIDES IN COSMETICS: PROPERTIES, APPLICATIONS, AND FUTURE PERSPECTIVES

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ABSTRACT

Oligosaccharides and polysaccharides are important carbohydrates widely used in the food, pharmaceutical, and industrial sectors. Their main applications include use in the food industry as sweeteners and texture modifiers; as dietary fiber with health-promoting effects; in infant nutrition; as animal feed additives; in pharmaceutical formulations and drug delivery systems; and in industrial processes such as the production of biodegradable plastics. In addition, oligosaccharides and polysaccharides are extensively used in cosmetics due to their moisturizing, thickening, soothing, film-forming, stabilizing, and texturizing properties.

This review aims to discuss the oligosaccharides and polysaccharides most commonly used in cosmetics, their applications, and future perspectives. Alpha-glucan oligosaccharides, galacto-oligosaccharides, fructo-oligosaccharides, xylo-oligosaccharides, and mannan oligosaccharides are reviewed in this paper as oligosaccharides used in modern dermocosmetic products. Their properties, such as prebiotic, moisturizing, soothing, and skin barrier-supporting properties of these compounds, are discussed in detail. Compatibility with the skin, biodegradability, anti-aging, antioxidant, film-forming, anti-inflammatory, and microbiome-friendly effects, and versatility make polysaccharides highly valuable in the manufacturing of modern cosmetic products.

Polysaccharides, which are discussed in this review, are the following:

- Hyaluronic acid - humectant/moisturizer, skin-plumping and anti-aging ingredient;
- Alginate – used as a thickener, gelling agent, stabilizer, and film former;
- Chitosan – film-forming, antimicrobial, soothing, and wound-healing effects;
- Cellulose and cellulose derivatives – used mainly as thickeners, stabilizers;
- Pectin – used as a gelling, stabilizing, moisturizing, and soothing agent;

- Carageenan -used as a thickener, stabilizer, and gel-forming agent;
- Pullulan – used for its film-forming, smoothing, and tightening effects, especially in anti-aging and instant-lift products.

Current perspectives highlight the growing interest in oligosaccharides and polysaccharides as multifunctional cosmetic ingredients, particularly because of their potential to support skin hydration, barrier function, and microbiome balance. In conclusion, both oligosaccharides and polysaccharides play a relevant role in cosmetic science and formulation.

Keywords: Fructo-oligosaccharides, biodegradability, hyaluronic acid, cellulose

CYCLODEXTRINS: FROM SUPRAMOLECULAR HOST - GUEST CHEMISTRY TO DRUG DELIVERY APPLICATIONS

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ABSTRACT

Cyclodextrins are cyclic oligosaccharides best known as "molecular containers" that can include hydrophobic guests inside a relatively nonpolar cavity while remaining hydrophilic on the outside. Although they are often introduced as excipient solubilizers, their medical relevance extends far beyond just solubilization. The chemistry of host - guest recognition, cavity size selectivity, and substituent effects on binding strength has transformed cyclodextrins into important tools in pharmaceutical technology. A chemical-focused perspective is therefore essential to understanding why these apparently simple sugar-derived compounds can act as solubilizers, stabilizers, and taste-masking agents.

This paper focuses on the following main aspects:

1. Supramolecular chemistry of cyclodextrins. Structural differences between α -, β - and γ -cyclodextrins, hydrophobic cavity effects and the influence of guest size, polarity and substituents on association constants;
2. Pharmaceutical formulation applications. Improvement of aqueous solubility, protection against oxidation and hydrolysis, and control of volatility and odor;
3. Cyclodextrins as active medical tools. The role of modified cyclodextrins in reducing local drug toxicity, modulating membrane cholesterol, and how host - guest chemistry can be used therapeutically to encapsulate and inactivate steroidal blockers;

Limitations and future perspectives. Toxicological concerns, stability and cost issues, and the development of better cyclodextrin-based systems for targeted delivery and responsive release and supramolecular antidote design.

Keywords: Cyclodextrins, host- guest chemistry, drug delivery

DETECTION OF AMITRAZ AND FLUMETRIN RESIDUES IN PROPOLIS

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ABSTRACT

Propolis is a complex natural product created by honeybees with plant resins, beeswax and enzymes. The instinctive behavior of honeybees includes resin collection and propolis production. The study examined some of the key functions of propolis, such as sealing and protecting openings in beehives, mummifying the bodies of intruders, and acting as a cleaning agent within the hive. Propolis, as an additive in honeycomb wax, strengthens the entire structure of the honeycomb. It is estimated that it accounts for approximately 5–10% of the honeycomb's composition. Amitraz and flumethrin, a type of pesticide, are chemical compounds used against acarists in honeybees. In this study, a literature review was conducted to determine the residue presence and levels of pesticides commonly used against acarists in beekeeping on propolis. As it is known that amitraz and flumethrin, which are used particularly for the control of Varroa destructor, can accumulate on lipophilic surfaces inside the hive, the risk of residues in propolis samples is considered a significant quality and safety parameter. It has been established that residue screening can be carried out on samples of bee products sourced from different geographical regions and production conditions in Turkey using advanced chromatographic methods. It was mainly analyzed by high-performance liquid chromatography (HPLC), gas chromatography-mass spectrometry (GC-MS) and liquid chromatography-mass spectrometry (LC-MS) methods. The analysis results revealed that residues of amitraz and flumethrin were detected in varying concentrations in some samples of bee products. Findings: Propolis is a bee product with a high tendency to retain residues of fat-soluble active compounds. The reason for this is that propolis has a higher lipid content, ranging from 25% to 50%. In terms of bee products in the EU, amitraz MRL in honey has been determined as 200 µg/kg. Although EU legislation has made a distinction between edible and inedible propolis, propolis has not been taken into account as much as honey in terms of determining official MRLs for active ingredients. In particular, research indicates that the dosage and timing of chemicals used for therapeutic purposes in hive management have a decisive impact on the chemical purity of propolis. These results have shown that amitraz and flumethrin can accumulate in propolis at detectable levels. Residues in propolis are not sufficiently known and have not been adequately tested. As propolis is classified as a pharmaceutical and food supplement, the importance of residue monitoring studies in terms of its safety should be emphasized, and best practice recommendations for beekeepers to reduce residues should be supported.

Keywords: Amitraz, Flumethrin, Propolis, Varroa destructor

PROPOLİSTE AMİTRAZ VE FLUMETRİN KALINTI TESPİTİ

ÖZET

Propolis, bal arıları tarafından bitki reçineleri, balmumu ve enzimlerle oluşturulan kompleks bir doğal üründür. Bal arılarının içgüdüsel davranışlarında reçine toplama ve propolis üretimi vardır. Propolisin arı kolonilerindeki kovan açıkların kapatılması ve korunması, istilacıların cesetlerinin mumyalanması, kovan içi temizlik malzemesi gibi bazı önemli fonksiyonları incelenmiştir. Propolis, petek mumunda katkı maddesi olarak peteğin tüm yapısını güçlendirir. Petek bileşimindeki payının yaklaşık %5-10 olduğu tahmin edilmektedir. Bir pestisit türü olan amitraz ve flumetrin ise bal arılarında akaristlere karşı kullanılan kimyasal bileşenlerdir. Bu çalışma, arıcılıkta akaristlere karşı yaygın olarak kullanılan pestisitlerin, propolis üzerindeki kalıntı varlığını ve düzeylerini belirlemek amacıyla literatür taraması yapılmıştır. Özellikle Varroa destructor kontrolünde uygulanan amitraz ve flumetrinin, kovan içi lipofilik yüzeylerde birikebildiği bilindiğinden, propolis örneklerinde kalıntı riski önemli bir kalite ve güvenlik parametresi olarak değerlendirilmektedir. Türkiye’de farklı coğrafi bölgelerden ve üretim koşullarından temin edilen arı ürünleri örneklerinde, ileri kromatografik yöntemler kullanılarak kalıntı taraması yapılabilirliği tespit edilmiştir. Ağırlıklı yüksek performanslı sıvı kromatografisi (HPLC), gaz kromatografi-kütle spektrometrisi (GC-MS) ve Sıvı kromatografi-kütle spektrometrisi (LC-MS) yöntemleriyle analiz edilmiştir. Analiz sonuçları, bazı arı ürünleri

örneklerinde değişen konsantrasyonlarda amitraz ile flumetrin kalıntılarının tespit edildiğini ortaya koymuştur. Bulgular; propolis, yağda çözünen aktif maddelerin kalıntılarını tutma eğilimi yüksek olan bir arı ürünüdür. Bunun nedeni, propolisin %25-50 arasında değişen daha yüksek lipid içeriğidir. AB'deki arı ürünleri açısından, balda amitraz MRL 200 µg/kg olarak belirlenmiştir. AB yasası yenilebilir ve yenilemez propolis arasında bir ayrım yapmış olsada, propolisin aktif maddeler için resmi MRL'lerin belirlenmesi açısından bal kadar dikkate alınmamıştır. Özellikle kovan yönetiminde, tedavi amaçlı kullanılan kimyasalların uygulama miktarının ve uygulama zamanlarının propolisin kimyasal saflığı üzerinde belirleyici etkileri olduğunu göstermektedir. Bu sonuçlar, amitraz ve flumetrinin propolislerde tespit edilebilir seviyelerde birikebildiğini ortaya koymuştur. Propolisteki kalıntılar yeterince bilinmemekte ve yeterince test edilmemiştir. Farmasötik ve gıda takviyesi olarak değerlendirilen propolis, güvenilirliği açısından kalıntı izleme çalışmalarının önemini vurgulamalı ve arıcılar için kalıntı azaltıcı iyi uygulama önerileri desteklenmelidir.

Anahtar Kelimeler: Amitraz, Flumetrin, Propolis, Varroa destructor

INVESTIGATION OF THE PRESENCE OF MICROPLASTICS IN HONEY BEE AND BEE PRODUCTS

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ABSTRACT

Microplastics (MP; <5 mm) are among the important pollutants that accumulate rapidly in environmental environments and pose risks to ecosystem health on a global scale. While the threat posed by synthetic pesticides to pollinator organisms is well known, other pollutants such as plastic derived microparticles have been ignored for a long time and have recently become the focus of research. This situation is giving rise to growing concern due to its potential impact on the health of honeybees and the sustainability of ecosystem services. Especially in recent years, the number of studies investigating the presence of microplastics in honeybees (*Apis mellifera* L.) and the bee products produced by them, which are considered biological indicators of environmental pollution, have increased significantly. This study aims to comprehensively evaluate the current literature on the detection of microplastics in basic bee products such as honey, pollen, bee bread, beeswax and propolis. The most commonly reported types of MP in studies are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and polyethylene terephthalate (PET), and these polymers have been reported to be mostly found in fiber and particle form. In addition, analytical techniques such as stereomicroscopic examination, Fourier Transform Infrared (FTIR) spectroscopy, Raman micro spectroscopy and scanning electron microscopy (SEM) are widely used. It is reported that the microplastic concentrations detected in honey range on average from 10 to 600 particles per kilogram. Pollen and bee bread generally contain higher levels of microplastics as they are in more direct contact with the environment, and it has been observed that microplastics in fibre form predominate in these products. Due to its lipophilic nature, beeswax stands out as the bee product with the highest potential for microplastics. Current findings indicate that honeybees and bee products are exposed to environmentally microplastic pollution and represent a potential source of exposure for humans. However, there are significant gaps in our understanding regarding the effects of microplastics on the physiological processes of honeybees, their long-term accumulation at the colony level, and the quantitative assessment of risks to human health. It is therefore of critical importance to gain a more comprehensive understanding of the interactions between microplastics, pollinators and ecosystems. Future research, supported by standardized analytical protocols, extensive geographical sampling areas and toxicological studies, will help to shed further light on the subject.

Keywords: Microplastics, Honeybee, Bee products

BAL ARISI VE ARI ÜRÜNLERİNDE MİKROPLASTİKLERİN VARLIĞININ ARAŞTIRILMASI

ÖZET

Mikroplastikler (MP; <5 mm), çevresel ortamlarda hızla biriken ve ekosistem sağlığı üzerinde küresel ölçekte risk oluşturan önemli kirleticiler arasında yer almaktadır. Tozlayıcı organizmalar açısından sentetik pestisitlerin oluşturduğu tehdit iyi bilinirken, plastik kaynaklı mikro partiküller gibi diğer kirleticiler uzun süre göz ardı edilmiş ve yeni yeni araştırma odağı hâline gelmiştir. Bu durum, bal arılarının sağlığı ve ekosistem hizmetlerinin sürdürülebilirliği üzerindeki potansiyel etkiler nedeniyle giderek artan bir endişeye yol açmaktadır. Özellikle son yıllarda, çevresel kirlenmenin biyolojik göstergeleri olarak kabul edilen bal arıları (*Apis mellifera* L.) ve onların ürettiği arı ürünlerinde mikroplastik varlığını araştıran çalışmaların sayısı belirgin şekilde artmıştır. Bu çalışma, bal, polen, arı ekmeği, balmumu ve propolis gibi temel arı ürünlerinde mikroplastik tespitine ilişkin güncel literatürü kapsamlı bir biçimde değerlendirmeyi amaçlamaktadır. Araştırmalarda en yaygın rapor edilen MP türleri polietilen (PE), polipropilen (PP), polistiren (PS), polivinil klorür (PVC) ve polietilen tereftalat (PET) olup, bu polimerlerin çoğunlukla lif ve partikül formunda bulunduğu bildirilmiştir. Ayrıca stereomikroskopik inceleme, Fourier Transform Infrared (FTIR) spektroskopisi, Raman mikrospektroskopisi ve taramalı elektron mikroskobu (SEM) gibi analitik teknikler yaygın olarak kullanılmaktadır. Balda belirlenen mikroplastik yoğunluklarının ortalama olarak 10–600

partikül/kg aralığında seyrettiği ifade edilmektedir. Polen ve arı ekmeği çevre ile daha doğrudan temas hâlinde olduklarından genellikle daha yüksek mikroplastik yüküne sahiptir ve bu ürünlerde lif formundaki mikroplastiklerin baskın olduğu gözlemlenmektedir. Lipofilik yapısı nedeniyle balmumu ise mikroplastiklerin en yüksek potansiyele sahip arı ürünü olarak öne çıkmaktadır. Mevcut bulgular, bal arısı ve arı ürünlerinin çevresel mikroplastik kirliliğe maruz kaldığı ve insanlar için potansiyel bir maruziyet kaynağı olduğunu ortaya koymaktadır. Ancak mikroplastiklerin bal arılarının fizyolojik süreçleri üzerindeki etkileri, koloni düzeyinde uzun dönemli birikimi ve insan sağlığına yönelik risklerin nicel olarak değerlendirilmesi konularında önemli bilgi boşlukları bulunmaktadır. Bu nedenle mikroplastik–tozlayıcı–ekosistem etkileşimlerinin daha kapsamlı şekilde anlaşılması kritik öneme sahiptir. Gelecek araştırmaların, standartlaştırılmış analitik protokoller, geniş coğrafi örneklem alanları ve toksikolojik çalışmalarla desteklenmesi, konunun daha net bir şekilde aydınlatılmasına katkı sağlayacaktır.

Anahtar Kelimeler: Mikroplastikler, Bal arısı, Arı ürünleri

**DIGITALIZATION AND ITS CLIMATE COST: THE OVERLOOKED ECOLOGICAL
FOOTPRINT OF THE TWIN TRANSITION**

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ABSTRACT

In recent years, digitalization has been increasingly promoted as a key policy instrument in the fight against climate change due to its potential to enhance energy efficiency, optimize processes, and improve carbon management. This approach is commonly framed within the concept of the “Twin Transition,” which refers to the simultaneous advancement of green and digital transformations. However, a growing body of literature indicates that digitalization is not solely a solution-oriented pathway; rather, it also entails substantial environmental costs. This study adopts a critical perspective to examine the role of digital technologies in climate change mitigation, focusing on the direct and indirect emissions generated by digital infrastructures. Based on an extensive literature review, the climate footprint of the digital ecosystem is analyzed across three main dimensions. First, the energy intensity and water consumption of data centers are evaluated. Recent studies show that data centers account for approximately 1–2% of global electricity consumption, with a significant share of this demand arising from cooling systems. Moreover, the training of artificial intelligence models and large-scale data processing systems has been found to generate substantially higher carbon emissions compared to conventional software applications. These findings suggest that, contrary to common assumptions, digitalization may increase overall energy demand in certain contexts. The second analytical dimension focuses on the life cycle assessment (LCA) of digital hardware. Existing research demonstrates that the majority of a digital device’s total carbon footprint is generated during the production phase, particularly through raw material extraction, manufacturing, and global supply chains. The mining of rare earth elements, which are essential for many digital technologies, is associated with high energy consumption, ecosystem degradation, and significant environmental externalities. As a result, the environmental burden of digitalization extends well beyond the operational phase of digital devices. The third dimension addresses the growing global challenge of electronic waste (e-waste). Short product lifespans, rapid technological obsolescence, and consumption-driven upgrade cycles have led to a sharp increase in e-waste generation worldwide. The improper management of e-waste poses serious risks to soil and water systems and exerts increasing pressure on biodiversity. In conclusion, the literature clearly indicates that digitalization can only contribute to climate objectives if it is guided by comprehensive “Green IT” strategies. Energy-efficient software design, the integration of renewable energy sources into data centers, and policies aimed at extending hardware lifespans are essential prerequisites. Without these measures, digitalization risks evolving from a potential climate solution into a new source of environmental pressure rather than becoming a genuine driver of climate mitigation.

Keywords: Digitalization, Climate Change, Carbon Footprint, Data Centers, Green IT, Twin Transition.

**DİJİTALLEŞMENİN İKLİM MALİYETİ: İKİZ DÖNÜŞÜMÜN GÖRÜNMEYEN EKOLOJİK
AYAK İZİ**

ÖZET

İklim değişikliğiyle mücadelede dijitalleşme; enerji verimliliği, süreç optimizasyonu ve karbon yönetimi açısından son yıllarda temel bir politika aracı olarak öne çıkmaktadır. Bu yaklaşım, yeşil dönüşüm ile dijital

dönüşümün eş zamanlı yürütülmesini ifade eden “İkiz Dönüşüm” kavramı çerçevesinde ele alınmaktadır. Ancak mevcut literatür, dijitalleşmenin yalnızca çözüm odaklı bir araç olmadığını; aynı zamanda önemli çevresel maliyetler ürettiğini ortaya koymaktadır. Bu çalışma, dijital teknolojilerin iklim değişikliğiyle mücadeledeki rolünü eleştirel bir perspektifle inceleyerek, dijital altyapının neden olduğu doğrudan ve dolaylı çevresel etkileri değerlendirmeyi amaçlamaktadır. Literatür taraması sonucunda dijital ekosistemin iklim maliyeti üç temel eksenle ele alınmıştır. İlk olarak, veri merkezlerinin enerji tüketimi ve su ayak izi incelenmiştir. Güncel araştırmalar, veri merkezlerinin küresel elektrik tüketiminin yaklaşık %1–2’sinden sorumlu olduğunu ve özellikle soğutma sistemleri nedeniyle ciddi miktarda su tükettiğini göstermektedir. Yapay zekâ ve büyük dil modelleri gibi yüksek hesaplama gücü gerektiren teknolojilerin eğitim süreçleri, geleneksel yazılımlara kıyasla çok daha yüksek karbon emisyonuna yol açmaktadır. Bu durum, dijitalleşmenin enerji talebini azaltmak yerine bazı alanlarda artırdığını ortaya koymaktadır. İkinci eksenle, dijital donanımların yaşam döngüsü analizi (LCA) ele alınmıştır. Çalışmalar, akıllı telefonlar, sunucular ve veri işleme ekipmanlarının toplam karbon ayak izinin büyük bir bölümünün üretim, hammadde çıkarımı ve tedarik zinciri aşamalarında oluştuğunu göstermektedir. Özellikle nadir toprak elementlerinin madenciliği hem yüksek enerji tüketimine hem de ekosistem tahribatına neden olmaktadır. Üçüncü olarak, elektronik atık (e-atık) sorunu değerlendirilmiştir. Dijital cihazların kısa kullanım ömürleri ve hızlı teknolojik eskime, küresel ölçekte ciddi bir e-atık krizini beraberinde getirmekte; bu durum toprak, su ve biyolojik çeşitlilik üzerinde önemli baskılar oluşturmaktadır. Sonuç olarak, literatür bulguları dijitalleşmenin iklim hedeflerine katkı sunabilmesi için “Yeşil BT” yaklaşımlarının zorunlu olduğunu ortaya koymaktadır. Enerji verimli yazılım tasarımı, yenilenebilir enerjiyle çalışan veri merkezleri ve donanım ömrünü uzatmaya yönelik döngüsel ekonomi politikaları benimsenmediği sürece, dijitalleşmenin bir iklim çözümünden ziyade yeni bir çevresel risk alanı yaratma potansiyeli bulunmaktadır.

Anahtar Kelimeler: Dijitalleşme, İklim Değişikliği, Karbon Ayak İzi, Veri Merkezleri, Yeşil BT, İkiz Dönüşüm.

DEVELOPMENT OF MULTIFUNCTIONAL CARBOXYMETHYLATED KAPPA-CARRAGEENAN PLATFORMS FOR HEMOSTATIC AND TISSUE ENGINEERING APPLICATIONS¹

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ABSTRACT

Kappa-carrageenan (KC) is a naturally derived polysaccharide with promising biomedical applications; however, its limited functionality and solubility restrict its performance. In this study, KC was chemically modified via Williamson ether synthesis to obtain carboxymethylated derivatives with improved properties. Carboxymethylation introduces hydrophilic carboxyl groups, improving solubility, swelling behavior, and intermolecular interactions, which are critical for hemostatic and tissue engineering applications. Different monochloroacetic acid (MCA):KC ratios were used to create three distinct formulations, and ¹H NMR spectra were used to calculate the degree of substitution (DS), ranging from 0.7 to 0.94. Structural characterization by FT-IR and ¹³C NMR confirmed the successful carboxymethylation. Solubility studies revealed significantly improved aqueous behavior compared to native KC with the optimal modification at a 3.5:1 MCA:KC ratio. This improved solubility is crucial for hydrogel formation, enabling homogeneous polymer dispersion and efficient network formation. The optimized derivative of carboxymethylated KC (CMKC) was incorporated into polymer-based nanofibers via electrospinning (0.15–2 mL/h, 10–24 kV, 10–20 cm). Morphological properties and fiber diameter distributions were analyzed by scanning electron microscopy (SEM). Swelling behavior of the nanofibers was evaluated in three different media, showing high swelling capacity in phosphate-buffered saline (PBS) after 24 h without structural degradation. Overall, the results highlight the successful development of a multifunctional CMKC platform with enhanced physicochemical and structural properties. This platform demonstrates strong potential for hemostatic applications through nanofiber systems, while its improved solubility and swelling behavior indicate its suitability for hydrogel-based applications in tissue engineering.

Keywords: Carboxymethyl-Kappa Carrageenan, Hydrogel, Hemostatic Materials, Nanofiber, Tissue Engineering

¹This work was funded by the Scientific and Technological Research Council of Türkiye (TÜBİTAK) with project number 20AG041. Kübra Arancı is supported by the YOK (The Council of Higher Education) 100/2000 Scholarship Programme for Ph.D. students.

EFFECT of pH on the REMOVAL of REACTIVE BLUE 221 from AQUEOUS SOLUTIONS via a MAGNETIC PHOTOCATALYTIC ADSORBENT

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ABSTRACT

Today, the environmental impacts of climate change and the sustainable management of water resources have made scientific research on water conservation a strategic priority. Wet processing in the textile industry represents one of the highest environmental risks due to intensive water consumption and complex pollutant loads. The removal of surfactants and synthetic dyes used in these processes is of great importance for water recovery and compliance with discharge standards. In this study, the adsorption and photocatalytic degradation processes of Reactive Blue 221 (RB 221) were investigated in an integrated manner to remediate dye pollution in textile wastewater. In the experimental stage, working solutions of various concentrations were prepared by dilution from a 100 mg/L stock solution, and linear calibration curves were established for quantitative analysis. The PANY-1 polymer, which exhibits magnetic properties, was employed as the adsorbent material. Within the scope of the experimental protocol, 0.01 g of PANY-1 polymer was interacted with 10 mL of RB 221 solution at a concentration of 50 mg/L. The effect of medium pH on removal efficiency was systematically investigated. Samples adjusted to different pH values were analyzed at a wavelength of 612 nm, where RB 221 shows maximum absorption, using a UV-VIS spectrophotometer after a 24-hour contact time, which was confirmed by pre-kinetic experiments to reach chemical equilibrium. The findings revealed that in the removal of RB 221 with PANY-1 polymer, the protonation and subsequent positive charging of the adsorbent surface at pH 3 maximized the electrostatic attraction forces between the surface and the anionic RB 221 molecules. These results indicate that the PANY-1 polymer can be used as a potential adsorbent for specific dye removal and industrial wastewater treatment processes. In addition, due to the magnetic photocatalytic properties of the PANY-1 polymer, hydroxyl and superoxide radicals generated under daylight conditions contribute to photocatalytic degradation, resulting in a higher overall removal efficiency compared to dark conditions, where only adsorption occurs.

Keywords: Wastewater treatment, Adsorption, PANY-1 polymer, pH effect, Reactive Blue 221.

REAKTİF MAVİ 221'in MANYETİK FOTOKATALİTİK ADSORBAN ile SULU ÇÖZELTİLERDEN GİDERİLMESİNDE pH ETKİSİNİN İNCELENMESİ

ÖZET

Günümüzde iklim değişikliğinin çevresel etkileri, su kaynaklarının korunması ve sürdürülebilir yönetimi üzerine yapılan bilimsel çalışmaları stratejik bir öncelik haline getirmiştir. Tekstil endüstrisinde gerçekleştirilen ıslak işlem prosesleri, yüksek su tüketimi ve beraberinde getirdiği kompleks kirlenici yükü nedeniyle çevresel riskin en yüksek olduğu aşamalardan biridir. Bu proseslerde kullanılan yüzey aktif maddelerin ve sentetik boyarmaddelerin atık sulardan uzaklaştırılması, suyun geri kazanımı ve deşarj

standartlarının sağlanması açısından büyük önem arz etmektedir. Gerçekleştirilen bu araştırmada, tekstil endüstrisi kaynaklı boyarmadde kirliliğinin bertarafı kapsamında, Reaktif Mavi 221 (RB 221) tekstil boyasının adsorpsiyon ve fotokatalitik parçalanma mekanizmaları hibrit bir yaklaşımla ele alınmıştır. Deneysel aşamada, 100 mg/L başlangıç konsantrasyonuna sahip stok çözeltiden seyreltme yöntemiyle farklı konsantrasyonlarda çalışma çözeltileri hazırlanmış ve kantitatif analizler için doğrusal regresyon katsayısı yüksek kalibrasyon eğrileri oluşturulmuştur. Adsorpsiyon sürecinde adsorban materyal olarak manyetik özellik gösteren PANY-1 polimeri kullanılmıştır. Deneysel protokol kapsamında; 0,01 g PANY-1 polimeri, 50 mg/L konsantrasyonundaki 10 mL RB 221 çözeltisi ile etkileşime bırakılmıştır. Çalışmada, giderim verimliliği üzerine ortam pH'nın etkisi sistematik olarak araştırılmıştır. Farklı pH değerlerine ayarlanan örnekler, sistemin kimyasal dengeye ulaştığı ön kinetik deneylerle teyit edilen 24 saatlik temas süresi sonunda UV-VIS spektrofotometresi ile RB 221 boyarmaddesinin maksimum absorpsiyon gösterdiği 612 nm dalga boyunda analiz edilmiştir. Elde edilen bulgular, PANY-1 polimeri ile gerçekleştirilen RB 221 gideriminde, pH 3 değerinde adsorban yüzeyinin protonlanarak pozitif yüklenmesinin, anyonik yapıdaki RB 221 molekülleri ile yüzey arasındaki elektrostatik çekim kuvvetlerini maksimize ettiğini ortaya koymuştur. Bu sonuçlar, PANY-1 polimerinin spesifik boyarmadde giderimi ve endüstriyel atık su ıslahı süreçlerinde potansiyel bir adsorban olarak kullanılabileceğini göstermektedir. Ayrıca, PANY-1 polimerinin manyetik fotokatalitik özellikleri sayesinde, gün ışığı altında oluşan hidroksil ve süperoksit radikallerinin fotokatalitik degradasyon sonucu, sadece adsorpsiyonun gerçekleştiği karanlık ortama kıyasla toplam giderim veriminin arttığı saptanmıştır.

Anahtar Kelimeler: Atık su arıtımı, Adsorpsiyon, PANY-1 polimeri, pH etkisi, Reaktif Mavi 221.

INVESTIGATION of The CONCENTRATION EFFECT on The REMOVAL of REACTIVE BLUE 221 from AQUEOUS SOLUTIONS USING MAGNETIC PHOTOCATALYTIC ADSORBENT

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ABSTRACT

Synthetic dye discharge, a major environmental challenge for the textile industry, exerts an irreversible pollution pressure on aquatic ecosystems. This study investigates the performance of PANY-1 polymer a hybrid material possessing both magnetic and photocatalytic properties in the removal of Reactive Blue 221 (RB 221) from aqueous solutions. The research primarily focuses on the critical impact of initial dye concentration on overall removal efficiency. In the experimental phase, PANY-1 was interacted with RB 221 solutions at varying concentrations, with quantitative analyses performed via spectrophotometry. The results indicated that while the amount of dye adsorbed per unit mass (q_e) increased with higher contaminant concentrations, the total removal percentage exhibited a downward trend as active sites approached saturation. Notably, under acidic conditions (pH 3), the protonation of the adsorbent surface enhanced the electrostatic attraction toward the anionic RB 221 molecules, bringing the removal efficiency to its peak. Furthermore, exposure to daylight triggered a photocatalytic degradation mechanism, extending the process beyond mere physical adsorption. This hybrid approach significantly improved the overall removal efficiency compared to dark conditions. Ultimately, the PANY-1 polymer proved to be a sustainable and high-performance alternative for industrial wastewater remediation, particularly given its ease of magnetic recovery after treatment.

Keywords: Wastewater treatment, Hybrid mechanism, PANY-1 polymer, Reactive Blue 221, Concentration effect.

MANYETİK FOTOKATALİTİK ADSORBAN ile REAKTİF MAVİ 221'in SULU ÇÖZELTİLERDEN GİDERİLMESİNDE KONSANTRASYON ETKİSİNİN İNCELENMESİ

ÖZET

Tekstil endüstrisinin en büyük çevresel sorunlarından biri olan sentetik boyar madde deşarjı, su ekosistemleri üzerinde geri dönülmesi güç bir kirlilik baskısı yaratmaktadır. Bu araştırmada, Reaktif Mavi 221'in (RB 221) sulu ortamlardan uzaklaştırılması için hem manyetik hem de fotokatalitik özelliklere sahip hibrit bir materyal olan PANY-1 polimerinin etkisi incelenmiştir. Çalışmanın odağında, başlangıç boyar madde derişimindeki değışimlerin giderim performansı üzerindeki belirleyici rolü yer almaktadır. Deneysel aşamada, farklı konsantrasyonlardaki RB 221 çözeltileri PANY-1 örneğı ile temas ettirilmiş; kantitatif analizler spektrofotometrik yöntemle gerçekleştirilmiştir. Elde edilen veriler, kirletici derişimi arttıkça birim kütle başına adsorplanan boya miktarının (q_e) yükseldiğini, ancak aktif bölgelerin doyunluğa yaklaşmasıyla toplam giderim yüzdesinin aşağı yönlü bir eğilim sergilediğini göstermiştir. Özellikle asidik koşullarda (pH 3), adsorban yüzeyinin protonlanarak pozitif yük kazanması giderim verimini en üst düzeye çıkarmıştır. Buna ek olarak, PANY-1 polimeri gün ışığına maruz kaldığında, süreci fotokatalitik bir parçalanma mekanizmasıyla

destekleyerek verimi karanlık ortama kıyasla belirgin şekilde artırmıştır. Sonuç olarak, manyetik yapısıyla kolayca geri kazanılabilen PANY-1 polimerinin, endüstriyel atık su ıslahı için sürdürülebilir bir alternatif olduğu saptanmıştır.

Anahtar Kelimeler: Atık su arıtımı, Hibrit mekanizma, PANY-1 polimeri, Reaktif Mavi 221, Konsantrasyon Etkisi.

**THE RELATIONSHIP BETWEEN PSYCHOLOGICAL RESILIENCE AND JOB STRESS AMONG
HEALTHCARE WORKERS: EVIDENCE FROM ISTANBUL**

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ABSTRACT

Healthcare workers operate in work environments characterized by heavy workloads, time pressure, and high emotional demands. These conditions increase the likelihood of experiencing job stress and may negatively affect both employees' psychological well-being and the quality of healthcare services provided. In this context, psychological resilience is considered an important personal resource that reflects individuals' capacity to cope with stressful situations and adapt to challenging conditions. The aim of this study is to examine the relationship between psychological resilience and job stress among healthcare workers. The empirical data of the study were obtained from healthcare personnel working in public and private hospitals in Istanbul. The data were collected through questionnaires administered both online and face-to-face using a simple random sampling method. The analyses were conducted based on 698 valid questionnaires. Statistical analyses were performed using IBM SPSS 25 and IBM AMOS 22 software packages. In the first stage, various statistical analyses were conducted to determine the reliability and validity of the measurement scales, and the measurement model was tested through confirmatory factor analysis (CFA). Structural equation modeling (SEM) was used to test the research hypotheses. The findings reveal a negative and statistically significant relationship between psychological resilience and job stress among healthcare workers. This result indicates that employees with higher levels of psychological resilience are able to manage job stress more effectively. In this context, it is suggested that initiatives aimed at strengthening the psychological resilience of healthcare workers may contribute to reducing job stress in healthcare institutions.

Keywords: Psychological Resilience, Job Stress, Healthcare Workers, Empirical Research.

**SAĞLIK ÇALIŞANLARINDA PSİKOLOJİK DAYANIKLILIK VE İŞ STRESİ İLİŞKİSİ:
İSTANBUL ÖRNEĞİ**

ÖZET

Sağlık çalışanları yoğun iş yükü, zaman baskısı ve yüksek duygusal taleplerin bulunduğu çalışma ortamlarında görev yapmaktadır. Bu durum sağlık çalışanlarının iş stresi yaşama olasılığını artırmakta ve hem çalışanların psikolojik iyi oluşunu hem de sunulan sağlık hizmetinin kalitesini etkileyebilmektedir. Bu bağlamda psikolojik dayanıklılık, bireylerin stresli durumlarla başa çıkabilme ve zorlu koşullara uyum sağlayabilme kapasitesini ifade eden önemli bir kişisel kaynak olarak değerlendirilmektedir. Bu çalışmanın amacı sağlık çalışanlarında psikolojik dayanıklılık ile iş stresi arasındaki ilişkiyi incelemektir. Araştırmanın ampirik verileri İstanbul'da faaliyet gösteren kamu ve özel hastanelerde çalışan sağlık personelinin elde edilmiştir. Veriler basit tesadüfi örnekleme yöntemi kullanılarak hem çevrim içi hem de yüz yüze uygulanan anketler aracılığıyla toplanmıştır. Analizler 698 geçerli anket verisi üzerinden gerçekleştirilmiştir. Toplanan verilerin analizi IBM SPSS 25 ve IBM AMOS 22 programları kullanılarak yapılmıştır. İlk aşamada ölçeklerin güvenilirlik ve geçerliliğini belirlemek amacıyla çeşitli istatistiksel analizler uygulanmış ve ölçüm modelinin uygunluğu doğrulayıcı faktör analizi (DFA) ile test edilmiştir. Araştırma hipotezlerinin test edilmesi amacıyla ise yapısal eşitlik modeli (SEM) kullanılmıştır. Araştırma bulguları sağlık çalışanlarında psikolojik dayanıklılık ile iş stresi arasında negatif ve istatistiksel olarak anlamlı bir ilişki olduğunu ortaya koymaktadır. Bu durum, psikolojik dayanıklılığı yüksek olan çalışanların iş stresini daha etkin bir şekilde yönetebildiğini göstermektedir. Bu bağlamda, sağlık kurumlarında çalışanların psikolojik dayanıklılığını güçlendirmeye yönelik uygulamaların iş stresinin azaltılmasına katkı sağlayabileceği değerlendirilmektedir.

Anahtar Kelimeler: Psikolojik Dayanıklılık, İş Stresi, Sağlık Çalışanları, Ampirik Araştırma

THE RELATIONSHIP OF PERCEIVED SOCIAL SUPPORT, INTERNALIZED STIGMA, AND EXPERIENTIAL AVOIDANCE WITH THE SEVERITY OF ALCOHOL USE DISORDER IN INDIVIDUALS WITH ALCOHOL USE DISORDER

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ABSTRACT

This study aims to examine the relationships between perceived social support, internalized stigma, experiential avoidance, and the severity of alcohol use disorder. By analyzing both direct and indirect effects, the role of psychological and social factors in alcohol use disorder severity was tested. The research sample consisted of volunteers aged 18 and over who applied to Alcoholics Anonymous (AA) Istanbul groups. To maintain the focus of the study, individuals with comorbid substance use or additional diagnoses such as intellectual disability or dementia were excluded. Data were collected through online platforms using a purposive sampling method. The research utilized a Demographic Information Form, the Multidimensional Scale of Perceived Social Support, the Internalized Stigma of Mental Illness Scale, the Multidimensional Experiential Avoidance Questionnaire, and the Alcohol Use Disorders Identification Test. The obtained data were analyzed using SPSS 27.0 and AMOS software. Pearson correlation analysis was employed to determine the strength and direction of the relationships between variables, and Structural Equation Modeling was applied to test the hypotheses. Additionally, t-tests and ANOVA were utilized to determine the effects of sociodemographic variables.

Keywords: Support, Internalized Stigma, Avoidance, Alcohol Addiction.

ALKOL KULLANIM BOZUKLUĞU OLAN BİREYLERDE ALGILANAN SOSYAL DESTEK, İÇSELLEŞTİRİLMİŞ DAMGALANMA VE YAŞANTISAL KAÇINMANIN ALKOL KULLANIM BOZUKLUĞU ŞİDDETİ İLE İLİŞKİSİ

ÖZET

Bu çalışma; bireylerin algıladıkları sosyal destek düzeyi, içselleştirilmiş damgalanma ve yaşantısal kaçınma davranışları ile alkol kullanım bozukluğu şiddeti arasındaki ilişkileri incelemeyi amaçlamaktadır. Araştırmada doğrudan ve dolaylı etkiler analiz edilerek, psikolojik ve sosyal etmenlerin alkol kullanım bozukluğu üzerindeki rolü test edilmiştir. Araştırmanın örneklemini, Adsız Alkolikler (AA) İstanbul gruplarına başvuran 18 yaş ve üzeri gönüllüler oluşturmuştur. Çalışmanın odağını korumak amacıyla; eşlik eden madde kullanımı, zihinsel yetersizlik veya demans gibi ek tanıları olan bireyler araştırma dışında tutulmuştur. Veri toplama sürecinde, amaçlı örnekleme yöntemi kullanılarak katılımcılara çevrimiçi platformlar üzerinden ulaşılmıştır. Araştırmada; Demografik Bilgi Formu, Çok Boyutlu Algılanan Sosyal Destek Ölçeği, Ruhsal Hastalıklarda İçselleştirilmiş Damgalanma Ölçeği, Çok Boyutlu Yaşantısal Kaçınma Ölçeği ve Alkol Kullanım Bozukluklarını Tanıma Testi kullanılmıştır. Elde edilen veriler SPSS 27.0 ve AMOS paket programları aracılığıyla analiz edilmiştir. Değişkenler arasındaki ilişkilerin gücünü ve yönünü belirlemek amacıyla Pearson korelasyon analizi, hipotezlerin test edilmesi için ise Yapısal Eşitlik Modellemesi uygulanmıştır. Ayrıca sosyodemografik değişkenlerin etkisini belirlemek adına t-testi ve ANOVA analizlerinden yararlanılmıştır.

Anahtar Kelimeler: Sosyal Destek, İçselleştirilmiş Damgalanma, Yaşantısal Kaçınma, Alkol Bağımlılığı.

**THE INFLUENCE OF THE DATING VIOLENCE ATTITUDE AND DEPRESSION LEVEL ON
DEMAND WITHDRAW COMMUNICATION PATTERNS**

Kardelen DUDULAR CİNALİ

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ABSTRACT

This study examined the predictive effect of dating violence attitudes and depression level on the demand-withdraw communication pattern. The research involves a total of two hundred ninety nine university students, one hundred and sixty nine female and one hundred and thirty two men, after exclusion, who are studying in various departments of Hacettepe University. Participants were required to have an ongoing or steady relationship that lasted at least three months. Thus, not having a romantic relationship was considered as an exclusion criterion. The students who participated in the study are selected through convenience sampling. The scales that are used in the study were applied collectively and in the classroom environment. Research data were collected using Demographic Information Form, Short Communication Pattern Scale, Flirting Violence Attitude Scale and Beck Depression Inventory. IBM SPSS-25 program was used in the statistical evaluation of the data. One-Way Analysis of Variances were run to assess whether the demand-withdrawal communication pattern, dating abuse and depression change according to demographic variables. Correlation analyses were used to evaluate whether there are significant relationships between these variables. Multiple regression analyses were conducted to examine the predictive effect of depression level and dating violence attitudes on the demand-withdraw communication pattern.

Keywords: Depression, communication pattern, dating violence attitude

**FLÖRT ŞİDDET TUTUMU VE DEPRESYON DÜZEYİNİN TALEP ETME GERİ ÇEKİLME
İLETİŞİM ÖRÜNTÜSÜ ÜZERİNDEKİ ETKİSİ**

ÖZET

Bu çalışmada, flört şiddet tutumu ve depresyon düzeyinin talep etme-geri çekilme iletişim örüntüsü üzerindeki yordayıcı etkisinin incelenmesi amaçlanmıştır. Çalışmaya Hacettepe Üniversitesi'nin çeşitli bölümlerinde eğitim gören yüz altmış yedi kadın, yüz otuz iki erkek olmak üzere toplam iki yüz doksan dokuz üniversite öğrencisi katılmıştır. Katılımcıların süregiden ya da önceden yaşamış oldukları en az 3 ay süren düzenli bir ilişkileri olması koşulu aranmıştır. Romantik bir ilişki yaşamıyor olmak dışlama ölçütü olarak kabul edilmiştir. Çalışmaya katılacak öğrenciler kolay örneklem yoluyla seçilmiştir. Çalışmada kullanılan ölçekler toplu halde ve sınıf ortamında uygulanmıştır. Araştırma verileri, Demografik Bilgi Formu, İletişim Şekilleri Ölçeği Formu, Flört Şiddeti Tutum Ölçeği ve Beck Depresyon Ölçeği kullanılarak toplanmıştır. Verilerin istatistiksel olarak değerlendirilmesinde, IBM SPSS-25 programından yararlanılmıştır. Talep etme-geri çekilme iletişim örüntüsü, ilişkide şiddet tutumu ve depresyonun, demografik değişkenlere göre değişip değişmediğini değerlendirmek amacıyla Tek Yönlü Varyans Analizleri kullanılmıştır. Yine bu değişkenler arasında anlamlı ilişkiler bulunup bulunmadığını değerlendirmek için korelasyon analizleri kullanılmıştır. Katılımcıların depresyon düzeyinin ve flört şiddet tutumunun talep etme geri çekilme iletişim örüntüsü üzerindeki etkisinin değerlendirilmesi için çoklu regresyon analizi yapılmıştır.

Anahtar Kelimeler: Depresyon, iletişim örüntüsü, flört şiddet tutumu

**ON THE FRINGES OF HUMANITY: AFFIRMATIVE ETHICS AND POSTHUMANIST KINSHIP
IN HELEN MCDONALD'S *H IS FOR HAWK***

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ABSTRACT

Helen McDonald's *H is for Hawk* (2014) is a genre defying memoir that recounts the author's transformative and healing experience of training a goshawk, Mabel, in the aftermath of her father's sudden death. Widely acclaimed—recipient of the Samuel Johnson Prize for Non-Fiction and the Costa Book of the Year, later followed by a BBC documentary *H is for Hawk: New Chapter* and forthcoming film directed by Philippa Lowthorpe—the text has been recognized not only for its literary experimentation but also for its profound engagement with questions of interspecies relations. This essay situates McDonald's work within ecocritical discourse, drawing on the theoretical frameworks of Donna Haraway and Rosi Braidotti to interrogate the intersections of humanism and posthumanism. Central to the analysis is Haraway's notion of *naturecultures* and the call for kinship, ethical responsibility, and affective relationality between humans and nonhuman species. By foregrounding themes of human fragility, precariousness, and the affirmative potential of interspecies ethics, the essay argues that McDonald's narrative reconfigures the boundaries of humanity itself. In doing so, *H is for Hawk* exemplifies how literature can cultivate an expanded, ethically attuned conception of the human through its engagement with the non-human world. Moreover, the essay underscores the broader implications of McDonald's text for contemporary ecocritical and posthumanist thought. It invites readers to reconsider the human not as a fixed essence but as a relational being constructed and deconstructed by encounters with nonhuman others. *H is for Hawk* demonstrates how literary works can function as a site of ethical experimentation by cultivating different modes of coexistence and challenging anthropocentric approaches.

Keywords: Helen McDonald, ecocriticism, interspecies ethics

THE POSITION OF WOMEN IN THE KOSOVO VILAYET DURING THE LATE OTTOMAN PERIOD

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ABSTRACT

This study analyzes the position of women in the Kosovo Vilayet during the late Ottoman period (1877–1912), focusing on their legal, social, and administrative status as reflected in archival sources. Based on documents from the Ottoman State Archives, it examines issues such as violence, legal disputes, imprisonment, and mobility, as well as women's interactions with state institutions. The sources indicate that women appeared both as subjects of protection and as participants in legal and bureaucratic processes, revealing patterns of vulnerability alongside mechanisms of state intervention. Measures such as judicial proceedings, administrative oversight, and the establishment of dedicated institutions illustrate the growing role of the Ottoman state in regulating social order. By situating these dynamics within the broader context of late Ottoman reforms and provincial governance, the study contributes to a more nuanced understanding of gender relations and state authority in the Kosovo Vilayet.

Keywords: Women; gender history, Kosovo Vilayet; Ottoman law, state authority; social regulation, late Ottoman Balkans

PHOTOCATALYTIC DEGRADATION OF ORGANIC CONTAMINANTS USING GREEN-SYNTHESIZED TiO₂ NANOPARTICLES FROM GINGER ROOT POWDER IMMOBILIZED IN CHITOSAN BEADS: A COMBINED EXPERIMENTAL AND THEORETICAL INVESTIGATION FOR SUSTAINABLE WATER PURIFICATION

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ABSTRACT

In this study, titanium dioxide nanoparticles (TiO₂ NPs) were synthesized via a green and sustainable approach using crude aqueous extract of ginger root (*Zingiber officinale*) as a natural reducing and stabilizing agent. Phytochemicals such as flavonoids, phenolics, and terpenoids facilitated nanoparticle nucleation, growth, and stabilization without the need for toxic chemicals or high-energy inputs. A Box–Behnken design (BBD) was employed to optimize precursor concentration, CAE volume, and calcination temperature, yielding TiO₂ nanoparticles with a high BET surface area (150.49 m²/g) and small particle size (10.38 nm) under optimal conditions (0.3 M precursor, 5 mL crude aqueous extract (CAE), 400 °C). Characterization confirmed a mesoporous structure, mixed anatase–rutile phases, nanoscale morphology, and strong dispersion within the chitosan support to form the CS@TiO₂ nanocomposite. The CS@TiO₂ nanocomposite exhibited excellent photocatalytic degradation of Crystal Violet (CV) and Methylene Violet (MV), with synergistic enhancement attributed to increased surface reactivity, efficient electron–hole separation, and rapid charge transfer. Density functional theory (DFT) analysis confirmed a reduced HOMO–LUMO energy gap, higher global softness, and favorable charge transfer pathways in the composite, explaining its enhanced photocatalytic efficiency. Photocatalytic performance was further validated using real textile effluent, where UV–Vis analysis revealed a prominent absorption peak at 524 nm corresponding to the dye mixture. Under light irradiation, CS@TiO₂ achieved ~98–100% decolorization within 60 min, accompanied by significant reductions in BOD₅ (75%), COD (87.75%), and electrical conductivity (98.35%). These results demonstrate the practical potential of the nanocomposite in efficiently treating complex industrial wastewater. The integration of experimental,

theoretical, and real-effluent validation highlights CS@TiO₂ as a highly reactive, stable, and sustainable photocatalyst with strong promise for environmental remediation applications.

Keywords : Photocatalysis, Chitosan, TiO₂ nanoparticles, Green synthesis, Textile dye degradation.

POST-PANDEMIC RETURN TO THE OFFICE DEBATES: MANAGERS INSIST, EMPLOYEES RESISTED

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ABSTRACT

Flexible working models began to become widespread in labor markets in the 1970s. The development of technological tools and the increasing digitalization following the Fourth Industrial Revolution were influential in the spread of these models. Furthermore, the economic crisis of the 1970s facilitated the widespread adoption of neoliberal policies in labor markets. One of the flexible working models that emerged during this period is the remote working model. The remote working model was implemented worldwide between 2019 and 2022 due to the challenging impact of the pandemic. During this period, both remote and hybrid work models became widespread in the labor market. Jobs suitable for remote and hybrid work were carried out using these models. With the implemented policies and vaccinations, the pandemic began to subside in early 2022. The extraordinary period in the labor market came to an end. Employees who had been working remotely and in hybrid roles during the pandemic began returning to offices. However, a complete return to offices has not occurred, particularly in the labor markets of developed countries. In line with both company policies and employee demands, a 12% remote work model and a 40% hybrid work model have become permanent in these markets. However, over time, especially in developed countries, companies and public institutions have begun to develop policies to end this type of work and have started to call their employees back to work in traditional office environments. While some companies are trying to convert remote work models to hybrid models, others are turning to calling their remote and hybrid employees back to the office five days a week. Companies and institutions have cited increased productivity, collaboration, and easier management as reasons for this. Employees who do not want to return to the office state that flexible working is beneficial for their work-life balance. They also indicate that flexible working increases organizational commitment and reduces costs for employers. Research shows that employees are willing to accept a 10% salary reduction rather than return to the office. Furthermore, they state that they will leave their jobs at the first opportunity if flexible working options are not provided. One reason why companies that implemented flexible working arrangements are insisting on returning to the office after many years is to be able to lay off workers at a lower cost. The US Federal government and international companies such as Amazon, Dell, Microsoft, IBM, Uber, Tesla, and TikTok are leading this process. Their statements resonate globally. This issue is crucial for understanding the transformation of labor markets. Why have companies abandoned flexible models after implementing them for so long? After working in traditional work models for years, employees are so attached to the flexible work models they have been using for about 5 years. In this period when artificial intelligence is being discussed in labor markets, seeking answers to these questions is important from a literature perspective.

Keywords: Hybrid Work, Labor Markets, Pandemic, Remote Work

PANDEMİ SONRASI OFİSE DÖNÜŞ TARTIŞMALARI: YÖNETİCİLER ISRAR EDİYOR, ÇALIŞANLAR DİRENİYOR

ÖZET

İşgücü piyasalarında esnek çalışma modelleri 1970'li yıllarda yaygınlaşmaya başlamıştır. Dördüncü sanayi devriminin etkisi ile teknolojik aletlerin gelişimi ve zamanla dijitalleşmenin yaygınlaşması bu modellerin yaygınlaşmasında etkili olmuştur. Ayrıca 1970'li yıllarda ortaya çıkan ekonomik kriz neoliberal politikaların işgücü piyasalarında yaygınlaşmasını sağlamıştır. Bu dönemde ortaya çıkan esnek çalışma modellerinden birisi de uzaktan çalışma modelidir. Uzaktan çalışma modeli 2019-2022 yıllarında pandeminin zorlayıcı etkisi ile tüm dünyada uygulamaya geçirilmiştir. Bu dönemde uzaktan çalışma modeli ile birlikte hibrit çalışma modeli de işgücü piyasalarında yaygınlaşmıştır. Bu dönemde uzaktan çalışmaya ve hibrit çalışmaya uygun işler bu modellerle gerçekleştirilmiştir. Uygulanan politikalar ve aşılama ile birlikte pandemi 2022 yılının başında sönümlenmeye başlamıştır. İşgücü piyasalarındaki olağanüstü dönem sona ermiştir. Pandemi döneminde

uzaktan ve hibrit çalışma yürüten çalışanlar ofislere dönmeye başlamışlardır. Fakat özellikle gelişmiş ülke işgücü piyasalarında tümüyle ofislere dönüş gerçekleşmemiştir. Hem şirketlerin politikaları hem de çalışanların talepleri doğrultusunda %12 uzaktan çalışma, %40 hibrit çalışma modeli bu piyasalarda kalıcı duruma gelmiştir. Fakat zamanla özellikle gelişmiş ülkelerde şirketler ve kamu kurumları bu tarz çalışmaları sonlandırmak için politikalar üretmeye başlamışlar ve çalışanlarını geleneksel ofis ortamlarında çalışmaya çağırmaya başlamışlardır. Kimi şirketler uzaktan çalışma modellerini hibrit modellere çevirmeye çalışırken kimileri uzaktan ve hibrit çalışanlarını haftanın beş günü ofislerine çağırmaya yönelmişlerdir. Şirketler ve kurumlar gerekçe olarak, verimliliğin artmasını, iş birliğini ve yönetimin kolaylaşmasını göstermişlerdir. Ofislere dönmek istemeyen çalışanlar esnek çalışmanın iş-yaşam dengeleri açısından yararlı olduğunu ifade etmektedirler. Esnek çalışmanın örgütsel bağlılığı arttırdığını ve işverenlere maliyetleri düşürdüğünü ifade etmektedirler. Yapılan araştırmalar çalışanların ofislere dönmek yerine ücretlerinde %10 gibi düşüşü kabul etmeye hazır olduklarını göstermektedir. Ayrıca esnek çalışma imkânı verilmez ise ilk fırsatta işlerinden ayrılacaklarını belirtmektedirler. Esnek çalışma yürüten şirketlerin yıllar sonra ofise dönüş ısrarlarının altında yatan bir neden de daha az maliyetle işçi çıkarmak olduğu da belirtilmektedir. Bu süreçte ABD Federal hükümeti, Amazon, Dell, Microsoft, IBM, UBER, Tesla, Tiktok gibi uluslararası firmalar öncülük etmektedirler. Bu firmaların açıklamaları tüm dünya da yankı uyandırmaktadır. Bu konu işgücü piyasalarındaki dönüşümü anlamak açısından önemlidir. Şirketler uzun süre esnek modelleri uygulayıp neden vazgeçmişlerdir. Çalışanlar yıllarca geleneksel çalışma modelinde çalıştıktan sonra yaklaşık 5 yıldır çalıştıkları esnek çalışma modellerine bu kadar sahip çıkmaktadırlar. İşgücü piyasalarında yapay zekanın tartışıldığı bu dönemde bu soruların cevaplarını aramak literatür açısından önem taşımaktadır.

Anahtar Kelimeler: Hibrit Çalışma, İşgücü Piyasaları, Pandemi, Uzaktan Çalışma

EXAMINING THE RELATIONSHIP BETWEEN NATIONAL INVESTMENTS IN ARTIFICIAL INTELLIGENCE AND HEALTH EXPENDITURES

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ABSTRACT

AI agents, defined as digital workers, are transforming organizational processes and decision-making mechanisms. Healthcare systems, where human interaction is central, are directly affected by this shift. However, empirical evidence on the impact of rising AI investments on health expenditures remains limited. Whether AI reduces long-term costs is still uncertain, making it a critical policy issue. This study aims to examine the relationship between countries' AI investments and healthcare expenditures. Using 2024 data from ten countries, the relationships between per capita AI investment, the ratio of AI investments to GDP, and the ratio of healthcare expenditures to GDP are analyzed. The findings show significant differences between countries in terms of per capita AI investment. The United States has the highest per capita investment level, at approximately \$316, while Israel (\$140), Canada (\$72), and the United Kingdom (\$67) are at relatively high levels. In contrast, India and China have lower per capita investment intensity. A similar distribution is observed in the ratio of AI investment to GDP. In terms of the ratio of health expenditures to GDP, the United States (16.7%), Germany (15.5%), and Canada (14.0%) stand out. Correlation analysis reveals a very strong positive association ($r = 0.98$) between per capita AI investment and the ratio of AI to GDP. More importantly, a moderate positive correlation ($r = 0.57$) was found between per capita AI investment and the ratio of health expenditures to GDP. Similarly, there is a positive relationship ($r = 0.51$) between the ratio of AI investments to GDP and the ratio of health expenditures to GDP. The findings show that countries with high AI intensity also have high health expenditures as a percentage of national income. In conclusion, the current data do not provide evidence that AI investments have a short-term negative impact on health expenditures; rather, they suggest that these investments may be a complementary element supporting existing health standards in developed economies.

Keywords: Artificial Intelligence Investments, Health Expenditures, Digital Transformation.

ÜLKELERİN YAPAY ZEKÂ YATIRIMLARI İLE SAĞLIK HARCAMALARI ARASINDAKİ İLİŞKİNİN İNCELENMESİ

ÖZET

Yapay zekâ (YZ) ajanları, organizasyonların iş süreçlerini ve karar alma mekanizmalarını dönüştürmektedir. İnsan etkileşiminin merkezi olduğu sağlık sistemleri bu değişimden doğrudan etkilenmektedir. Ancak artan YZ yatırımlarının sağlık harcamalarına etkisine dair ampirik kanıtlar sınırlıdır. YZ'nin uzun vadede maliyetleri azaltıp azaltmadığı belirsizdir; bu durum politika tartışmalarını önemli kılmaktadır. Bu çalışma, ülkelerin yapay zekâ yatırımları ile sağlık harcamaları arasındaki ilişkiyi incelemeyi amaçlamaktadır. On ülkenin 2024 yılına ait verileri kullanılarak kişi başına YZ yatırımı, YZ yatırımlarının GSYH'ye oranı ve sağlık harcamalarının GSYH'ye oranı arasındaki ilişkiler analiz edilmiştir. Bulgular, kişi başına YZ yatırımı bakımından ülkeler arasında belirgin farklılıklar olduğunu göstermektedir. ABD yaklaşık 316 USD ile en yüksek kişi başı yatırım düzeyine sahipken, İsrail (140 USD), Kanada (72 USD) ve Birleşik Krallık (67 USD) görece yüksek seviyelerde yer almaktadır. Buna karşılık Hindistan ve Çin daha düşük kişi başı yatırım yoğunluğuna sahiptir. Benzer bir dağılım YZ yatırımlarının GSYH'ye oranında da gözlenmektedir. Sağlık harcamalarının GSYH'ye oranında ise ABD (%16,7), Almanya (%15,5) ve Kanada (%14,0) öne çıkmaktadır.

Korelasyon analizleri, kişi başına YZ yatırımı ile YZ'nin GSYH'ye oranı arasında çok yüksek düzeyde pozitif ilişki ($r = 0,98$) bulunduğunu ortaya koymaktadır. Daha önemlisi, kişi başına YZ yatırımı ile sağlık harcamalarının GSYH'ye oranı arasında orta düzeyde pozitif ilişki ($r = 0,57$) tespit edilmiştir. Benzer şekilde, YZ yatırımlarının GSYH'ye oranı ile sağlık harcamalarının GSYH'ye oranı arasında da pozitif bir ilişki ($r = 0,51$) bulunmaktadır. Bulgular, YZ yoğunluğu yüksek ülkelerin aynı zamanda sağlık harcamalarının milli gelir içindeki payının da yüksek olduğunu göstermektedir. Sonuç olarak, mevcut veriler YZ yatırımlarının kısa vadede sağlık harcamalarını azaltıcı bir etkisine dair kanıt sunmamaktadır; aksine bu yatırımların gelişmiş ekonomilerde mevcut sağlık standartlarını destekleyen tamamlayıcı bir unsur olabileceğine işaret etmektedir.

Anahtar Kelimeler: Yapay Zekâ Yatırımları, Sağlık Harcamaları, Dijital Dönüşüm.

A RELATIONAL SOCIOLOGICAL ANALYSIS OF RETIREMENT POVERTY IN TURKEY

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ABSTRACT

The aim of this paper is to discuss the transformation of contemporary democracies, focusing on the deeply experienced "Retirement Poverty" in Turkey, drawing on Achille Mbembe's work **Necropolitics**. Mbembe defines sovereignty not merely as a form of power regulating life, but as a "politics of death" operating through the authority to decide who lives and who dies. Within this framework, democracy is analyzed using the metaphor of the "night body" due to its historical connection with violence. Today, increasing inequalities and authoritarian-populist politics are paving the way for the erosion of liberal democratic values. The paper also examines how political power is legitimized through religious discourses, using the concepts of patience and gratitude. Carl Schmitt's linking of sovereignty to the power to declare a state of emergency in his work **Political Theology**, and Giorgio Agamben's conceptualization of "bare life" within the context of **Homo Sacer**, make visible the metaphysical foundations of modern power. In this context, there is a strong relationship between necropolitics and theopolitics. Indeed, the rule of those who condemn people to wages far below the poverty line is often normalized through discourses of sacred mission, fate, or national survival. The method of this study is critical discourse analysis. By examining the speeches of trade unionists, retirees, and political leaders, as well as policy documents and media texts, the linguistic strategies used to legitimize violence and exclusion will be analyzed. Thus, the processes of contemporary societies moving away from democracy will be revealed at the discourse level in a relational sociological manner from a critical perspective.

Keywords: Relational Sociology, necropolitics, theopolitics, critical discourse analysis, Turkiye.

**MANAGEMENT OF GINGIVAL RECESSIOIN DUE TO OVER AGGRESSIVE BRUSHING WITH
SUBEPITHELIAL CONNECTIVE TISSUE GRAFTS: A CASE REPORT**

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ABSTRACT

Background and aim: Traumatic gingival lesions can occur due to iatrogenic, accidental, and factitious traumas. They are physical, chemical, or thermal in nature, are among the most common in the mouth. Toothbrushing is an oral hygiene practice that has successfully maintained oral health. However, brushing can also be detrimental for the individual if not performed correctly. Previous studies have reported that brushing overaggressive and incorrectly for short periods can cause either cervical abrasions or gingival recession, eventually leading to dentinal hypersensitivity. This situation causes patients to experience excessive discomfort, distress, and pain, making it difficult to maintain oral hygiene. The purpose of this case report was to illustrate the destructive nature of the incorrect brushing and to describe the successful treatment of this case. **Case Report/Methods:** A 36-year-old male with pain, discomfort, sensitivity and recession in the maxillary region was admitted to periodontology clinic. Upon questioning, the patient admitted to brushing over aggressive and incorrectly for short periods. Proper brushing technique and duration were taught to maintain oral hygiene and prevent soft tissue damage. Treatment consisted of oral hygiene instruction, mechanical debridement, and surgical periodontal treatment. **Results:** Postoperatively, complete root coverage, gains in clinical attachment levels, and highly significant increases in the width of keratinized gingiva were observed. **Conclusions:** This case report shows that it is possible to treat gingival recession and maintain the periodontal health of a patient with brushing overaggressive. Brushing as a routine oral hygiene measure depends on correct execution for good oral health. Dentists can recommend products and techniques specific to an individual's condition and dexterity, promoting the most suitable oral hygiene routine for them.

Keywords: toothbrush, brushing technique, brushing force, cervical abrasion, gingival recession, dentinal hypersensitivity, subepithelial connective tissue grafts, root coverage

THE RELATIONSHIP BETWEEN SALIVARY ALPHA-DEFENSIN (HNP 1-3) LEVELS AND DENTAL CARIES

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ABSTRACT

Objective: Oral and dental health is not only a local issue but is also associated with systemic health. Dental caries, in particular, are among the most common oral diseases in the population and interact with the oral immune response. This study aimed to investigate the relationship between salivary levels of Human Neutrophil Peptides 1-3 (HNP 1-3), an antimicrobial peptide involved in infection and inflammation, and dental caries using ICDAS and DMFT scores. **Materials and Methods:** A total of 87 individuals aged 18-65 years without chronic diseases were included in the study. Dental caries were assessed using the ICDAS system, and dental status was evaluated using the DMFT index. Saliva samples were collected in the morning from individuals who had not consumed any food for at least one hour, using cotton pellets, then centrifuged and stored at -80°C. HNP 1-3 levels were measured by ELISA. Data were analyzed using STATISTICA 13.5; normality was assessed with the Shapiro-Wilk test, and intergroup differences were evaluated using the Mann-Whitney U test or Kruskal-Wallis test. **Results:** The study included 43 males (49.4%) and 44 females (50.6%). HNP 1-3 levels were slightly higher in males than in females; however, the difference was not statistically significant ($p=0.329$). Although some differences in ranking were observed among ICDAS and DMFT score groups, these were not statistically significant (ICDAS: males $p=0.976$, females $p=0.083$; DMFT: total $p=0.240$, females $p=0.124$, males $p=0.921$). No significant difference was found in comparisons between gender and DMFT scores. **Conclusion:** HNP 1-3 levels did not show a significant difference according to gender or dental caries status. Further studies with larger sample sizes and additional biomarkers are recommended.

Keywords: Dental caries, HNP 1-3, ELISA.

AĞIZ İÇİ TÜKÜRÜKTE ALFA-DEFENSİN (HNP 1-3) DÜZEYİNİN DİŞ ÇÜRÜĞÜ İLE İLİŞKİSİ

ÖZET

Amaç: Ağız ve diş sağlığı yalnızca lokal bir sorun olmayıp sistemik sağlıkla da ilişkilidir. Özellikle diş çürükleri, toplumda en yaygın diş hastalıklarındandır ve ağız içi immün yanıt ile etkileşim içerisindedir. Tükürükte bulunan ve enfeksiyon ile inflamasyonda rol oynayan antimikrobiyal bir peptid olan Human Neutrophil Peptides 1-3 (HNP 1-3) düzeylerinin, diş çürükleri ile ilişkisi ICDAS ve DMFT skorları kullanılarak araştırılması amaçlandı. **Gereç ve yöntem:** Çalışmaya 18-65 yaş arası, kronik hastalığı olmayan 87 birey dahil edildi. Diş çürükleri ICDAS, diş durumu DMFT sistemiyle değerlendirildi. Tükürük örnekleri sabah saatlerinde, son bir saat gıda alımı olmayan bireylerden pamuk peletler ile toplandı, santrifüj edilip -80°C’de saklandı. HNP1-3 düzeyleri ELISA yöntemi ile ölçüldü. Veriler STATISTICA 13.5 ile analiz edildi; normallik Shapiro-Wilk testi ile kontrol edildi, gruplar arası farklar Mann-Whitney U veya Kruskal-Wallis

testi ile değerlendirildi. **Bulgular:** Çalışmaya 43 erkek (%49,4) ve 44 kadın (%50,6) birey dahil edilmiştir. HNP1-3 düzeyleri erkeklerde kadınlara göre biraz yüksek bulundu, ancak fark anlamlı olarak saptanmadı ($p=0,329$). ICDAS ve DMFT skor gruplarında da bazı sıralama farklılıkları saptansa da istatistiksel olarak anlamlı bulunmadı (ICDAS: erkek $p=0,976$, kadın $p=0,083$; DMFT: toplam $p=0,240$, kadın $p=0,124$, erkek $p=0,921$). Cinsiyet ve DMFT karşılaştırmalarında da anlamlı fark saptanmadı. **Sonuçlar:** HNP1-3 düzeyleri cinsiyet ve diş çürüğü durumuna göre anlamlı farklılık göstermedi, ileri çalışmalarda daha büyük örneklem ve farklı biyobelirteçler ile ilişkiler araştırılabilir.

Anahtar kelimeler: Diş çürüğü, HNP 1-3, ELISA

INVESTIGATION OF GALECTIN-1, GALECTIN-3, AND GALECTIN-9 LEVELS IN PATIENTS WITH BLADDER CANCER

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ABSTRACT

Objective: Bladder cancer is one of the most common malignancies of the urinary system and constitutes a significant health problem due to its high recurrence rate, heterogeneous clinical course, and variable prognosis. Tumor development and progression are closely associated with complex biological processes such as cell proliferation, apoptosis, adhesion, and immune response. Among the biomolecules involved in these processes, Galectin-1 (Gal-1), Galectin-3 (Gal-3), and Galectin-9 (Gal-9) have increasingly important regulatory roles in cancer biology. This study aimed to determine the serum levels of these galectins in patients with bladder cancer and to investigate their potential diagnostic and prognostic value. **Materials and Methods:** The study included 26 patients diagnosed with bladder cancer and 26 individuals without any systemic disease. Serum samples collected in biochemistry tubes from all participants were analyzed for Gal-1, Gal-3, and Gal-9 protein levels using the ELISA method with the DSX™ Four-Plate Automated ELISA Processing System microplate reader. **Results:** Comparison of serum levels of Gal-1, Gal-3, and Gal-9 between the patient and control groups showed the following: The median Gal-1 values were 11.92 ng/ml in the patient group and 13.65 ng/ml in the control group, with no statistically significant difference ($p = 0.241$). Median Gal-3 values were 627.15 pg/ml in patients and 494.83 pg/ml in controls; levels were higher in the patient group and the difference was statistically significant ($p = 0.001$). For Gal-9, median values were 498.02 pg/ml in patients and 504.16 pg/ml in controls, with no significant difference between the groups ($p = 0.784$). **Conclusion:** The findings suggest that Gal-3 may serve as a potential biomarker for diagnosis or prognosis in bladder cancer, whereas Gal-1 and Gal-9 do not appear to be suitable for these purposes on their own.

Keywords: Bladder cancer, Galectin family, ELISA.

MESANE KANSERİ HASTALARINDA GALEKTİN-1, GALEKTİN-3 VE GALEKTİN-9 DÜZEYLERİNİN İNCELENMESİ

ÖZET

Amaç: Mesane kanseri, üriner sistemin en sık görülen malignitelerinden biri olup, yüksek nüks oranı, heterojen klinik seyri ve değişken prognozu nedeniyle önemli bir sağlık sorunu teşkil etmektedir. Tümör gelişimi ve progresyonu; hücre proliferasyonu, apoptoz, adezyon ve immün yanıt gibi karmaşık biyolojik süreçlerle yakından ilişkilidir. Bu süreçlerde görev alan biyomoleküller arasında yer alan galektin-1(Gal-1), galektin-3(Gal-3) ve galektin-9(Gal-9)'un kanser biyolojisindeki düzenleyici etkileri giderek artan bir öneme sahiptir. Bu çalışmada, mesane kanseri hastalarında söz konusu galektinlerin serum düzeylerinin belirlenmesi ve tanısal ile prognostik değerlerinin araştırılması amaçlandı. **Gereç ve yöntem:** Çalışmaya, 26 mesane

kanseri tanısı alan ve 26 herhangi bir sistemik hastalığın tanısı olmayan birey dahil edildi. Çalışmaya katılan bireylerden biyokimya tüplere alınan serum örneklerinden Gal-1, Gal-3 ve Gal-9 protein düzeyleri ELISA yöntemiyle DSXTM Four-Plate Automated ELISA processing system mikroELISA cihaz ile belirlendi.

Bulgular: Hasta ve kontrol gruplarında GAL-1, GAL-3 ve GAL-9 serum düzeyleri karşılaştırıldığında; GAL-1 için medyan değerler hasta grubunda 11.92 ng/ml, kontrol grubunda 13.65 ng/ml olup iki grup arasında istatistiksel olarak anlamlı fark bulunmadı ($p = 0.241$). GAL-3 medyan değerleri hasta grubunda 627.15 pg/ml, kontrol grubunda 494.83 pg/ml olarak ölçüldü; hasta grubunda değerler yüksek seyretti ve fark istatistiksel olarak anlamlı bulunmadı ($p = 0.001$). GAL-9 için medyan değerler hasta grubunda 498.02 pg/ml, kontrol grubunda 504.16 pg/ml olup, iki grup arasında anlamlı fark saptanmadı ($p = 0.784$) **Sonuçlar:** Elde edilen veriler, GAL-3'ün mesane kanserinde tanı veya prognoz belirleyici olarak potansiyel bir biyobelirteç olabileceğini göstermektedir; buna karşın GAL-1 ve GAL-9, tek başına bu amaç için uygun görünmemektedir.

Anahtar kelimeler: Mesane kanseri, Galektin ailesi, ELİSA

CHARACTERIZATION OF GLASS FIBER REINFORCED CHEMICALLY AND MECHANICALLY RECYCLED PA66 COMPOSITES

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ABSTRACT

With the reduction of the environmental impacts of plastic waste and the widespread adoption of sustainable production policies, recycling processes of engineering plastics has become an important research topic. In Polyamide 6,6 (PA66), which is widely used in many industrial applications, especially in the automotive sector, due to its high mechanical strength and thermal stability, investigating the effect of recycling methods on the final performance is of great importance. Although mechanical recycling is widely used, material properties may deteriorate due to chain scission and thermal aging during repeated processing cycles. In contrast, chemical recycling enables the polymer to be separated down to the monomer level, allowing the production of purer raw materials close to prime quality and providing a more stable performance. In this context, evaluating the physical and mechanical properties of chemically recycled PA66 will contribute to the development of sustainable and high-performance materials. This study aimed to make PA66, obtained through different recycling methods, suitable for industrial applications by reinforcing it with 35% glass fiber, a material frequently preferred in the automotive industry. Thanks to glass fiber reinforcement, it was aimed to increase critical mechanical properties such as tensile strength, impact strength, and thermal stability. Thus, it is planned to both reduce environmental impacts and develop high value-added recycled PA66 composites. This study aimed to determine the performance differences between chemically recycled PA66 composite, mechanically recycled PA66 composite, and primary grade composite. In this context, different formulations were tested, including 100% pure PA66, 100% mechanically recycled PA66, 100% chemically recycled PA66, a 50% pure–50% chemically recycled blend. The performance of the composite materials developed within the scope of the project was evaluated through mechanical tests according to ISO 527 (tensile), ISO 178 (flexural), and ISO 180 (impact) standards. As a result, it was demonstrated that chemically recycled PA66 can be converted into high-performance composite structures with glass fiber reinforcement. In addition, chemically recycled PA66 exhibited superior performance compared to mechanically recycled PA66 and was observed to provide properties very close to prime-grade material.

Keywords: Polyamide 66, Chemical recycling, Glass fiber, Mechanical strength

CAM ELYAF TAKVİYELİ KİMYASAL VE MEKANİK GERİ DÖNÜŞTÜRÜLMÜŞ PA66 KOMPOZİTLERİN KARAKTERİZASYONU

ÖZET

Plastik atıkların çevresel etkilerinin azaltılması ve sürdürülebilir üretim politikalarının yaygınlaşmasıyla birlikte, mühendislik plastiklerinin geri dönüşüm süreçleri önemli bir araştırma konusu haline gelmiştir. Yüksek mekanik dayanımı ve sıcaklık stabilitesi sayesinde otomotiv başta olmak üzere birçok endüstriyel uygulamada yaygın olarak kullanılan Poliamid 6,6 (PA66) malzemesinde, geri dönüşüm yöntemlerinin nihai performansa etkisinin araştırılması büyük önem taşımaktadır. Mekanik geri dönüşüm yöntemi yaygın olarak kullanılmakla birlikte, tekrarlı işlem döngülerinde zincir kırılması ve termal yaşlanma gibi nedenlerle malzeme özelliklerinde düşüş meydana gelebilmektedir. Buna karşılık kimyasal geri dönüşüm yöntemi, polimeri monomer seviyesine kadar ayrıştırarak daha saf ve primer kaliteye yakın hammaddelerin elde edilmesine olanak tanımakta ve daha kararlı bir performans sunmaktadır. Bu bağlamda, kimyasal geri dönüşüm ile elde edilen PA66'nın fiziksel ve mekanik özelliklerinin değerlendirilmesi, sürdürülebilir ve yüksek performanslı malzeme geliştirme çalışmalarına katkı sağlayacaktır. Bu çalışmada farklı geri dönüşüm yöntemleri ile elde edilen PA66'nın otomotivde sıklıkla tercih edilen %35 cam elyaf takviyesi ile endüstriyel uygulamalara uygun hale getirilmesi hedeflenmiştir. Cam elyaf takviyesi sayesinde çekme dayanımı, darbe dayanımı ve termal stabilite gibi kritik mekanik özelliklerin artırılması amaçlanmıştır. Böylece hem çevresel etkilerin azaltılması hem de yüksek katma değerli geri dönüştürülmüş PA66 kompozitleri geliştirilmiştir. Çalışmada kimyasal geri dönüşümle elde edilen PA66 kompozit, mekanik geri dönüşüm kaynaklı PA66 kompozit ve birinci kalite

kompozit arasındaki performans farklarının ortaya konması hedeflenmiştir. Bu kapsamda; %100 saf PA66, %100 mekanik geri dönüştürülmüş PA66, %100 kimyasal geri dönüştürülmüş PA66, %50 saf – %50 kimyasal geri dönüştürülmüş karışımlar olmak üzere farklı formülasyonlar denenmiştir. Çalışmada geliştirilen kompozit malzemelerin performansı, ISO 527 (çekme), ISO 178 (eğilme) ve ISO 180 (darbe) standartlarına göre mekanik testlerle değerlendirilmiştir. Sonuç olarak, kimyasal geri dönüşümle elde edilen PA66'nın cam elyaf takviyesiyle yüksek performanslı kompozit yapılara dönüştürülebileceği gösterilmiştir. Ayrıca kimyasal geri dönüştürülmüş PA66, mekanik geri dönüştürülmüş PA66 ile kıyaslandığında daha üstün performans sergilemiş ve primer kaliteye oldukça yakın özellikler sunduğu gözlenmiştir.

Anahtar kelimeler: Poliamid 66, Kimyasal geri dönüşüm, Cam elyaf, Mekanik dayanım

MECHANICAL AND CORROSION PROPERTIES OF AL-DP SHEETS IN RESISTANCE SPOT WELDING APPLICATIONS

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ABSTRACT

In this study, the joining of aluminum (Al) and dual-phase (DP) steel sheets, which are widely used in the automotive industry, by resistance spot welding at different current levels (7, 8, 9, 10, 11, and 12 kA) and the effects of the welded joints on mechanical and corrosion properties were investigated in detail. In this context, tensile-shear tests were performed on the samples produced under different welding parameters, and the current levels of 11 and 12 kA, which provided the highest tensile strength, were identified. Corrosion tests were carried out on the samples produced at these current levels in accordance with the ASTM G31 standard using 3.5% NaCl and 3.5% CaCl₂ solutions for durations of 3, 7, 14, and 21 days. The results showed that increasing welding current led to an increase in nugget diameter and joint strength. The nugget diameter increased from an average of 5.45 mm at 7 kA to approximately 6.92 mm at 11–12 kA, where the increase became limited. However, at higher current levels, expulsion formation and a corresponding decrease in mechanical properties were observed. Corrosion test results indicated that weight loss increased over time in both environments, while the rate of increase decreased. Additionally, higher weight loss values were obtained in the NaCl environment compared to the CaCl₂ environment. As a result, it was concluded that selecting an appropriate welding current enables the optimization of both mechanical performance and corrosion resistance in the resistance spot welding of dissimilar materials.

Keywords: Resistance Spot Welding, Welding Current, Nugget Diameter, Corrosion

NOKTA DİRENÇ KAYNAĞI UYGULAMALARINDA AL-DP SACLARININ MEKANİK VE KOROZYON ÖZELLİKLERİ

ÖZET

Bu çalışmada, otomotiv endüstrisinde yaygın olarak kullanılan alüminyum (Al) ve çift fazlı (DP) çelik sacların direnç nokta kaynağı ile farklı akım şiddetlerinde (7, 8, 9, 10, 11 ve 12 kA) birleştirilmesi ve kaynaklı bağlantının mekanik ve korozyon özellikleri üzerindeki etkileri incelenmiştir. Bu kapsamda, farklı kaynak parametrelerinde üretilen numuneler üzerinde çekme testleri gerçekleştirilmiş ve en yüksek çekme dayanımı 11 ve 12 kA akım seviyelerinde elde edilmiştir. Bu akım değerlerinde üretilen numuneler üzerinde, ASTM G31 standardına uygun olarak %3,5 NaCl ve %3,5 CaCl₂ çözeltilerinde 3, 7, 14 ve 21 gün süreyle korozyon deneyleri uygulanmıştır. Elde edilen sonuçlar, akım şiddetinin artmasıyla nugget çapı ve bağlantı dayanımının arttığını göstermiştir. Nugget çapı değerleri 7 kA’da ortalama 5,45 mm iken, 11–12 kA seviyelerinde yaklaşık 6,92 mm’ye ulaşmış ve bu bölgede artışın sınırlı kaldığı belirlenmiştir. Bununla birlikte, yüksek akım değerlerinde sıçrama oluşumu ve buna bağlı olarak mekanik özelliklerde düşüş meydana geldiği gözlemlenmiştir. Korozyon test sonuçları, her iki ortamda da ağırlık kaybının zamanla arttığını ancak artış hızının azaldığını göstermiştir. Ayrıca, NaCl ortamında elde edilen ağırlık kayıplarının CaCl₂ ortamına kıyasla daha yüksek olduğu belirlenmiştir. Sonuç olarak, uygun kaynak akımının seçimi ile farklı malzemelerin direnç

nokta kaynağında hem mekanik performans hem de korozyon direnci açısından optimum sonuçlar elde edilebileceği görülmüştür.

Anahtar Kelimeler: Direnç Nokta Kaynağı, Kaynak Akımı, Nugget Çapı, Korozyon

MORPHOLOGICAL TRANSFORMATION OF HISTORICAL MOTIFS: A RESEARCH-BASED DESIGN ATTEMPT THROUGH THE ISTANBUL ARCHAEOLOGICAL MUSEUM AND TOPKAPI PALACE

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ABSTRACT

The selected repertoire of ornamentation and symbols found in two of Istanbul's most significant cultural heritage sites, Topkapı Palace and the Istanbul Archaeology Museums, is reinterpreted in this study through a "morphological transformation" approach to produce contemporary architectural elements. The research is grounded in the assumption that historical motifs can be addressed not merely as surface decoration, but as active design inputs capable of structuring composition, determining proportions, and guiding typological production. In this context, the study analyzes the structural and formal logic of ornamentation and questions how historical references can be re-signified within contemporary architectural practice. The methodology is structured as a research-based design process consisting of: visual data collection through on-site photographic documentation; geometric analysis and decomposition of selected motifs via two-dimensional analytical drawings; formal abstraction and reconfiguration through three-dimensional modeling; and finally, the production of a prototype as an architectural component through digital rendering. Throughout this process, the proportional systems, symmetry axes, repetition patterns, and hierarchical compositional principles of the motifs were analytically examined. The resulting data were then integrated into the compositional framework of a contemporary window typology. The findings demonstrate that the selected motifs can generate a new "design syntax" grounded in structural principles such as repetition, symmetry, axial order, and hierarchical ornamental schemes. The developed prototype is interpreted as a holistic architectural element in which historical ornamental components are integrated through proportion-frame-void/solid relationships and actively inform the façade composition. Rather than replicating historical motifs literally, the proposed approach aims to preserve their underlying geometric logic and transform it into a contemporary architectural language. Ultimately, the study argues that the cultural heritage repertoire can be reconsidered as a reproducible and transformable resource for contemporary design, and that a morphology-based analytical method establishes a theoretically and practically coherent interface between historical reference and current architectural expression.

Keywords: Morphological transformation, Historical motif, Research-based design, Cultural heritage, Facade design

TARİHSEL MOTİFLERİN MORFOLOJİK DÖNÜŞÜMÜ: İSTANBUL ARKEOLOJİ MÜZESİ VE TOPKAPI SARAYI ÜZERİNDEN ARAŞTIRMA-TEMELLİ BİR TASARIM DENEMESİ

ÖZET

İstanbul'un iki güçlü kültürel miras odağı olan Topkapı Sarayı ve İstanbul Arkeoloji Müzesi'nde yer alan seçili bezeme ve sembol repertuarı, bu çalışmada çağdaş mimari eleman üretimi için "morfolojik dönüşüm" yaklaşımıyla yeniden okunmuştur. Araştırma, tarihsel motiflerin yalnızca yüzey süslemesi olarak değil; kompozisyon kurucu, oran belirleyici ve tipolojik üretime yön veren etkin bir tasarım girdisi olarak ele alınabileceği varsayımına dayanmaktadır. Bu bağlamda çalışma, bezemenin yapısal ve biçimsel mantığını çözümleyerek, tarihsel referansların çağdaş mimari üretimde nasıl yeniden anlamlandırılabilceğini sorgulamaktadır. Yöntem, alan araştırmasına dayalı görsel veri toplama (yerinde fotoğrafik belgeleme), seçili motiflerin geometrik çözümlemesi ve ayrıştırılması (iki boyutlu analitik çizimler), biçimsel soyutlama ve

yeniden kurgulama (üç boyutlu modelleme) ve nihayetinde mimari bir bileşen olarak prototip üretimi (dijital render) adımlarından oluşan araştırma-temelli tasarım hattı üzerinden kurgulanmıştır. Bu süreçte motiflerin oran sistemleri, simetri eksenleri, tekrar düzenleri ve hiyerarşik yerleşim ilkeleri analitik olarak incelenmiş; elde edilen veriler çağdaş bir pencere tipolojisinin kompozisyonel kurgusuna entegre edilmiştir. Çalışmanın bulguları, seçili motiflerin tekrar, simetri, aksiyal düzen ve hiyerarşik bezeme şemaları gibi yapısal ilkeler üzerinden yeni bir “tasarım söz dizimi” üretebildiğini göstermektedir. Geliştirilen prototip, tarihsel bezeme öğelerinin oran-çerçeve-boşluk/doluluk ilişkileriyle bütünleştiği ve cephe kompozisyonunu yönlendiren bütüncül bir mimari eleman olarak okunmaktadır. Önerilen yaklaşım, motifin literal kopyalanması yerine geometrik mantığının korunarak çağdaş bir eleman diline dönüştürülmesini hedeflemektedir. Sonuç olarak çalışma, kültürel miras repertuarının çağdaş tasarımda yeniden üretilebilir ve dönüştürülebilir bir kaynak olarak değerlendirilebileceğini; morfolojik dönüşüm temelli analitik bir yöntemin tarihsel referans ile güncel mimari ifade arasında kuramsal ve pratik düzlemde tutarlı bir arayüz kurduğunu ortaya koymaktadır.

Anahtar Kelimeler: Morfolojik dönüşüm, Tarihsel motif, Araştırma temelli tasarım, Kültürel miras, Cephe tasarımı

**POST-EARTHQUAKE URBAN DAMAGE DETECTION USING THE NORMALIZED
DIFFERENCE BUILT-UP INDEX (NDBI) AND SENTINEL-2 IMAGERY: THE CASE OF
İSKENDERUN, TÜRKİYE**

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ABSTRACT

The February 6, 2023, Kahramanmaraş earthquakes caused extensive physical destruction and spatial disruption across many cities in southeastern Türkiye. Rapid identification of damaged urban areas is critical for effective disaster response, recovery planning, and resilient urban development. Advances in satellite remote sensing and cloud-based geospatial analysis platforms enable rapid, large-scale assessment of disaster impacts. This study aims to detect earthquake-induced urban damage using Sentinel-2 satellite imagery and the Normalized Difference Built-up Index (NDBI) within the Google Earth Engine (GEE) platform. The analysis focuses on the central urban area of İskenderun, Hatay, one of the cities significantly affected by the earthquakes. Pre-earthquake (January 2023) and post-earthquake (February–March 2023) Sentinel-2 images were processed to calculate the NDBI and identify changes in built-up surfaces through a change detection approach. To reduce misclassification and exclude non-urban surfaces, ESA WorldCover land-cover data were used to mask non-built-up areas, and morphological filtering was applied to improve the spatial consistency of detected damage patterns. The results indicate that 36,697 damaged urban pixels were detected within the study area, corresponding to approximately 3,67 km² of damaged urban surface at a spatial resolution of 10 m. To estimate the number of potentially affected structures, building footprint data derived from OpenStreetMap were analyzed, and the median building footprint in the study area was estimated at approximately 170 m². Based on this assumption, the detected damaged urban surface corresponds to approximately 21,586 potentially damaged buildings. The findings demonstrate that satellite-based change detection methods integrated with cloud-based geospatial platforms provide a rapid and scalable approach for post-earthquake damage assessment and offer valuable spatial information for disaster management and urban recovery planning.

Keywords: Earthquake Damage Assessment, Sentinel-2 Imagery, Normalized Difference Built-up Index (NDBI), Google Earth Engine, Remote Sensing.

**NEOLIBERAL GOVERNANCE AND THE LIMITS OF AI INTEGRATION IN ISTANBUL'S
MULTIMODAL TRANSPORT SYSTEM**

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ABSTRACT

Sustainable urban mobility is a central problematic in contemporary urban governance, particularly in megacities where rapid urbanization intensifies socio-spatial tensions. Within this framework, Artificial Intelligence (AI) is conceptualized as a transformative tool for optimization. However, these technological interventions cannot be assessed in isolation from neoliberal urbanization, which reconfigures local governance capacities and decision-making structures. This paper argues that the selective AI integration in Istanbul's transport system is not merely a result of technological limitations. Rather, it reflects the structural characteristics of neoliberal urban governance, marked by fragmented institutional arrangements, project-based planning, and reactive practices. In this context, digital technologies function less as transformative instruments and more as mechanisms that reproduce existing governance patterns and socio-spatial hierarchies. B Focusing on Istanbul as a multimodal megacity, this study examines the extent to which AI coordinates road, maritime, and rail networks. Employing a qualitative case study and critical policy analysis, the research evaluates the Istanbul Metropolitan Municipality Strategic Plan and Open Data Portal datasets across three dimensions: data maturity, multimodal integration, and operational autonomy. Findings indicate that while Istanbul has achieved significant digitalization in data collection, AI applications remain confined to passive, descriptive, and revenue-oriented functions. Core operational decisions rely on static processes, contributing to the underutilization of sustainable modes like maritime services. The paper concludes that the primary barrier to transformation is the prevailing neoliberal governance model, which privileges isolated prestige projects over strategic integration. By examining this structural tension, the study contributes to debates on the intersection of governance, technology, and urban sustainability.

Keywords: Neoliberal Urbanism, AI Integration, Istanbul, Urban Mobility, Policy-Practice Gap.

SOCIAL EQUITY AND MOBILITY IN PROXIMITY-BASED URBANISM: A BIBLIOMETRIC ANALYSIS AND CRITICAL PERSPECTIVE OF THE "15-MINUTE CITY" LITERATURE

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ABSTRACT

The global climate crisis, the COVID-19 pandemic and rising urban inequalities have prompted a radical re-evaluation of traditional planning models. In this context, the "15-Minute City" (15mC) model—which envisions essential services being accessible within a 15-minute walk or bike ride—has become a key strategy for sustainable urbanization. However, despite its success in pioneering implementations such as Paris, heated debates have emerged in the literature regarding social equity, accessibility fairness, and potential gentrification effects. This study aims to examine the academic body of knowledge surrounding the 15mC concept through a systematic bibliometric analysis. The analysis, conducted using an extensive dataset retrieved from [Web of Science/Scopus] databases, identifies the most influential publications, institutional collaborations, and conceptual networks. Network analyses performed via VOSviewer and Bibliometrix demonstrate that while the literature initially focused on technical themes like "active transport" and "emission reduction," it has recently evolved toward critical concepts such as "social inclusion," "spatial justice," and "housing affordability." The findings suggest that the 15mC model should be treated not merely as a transportation strategy but as a social policy tool aimed at improving access to urban amenities for disadvantaged groups. Furthermore, in light of data from past implementations, warnings in the literature regarding the risk of the model triggering spatial segregation are categorized. This research provides a comprehensive theoretical roadmap for urban planners and policymakers to ensure that 15-minute city applications are grounded in a socially more just and inclusive framework.

Keywords: 15-Minute City, Social Equity, Urban Mobility, Spatial Justice, Bibliometric Analysis, Gentrification.

THE IDEOLOGY OF ENGLISH SUPERIORITY AND ITS ROLE IN CONTEMPORARY LINGUISTIC EXPLOITATION

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ABSTRACT

The English language has gained an unmatched global power over other languages. Its cultural dominance and economic control emerged using mechanisms such as media and education policies. English acts not only as a medium of communication but also shapes international narratives and reinforces social classes. This paper uses theories such as linguistic imperialism and critical applied linguistics to demonstrate how English sustains its dominance by being depicted as neutral, useful, and modern. Even though speaking English offers advantageous offers, it additionally reinforces linguistic hierarchies. This leaves non-native speakers feeling outcast in social settings. At the same time, it privileges native speakers and excludes educated non-native speakers in job-related contexts, regardless of the alternative languages and knowledge systems they bring. The analysis addresses the impact of ideological constructs on linguistic self-esteem, academic engagement, and the continuum of inequality through standard-language policies. The pricing of language tests strengthens the financial structures by benefiting the British economy and linking their exams (IELTS, TOEFL) to employment and social mobility. The study also examines how media discourses promote English as a cultural norm and direct us to learn English to enhance our value in the job market. Ultimately, the paper reveals the systemic and discursive forces that sustain the myth of English cultural superiority, legitimising its global expansion through consumption practices and media depictions associated with English-speaking countries.

Keywords: Linguistic imperialism, language ideology, media discourse, English linguistic hegemony, language commodification, centre-periphery dynamics

İNGİLİZCENİN ÜSTÜNLÜĞÜ İDEOLOJİSİ VE ÇAĞDAŞ DİLSEL SÖMÜRÜDEKİ ROLÜ

ÖZET

İngilizce dili, diğer diller üzerinde eşsiz bir küresel güç kazanmıştır. Kültürel tahakkümü ve ekonomik kontrolü, medya ve eğitim politikaları gibi mekanizmalar aracılığıyla ortaya çıkmıştır. İngilizce sadece bir iletişim aracı olarak değil, aynı zamanda uluslararası söylemleri şekillendiren ve toplumsal sınıfları güçlendiren bir unsur olarak hareket etmektedir. Bu makale, dilsel emperyalizm ve eleştirel uygulamalı dilbilim gibi teorilerden yararlanarak İngilizcenin tarafsız, faydalı ve modern bir dil olarak tasvir edilmesi yoluyla nasıl hâkimiyetini sürdürdüğünü göstermektedir. İngilizce konuşmak avantajlar sunarken, aynı zamanda dilsel hiyerarşileri de pekiştirmektedir. Bu durum, ana dili İngilizce olmayan konuşucuların sosyal ortamlarda dışlanmış hissetmesine yol açmaktadır. Aynı zamanda, ana dili İngilizce olanları ayrıcalıklı kılmakta ve eğitilmiş ana dili İngilizce olmayanları iş alanlarında, getirdikleri alternatif diller ve bilgi sistemleri dikkate alınmaksızın, dışlamaktadır. Analiz, ideolojik yapıların dilsel özsaygı, akademik katılım ve standart dil politikalarıyla eşitsizlik sürekliliği üzerindeki etkisini ele almaktadır. Dil sınavlarının fiyatlandırılması, İngiliz ekonomisine fayda sağlayarak finansal yapıları güçlendirmekte ve bu sınavların (IELTS, TOEFL) istihdam ve sosyal hareketlilik ile bağlantılı olmasına neden olmaktadır. Çalışma ayrıca medya söylemlerinin İngilizceyi kültürel bir norm olarak nasıl teşvik ettiğini ve iş piyasasında değerimizi artırmak için İngilizce öğrenmeye yönlendirdiğini incelemektedir. Sonuç olarak, makale İngiliz kültürel üstünlüğü mitini sürdüren sistematik ve söylemsel güçleri ortaya koymakta; bu üstünlüğü, İngilizce konuşulan ülkelere özgü tüketim pratikleri ve medya temsilleriyle meşrulaştırarak küresel yayılımını açıklamaktadır.

Anahtar Kelimeler: Dilsel emperyalizm, dil ideolojisi, medya söylemi, İngilizce dilsel hegemonyası, dilin metalaşması, merkez-çevre dinamikleri

THE IMPACT OF FINTECH ON CASHLESS PAYMENTS: THE ROLE OF "PASHA PAY" (M10) AND "E-MANAT" IN FINANCIAL INCLUSION.

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ABSTRACT

In recent years, the rapid development of financial technologies (fintech) has made a significant contribution to the expansion of cashless payment systems and the increase in access to financial services. In particular, the spread of digital payment tools has accelerated the integration of population groups with limited access to traditional banking services into the financial system, thereby creating conditions for strengthening financial inclusion. In this regard, empirically examining the impact of different fintech models on financial inclusion is of both scientific and practical importance. The aim of this study is to systematically analyze the impact of financial technologies on the expansion of cashless payment systems and the enhancement of financial inclusion. In particular, the effects of digital and physical payment infrastructures on access to financial services among different socio-economic groups are evaluated comparatively, based on the examples of the "Pasha Pay" (m10) mobile application and "E-manat" payment terminals, which are widely used in Azerbaijan. In this study, the application of a quantitative methodological approach is intended. It is planned to collect data through a survey from respondents who have experience using relevant digital and physical payment services. The survey instrument is expected to be designed based on a 5-point Likert scale and to consist of statements measuring key constructs such as perceived usefulness, ease of use, accessibility, trust, and usage intention. Financial inclusion is planned to be operationalized based on respondents' access to financial services and the intensity of use. The collected data are intended to be analyzed using descriptive statistics, confirmatory factor analysis (CFA), and regression analysis. It is expected that the findings of the study will more clearly reveal the role of fintech solutions in the development of a cashless economy and will contribute to the formulation of policies and practical mechanisms aimed at enhancing financial inclusion.

Keywords: Fintech, Cashless Payments, Financial Inclusion, Pasha Pay (m10), E-manat

**THE IMPACT OF PERCEIVED VALUE OF HEALTH AND THERMAL TOURISM PRODUCTS
ON VISIT INTENTION**

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ABSTRACT

In recent years, the health and thermal tourism sector has shown significant development worldwide. With the increasing demand for health, relaxation, and well-being, interest in these destinations has steadily grown. In this context, examining the value dimensions perceived by tourists toward health and thermal tourism products and how these perceptions influence visit intention has become increasingly important. The aim of this study is to examine the effects of different dimensions of perceived value in health and thermal tourism products on visit intention. A quantitative research method is planned to be employed in the study. The research data are planned to be collected through online and face-to-face survey methods from approximately 100–120 participants who live in Baku, are aged 40 and above, and have previously benefited from health or thermal tourism services. The survey form will consist of scale items measuring visit intention as well as statements designed to measure the functional, economic, and emotional dimensions of perceived value. The collected data are planned to be evaluated initially through descriptive statistics. In order to test the construct validity of the scales, Confirmatory Factor Analysis (CFA) will be applied, and multiple regression analysis will be conducted to examine the relationships between variables. In addition, difference analyses (t-test and ANOVA) will be performed according to demographic variables and participants' previous experience with health or thermal tourism. The findings of the research are expected to contribute to a better understanding of tourist behavior in the context of health and thermal tourism and to provide strategic recommendations for destination managers and tourism businesses. Furthermore, the study aims to contribute to the literature on health and wellness tourism by identifying the key factors shaping individuals' travel preferences.

Keywords: Health and Thermal Tourism, Perceived Value, Visit Intention

**9TH GRADE SPEAKING SKILLS IN THE TÜRKİYE CENTURY MAARIF MODEL: A
QUALITATIVE DOCUMENT ANALYSIS**

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ABSTRACT

Speaking skills are one of the most important components of learning a foreign language. Despite this, they are often left out by grammar and pronunciation skills. In this study aim is to examine speaking skills within the new English curriculum, the Türkiye Century Maarif Model. It also investigates whether the macro and micro skills within the speaking section are evenly distributed, how skills correspond to Bloom's Taxonomy, and how they align with the curriculum's intended outcomes. This study conducts a qualitative study examining how speaking skills are categorized, which activities are included, how cognitive processes contribute to student learning, and finally, how they align with the objectives. It has been investigated that micro skills such as vocabulary, grammar, and pronunciation are more prominent in speaking activities than the skills of inference and lexical integrity, which are often associated with macro activities. It also examines that most of the activities in the textbook focus on lower-order thinking skills such as comprehension and memorization, while activities focusing on higher-order thinking skills such as analysis and creativity are limited. These findings suggest that the Türkiye Century Maarif Model does not fully align with the holistic approach to education.

Keywords: speaking skills, micro skills, macro skills, Bloom's taxonomy, Türkiye Century Maarif Model, communicative competence

ENTROPY DYNAMICS IN FINANCIAL SYSTEMS: A THERMOFLUID FRAMEWORK FOR RISK, UNCERTAINTY, AND MARKET INEFFICIENCY

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ABSTRACT

This study develops a thermofluid-inspired framework for analyzing financial systems through the lens of entropy dynamics and market instability. Drawing from entropy generation principles in fluid mechanics and heat transfer, financial entropy is introduced as a quantitative measure of market uncertainty. A governing equation is formulated to describe its spatiotemporal evolution, incorporating key factors such as volatility, transaction costs (friction), and asymmetric information. To enhance generality, the model is expressed in dimensionless form, enabling applicability across diverse financial environments. Numerical simulations reveal that increases in volatility, transaction costs, and information asymmetry significantly elevate financial entropy, signalling heightened market instability. Conversely, improved information diffusion reduces entropy and promotes stability. A financial Reynolds number is further defined to characterize the transition from stable to unstable market regimes. The results demonstrate that entropy-based thermofluid modeling provides a unified and predictive framework for understanding financial instability, with potential applications in risk assessment and the design of effective regulatory policies.

Keywords: Entropy dynamics; Financial systems; Thermofluid Framework; Market uncertainty

**PERCEPTION OF ORANGE-FLESHED SWEET POTATOES AMONG FARMERS IN AFIKPO
ZONE EBONYI STATE, NIGERIA**

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ABSTRACT

The study examined the awareness and perception of orange-fleshed sweet potato (OFSP) among farmers in Afikpo Zone, Ebonyi State, Nigeria. It profiled socio-economic characteristics, described perceptions, and determined cultivation challenges. Data were collected from farmers using structured questionnaires and analyzed with descriptive statistics and binary logit regression. Respondents had a mean age of 45 years, average household size of 5.83, and 14 years of farming experience. Most (58%) were male, 78% had at least secondary education, and 76% belonged to social organizations. Farmers expressed positive perceptions, citing health benefits, high yield, and resilience, though some feared displacement of indigenous varieties. Major challenges included lack of agricultural insurance (89%), absence of initial cash support (89%), inadequate inputs (79%), and limited seed availability (68%). The binary logit model ($\chi^2 = 64.214$, $p < 0.01$, pseudo- $R^2 = 0.436$) indicated that higher education, larger farm and household sizes, and greater extension contact positively influenced awareness, while age had a negative effect. The study recommends strengthening extension services, expanding agricultural insurance and credit access, leveraging farmer networks for knowledge dissemination, and promoting conservation of indigenous varieties alongside OFSP adoption. Addressing these constraints can enhance the perception of OFSP.

Keywords: Orange-fleshed sweet potato (OFSP); Farmer perception; Agricultural adoption; Extension services; Nigeria

MARINE AND ISLAND ECONOMIC DEVELOPMENT POLICIES IN VIETNAM (1986–2020)

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ABSTRACT

This paper examines the evolution of Vietnam's marine and island economic policies from 1986 to 2020 through a historical–institutional and public policy analysis framework. The study identifies three major phases in the transformation of Vietnam's maritime development strategy. The first phase (post-1986) was characterized by a resource-extraction-oriented approach focusing on fisheries, oil and gas, and maritime transport. The second phase marked the institutionalization of a comprehensive maritime strategy, notably with the adoption of the Vietnam Marine Strategy to 2020 (2007), which articulated the vision of Vietnam as a “strong maritime nation.” The third phase, beginning in the late 2010s, reflects a strategic shift toward sustainable marine development, highlighted by Resolution No. 36-NQ/TW (2018), emphasizing the “blue economy,” environmental protection, and integrated ocean governance. The findings suggest that Vietnam has progressively developed a more coherent and comprehensive policy framework that contributes significantly to economic growth, national development, and the integration of economic objectives with sovereignty protection. However, persistent challenges remain, including fragmented governance, unsustainable resource exploitation, and environmental degradation. The paper argues that Vietnam's policy trajectory demonstrates a transition from an extractive model to a sustainability-oriented paradigm and highlights the need for improved institutional coordination, marine spatial planning, and adaptive governance mechanisms. These findings provide policy implications for enhancing the effectiveness of marine economic development in the context of global integration and climate change.

Keywords: marine economy; public policy; sustainable development; Vietnam.

THE IMPACT OF CORPORATE SOCIAL RESPONSIBILITY ON BUSINESS PERFORMANCE THROUGH CORPORATE REPUTATION IN THE CONTEXT OF NEW-GENERATION FREE TRADE AGREEMENTS: A CASE STUDY OF THE SEAFOOD INDUSTRY IN THE MEKONG DELTA

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ABSTRACT

As new-generation Free Trade Agreements (FTAs) introduce stringent non-tariff barriers related to labor and environmental standards, Corporate Social Responsibility (CSR) has transitioned from a voluntary initiative to a strategic necessity for exporters. This study investigates the impact of CSR on the business performance of seafood enterprises in Vietnam's Mekong Delta, with a specific focus on the mediating role of corporate reputation. Data were collected through a survey of managers from seafood processing and exporting firms in the region. Structural Equation Modeling (SEM) was employed to test the hypothesized relationships. The empirical results indicate that CSR dimensions—encompassing economic, legal, ethical, and philanthropic responsibilities—exert a significant positive influence on business performance. Notably, corporate reputation acts as a vital partial mediator, suggesting that CSR initiatives enhance performance by building trust and prestige among international stakeholders. Within the framework of new-generation FTAs, these findings underscore that CSR is not merely a compliance cost but a competitive tool for sustainable growth. The study provides practical recommendations for seafood exporters to integrate CSR into their core strategies to leverage trade preferences and mitigate risks in the global value chain

Keywords: Corporate social responsibility (CSR), Business performance, corporate reputation, New-generation FTAs, seafood industry, Mekong Delta, Vietnam.

**TOURIST SATISFACTION WITH OCOP-CERTIFIED AQUACULTURE PRODUCTS:
IMPLICATIONS FOR SUSTAINABLE TOURISM AND LOCAL VALUE CHAINS IN COASTAL
VIETNAM**

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ABSTRACT

This study examines domestic tourist satisfaction with OCOP (One Commune One Product) certified goods in Khanh Hoa, Vietnam, with particular relevance to sustainable local value chains and tourism-linked aquaculture products. In the context of increasing emphasis on green and smart development in coastal economies, OCOP products such as bird's nest and sea grapes represent an important interface between aquaculture, local livelihoods, and tourism consumption. Grounded in Expectation–Disconfirmation Theory and perceived value frameworks, the study investigates four determinants of satisfaction: product quality, price perception, reliability, and packaging. A survey of 110 domestic tourists was conducted, and the data were analyzed using exploratory factor analysis and multiple regression. The results indicate that all factors significantly influence satisfaction, with product quality and reliability emerging as the most critical drivers. The findings highlight that tourists increasingly value safe, traceable, and culturally authentic products, aligning with the principles of sustainable consumption and responsible tourism. This study contributes to the discourse on green and smart development by demonstrating how certified local products can enhance both tourist experience and local economic resilience. The results provide practical implications for integrating OCOP products into sustainable tourism and aquaculture value chains in coastal destinations.

Keywords: OCOP products; Aquaculture-based products; Tourist satisfaction, Sustainable consumption; VietNam

SEED OIL FOR MAKING OIL BASED PAINT

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ABSTRACT

This study focuses on the development of natural oil-based paint using locally sourced seed oil as an alternative to conventional imported raw materials. The increasing cost of commercial paints and dependency on imported oils such as linseed oil have created a need for more sustainable and cost-effective solutions in Malaysia's paint industry. Therefore, this project aims to utilize peanut oil (*Arachis hypogaea*) as the primary raw material in the production of alkyd resin for oil-based paint. The methodology involves several key stages including drying of peanut seeds, oil extraction using a hydraulic oil press, and synthesis of alkyd resin through the alcoholysis–polyesterification process. The extracted oil was analyzed using Fourier Transform Infrared Spectroscopy (FTIR) to determine the presence of linolenic acid, which is essential for drying properties. In addition, methanol solubility tests were conducted to evaluate the stability and completeness of monoglyceride formation in different samples. The results indicate that Sample 1 demonstrated the highest stability and most complete monoglyceride formation, supported by FTIR analysis showing higher linolenic acid content. In contrast, Samples 2 and 3 exhibited faster solubility in methanol, indicating lower stability and incomplete reactions. These findings confirm that peanut oil has strong potential as a suitable raw material for alkyd resin production. In conclusion, the use of locally sourced peanut oil offers a cost-effective, environmentally friendly, and sustainable alternative for oil-based paint production. This approach not only reduces dependence on imported oils but also supports the development of Malaysia's local resources and promotes a circular economy.

Keywords: Peanut oil, Alkyd resin, Oil-based paint, FTIR analysis, Sustainable materials

RADIONUCLIDE MOBILITY AND TRANSFER DYNAMICS IN SEMI-ARID MOROCCAN AGROECOSYSTEMS

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ABSTRACT

Understanding how radionuclides migrate from soil to edible plant tissues is essential for evaluating radiological exposure through food chains, particularly in regions where agriculture supports local livelihoods. This study examines these transfer processes in the semi-arid farmlands of Meknes, Morocco. Soil and crop samples were collected from multiple cultivated areas, and radionuclide activity concentrations were quantified using High-Purity Germanium gamma spectrometry and alpha spectrometry. The investigation focused on Th-234, Ra-226, Th-228, Ra-228, Pb-210, K-40, Cs-137, and Po-210. Transfer factors—defined as the ratio of radionuclide activity in plant tissues to that in corresponding soils—were used to assess radionuclide mobility and bioavailability within the soil–plant system. Standardized analytical procedures ensured consistency and allowed comparison with studies conducted under different environmental and agricultural conditions. The results demonstrated significant variations in transfer factors depending on soil properties, plant species, and radionuclide chemical behaviour. The elevated transfer values observed for K-40 highlight its essential nutritional function and greater mobility compared to actinides and other radionuclides. This study enhances understanding of radionuclide dynamics in semi-arid agroecosystems and underscores the importance of continued radiological monitoring to ensure food safety. The findings provide a reference framework for evaluating potential human health risks associated with contaminated crops and for guiding remediation strategies in vulnerable agricultural regions.

Keywords: Radionuclide transfer; Soil–plant system; Semi-arid agroecosystems; Food safety; Morocco

**PRODUCTION AND CHARACTERIZATION OF CARBON NANOTUBES FROM BIOCHAR
UNDER MICROWAVE IRRADIATION**

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ABSTRACT

Carbon nanotubes (CNTs) are widely used in a variety of fields to produce a diversity of products, including hydrogen storage systems, and field emitters. In the proposed study, CNTs synthesized via biochar under the microwave irradiation method. In this method, the combination of charcoal and ferrocene are used to synthesize CNTs from the biochar approach. Biochar samples for CNTs synthesis are made from pyrolyzed agro-industrial waste such as rapeseed cake, hazelnut hulls, wheat straw, and oat hulls at different temperatures. The biochar was produced from agro-industrial biomass. During experiments, 100g of biomass was placed in a microwave reactor. The samples were pyrolyzed at 400 °C to 600°C. SEM analysis was used to confirm the morphology of CNTs. SEM micrographs revealed the perfect structure of multiwall carbon nanotubes, while interlayers spacing was changed due to variation of catalysts and measured about 0.34nm. Further, the optical properties were examined by UV-visible spectroscopy. In the UV, one band is clear at 240 nm region due to resonance of nanotubes $\pi(\pi)$ electrons of carbon nanotubes. XRD was used to analyze the glassy structure of prepared CNTs under microwave revealed that the creation and growth of CNTs were mostly influenced by microwave irradiation and the ferrocene catalyst. The structure of CNTs was developed under microwave heating and in the presence of ferrocene catalyst. To research how nitrogen impurities adhere to CNTs, FTIR experiments were conducted in the 400–4000 cm^{-1} range. The sample's FTIR spectra exhibit prominent peaks that correspond to C-H and C=C, respectively.

Keywords: Carbon nanotubes; Biochar; Microwave irradiation; Agro-industrial waste; Nanomaterials

SEED OIL FOR MAKING OIL BASED PAINT

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ABSTRACT

This study focuses on the development of natural oil-based paint using locally sourced seed oil as an alternative to conventional imported raw materials. The increasing cost of commercial paints and dependency on imported oils such as linseed oil have created a need for more sustainable and cost-effective solutions in Malaysia's paint industry. Therefore, this project aims to utilize peanut oil (*Arachis hypogaea*) as the primary raw material in the production of alkyd resin for oil-based paint. The methodology involves several key stages including drying of peanut seeds, oil extraction using a hydraulic oil press, and synthesis of alkyd resin through the alcoholysis–polyesterification process. The extracted oil was analyzed using Fourier Transform Infrared Spectroscopy (FTIR) to determine the presence of linolenic acid, which is essential for drying properties. In addition, methanol solubility tests were conducted to evaluate the stability and completeness of monoglyceride formation in different samples. The results indicate that Sample 1 demonstrated the highest stability and most complete monoglyceride formation, supported by FTIR analysis showing higher linolenic acid content. In contrast, Samples 2 and 3 exhibited faster solubility in methanol, indicating lower stability and incomplete reactions. These findings confirm that peanut oil has strong potential as a suitable raw material for alkyd resin production. In conclusion, the use of locally sourced peanut oil offers a cost-effective, environmentally friendly, and sustainable alternative for oil-based paint production. This approach not only reduces dependence on imported oils but also supports the development of Malaysia's local resources and promotes a circular economy.

Keywords: Peanut oil, Alkyd resin, Oil-based paint, FTIR analysis, Sustainable materials

**BATCH NITROPHENOL ADSORPTION EMPLOYING LOW-COST ACTIVATED CARBON AND
FIXED-BED COLUMNS**

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ABSTRACT

This paper describes the synthesis of environmentally friendly, low-cost adsorbents and examines their adsorption capabilities in the removal of 4-nitrophenol from wastewater. Simple analysis, FTIR, and SEM were used to characterize unmodified date palm fibers biochar. The maximum adsorbed quantities for date palm fibers biochar were determined to be 81.076 mg/g, after isotherm experiments in the batch system were examined. Strong coefficient correlation (R^2), low RMSE, and χ^2 in the measurements of isotherms were well-suited for the Langmuir equation. To assess the column's functionality, fixed bed adsorption was investigated under operational settings, including bed height, 4-nitrophenol flow rate, and 2-nitrophenol inlet concentration. As the rate flow decreases and bed height increases, breakthrough and breakthrough curves both increases. With 4 cm (0.5 g) of bed height, 160 mg/L of intake 2-nitrophenol concentration, and 2 mL/min rate flow, the highest percentage of 4-nitrophenol solution treated (65.46%) and highest bed capacity of 31.42 mg/g were achieved. Nelson, the breakthrough curves were fitted using the Yoon and Thomas models. The models exhibit strong behavior of the breakthrough and an R^2 that is higher than 0.99, indicating their good applicability.

Keywords: 4-nitrophenol, Fixed bed adsorption, batch adsorption, biochar.

THERAPEUTIC AND IMMUNOMODULATORY POTENTIAL OF ALLIUM SATIVUM AND ALLIUM CEPA IN THE MANAGEMENT OF MALARIA: PHYTOCHEMICAL MECHANISMS AND FUTURE PERSPECTIVES

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ABSTRACT

Malaria remains a significant global health burden, exacerbated by the increasing prevalence of drug-resistant *Plasmodium* strains and the limitations of current therapeutic strategies. This review examines the therapeutic and immunomodulatory potential of *Allium sativum* (garlic) and *Allium cepa* (onion) as sustainable, plant-derived alternatives or adjuncts in malaria management. Historically recognized in various ethnomedicinal traditions, these *Allium* species possess a rich profile of bioactive phytochemicals, most notably organosulfur compounds such as allicin, ajoene, and diallyl sulfides, alongside potent flavonoids like quercetin and phenolic acids. Multiple mechanisms, including direct parasiticidal effects through inhibition of essential parasite cysteine proteases and interference with crucial metabolic processes, such as heme detoxification drive the antimalarial efficacy of these compounds. Beyond direct action against the parasite, *Allium* extracts exhibit significant immunomodulatory properties. They enhance the host's innate and adaptive immune responses by modulating the production of pro-inflammatory cytokines such as IFN- γ and TNF- α , stimulating nitric oxide synthesis, and promoting the activation of macrophages, natural killer cells, and T-lymphocytes. Furthermore, evidence suggests that these extracts can work synergistically with conventional antimalarials, potentially reducing required dosages and delaying the emergence of drug resistance. While generally considered safe, the review addresses toxicity considerations and the necessity for standardized preparation guidelines. Ultimately, this analysis underscores the promise of *Allium sativum* and *Allium cepa* in modern malariology and identifies critical directions for future research, including the need for rigorous clinical trials and the development of novel drug delivery systems to optimize their clinical utility.

Keywords: Antiplasmodial activity, Organosulphur compounds, Quercetin, Allicin, Oxidative stress, Immunomodulation

PRENATAL STRESS INCREASES SUSCEPTIBILITY TO APOMORPHINE ADDICTION AND MODIFIES THE RESPONSIVENESS OF 5HT-1A RECEPTORS IN ADULT RATS

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ABSTRACT

Prenatal stress is increasingly recognized as a significant risk factor for neurodevelopmental alterations that enhance vulnerability to substance abuse later in life. This study investigated the impact of prenatal unpredictable chronic mild stress on susceptibility to apomorphine addiction and the functional responsiveness of 5HT-1A receptors in adult male rats. Pregnant rats were exposed to chronic mild stress from gestational day 14 until delivery, and their male offspring were assessed in adulthood. Conditioned place preference (CPP) and behavioral sensitization to repeated apomorphine (1.0 mg/kg) were evaluated, followed by assessment of 5-HT syndrome behaviors and neurochemical analysis of serotonin (5HT) and its metabolite 5HIAA in the hippocampus, hypothalamus, midbrain, and caudate after challenge with the 5HT-1A receptor agonist 8-OH-DPAT (1.0 mg/kg). Prenatally stressed rats showed significantly greater preference for the apomorphine-paired compartment and heightened behavioral sensitization compared to unstressed controls, indicating increased addiction susceptibility. Moreover, these rats exhibited exaggerated 5-HT syndrome behaviors and region-specific reductions in 5HT and 5HIAA levels following 8-OH-DPAT challenge, suggesting altered 5HT-1A receptor responsiveness. These findings demonstrate that prenatal stress persistently enhances vulnerability to apomorphine addiction, likely through dysregulation of serotonergic signaling and altered 5HT-1A receptor function, highlighting early-life stress as a critical determinant of addiction risk and identifying 5HT-1A receptors as a potential therapeutic target.

Keywords: Prenatal stress; apomorphine dependency; 5HT-1A receptors; 5-HT syndrome; conditioned place preference

ENHANCING REPRODUCIBILITY IN VETERINARY PATHOLOGY THROUGH STRUCTURED LESION GRADING SYSTEMS

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ABSTRACT

Lesion grading is a central component of veterinary pathology, providing a structured framework for evaluating the severity, distribution, and progression of pathological changes in animal tissues. This study presents a synthesis of lesion grading principles, methodologies, and applications, highlighting its critical role in improving diagnostic accuracy and research reproducibility. It examines core grading approaches, including qualitative, semi-quantitative, and quantitative systems, and demonstrates how these methods transform descriptive morphological observations into standardized and analyzable data. Applications in both gross and microscopic pathology are explored, with emphasis on their utility in assessing inflammation, necrosis, fibrosis, and neoplastic changes across organ systems. The relevance of lesion grading in veterinary diagnostics, biomedical research, epidemiology, and regulatory science is critically discussed. Standardized scoring systems are shown to enhance consistency in pathological interpretation, reduce observer variability, and facilitate comparison across studies and institutions. Despite these advantages, key challenges persist, including lack of universal standardization, species-specific variability, and limitations in technical resources, particularly in low-resource settings. Emerging innovations in digital pathology and artificial intelligence are identified as transformative tools capable of improving objectivity, efficiency, and scalability in lesion assessment. These technologies offer promising avenues for automated image analysis, quantitative morphometry, and harmonization of grading systems across laboratories. In conclusion, the adoption of robust, standardized lesion grading frameworks is essential for the advancement of veterinary pathology. Therefore, strengthening methodological consistency and integration of modern technologies will enhance contributions of the discipline to animal health, translational research, and global public health within the One Health paradigm.

Keywords: Lesion grading; veterinary pathology; variability; scalability; digital pathology

**ASSESSMENT OF MEDICAL AND PHARMACEUTICAL WASTE MANAGEMENT PRACTICES
IN PRIMARY HEALTHCARE FACILITIES**

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ABSTRACT

Medical and pharmaceutical waste generated by healthcare facilities represents a significant risk to human health as well as to the environment, which requires rigorous and appropriate management. This study aimed to assess the management practices of medical and pharmaceutical waste generated by primary healthcare facilities. The study covered 57 healthcare facilities, including 9 urban health centers, 33 rural health centers, and 15 rural dispensaries. Data collection was carried out through field visits, direct observation, interviews, and the distribution of questionnaires. The management of medical and pharmaceutical waste within healthcare facilities currently remains irrational and insufficiently structured, despite the significant annual quantities generated. These amounts reach approximately 3,780 kg for urban health centers, 630 kg for rural health centers, and 89 kg for rural dispensaries. The main constraints identified in the management of this waste are human, material, financial, and organizational in nature. Raising awareness and training healthcare personnel, improving the segregation of medical and pharmaceutical waste, and implementing simple treatment facilities are the main measures proposed to improve waste management practices.

Keywords : Management, medical and pharmaceutical waste, primary healthcare facilities.

LIMONENE AS A NATURAL SOLUTION TO ANTIMICROBIAL RESISTANCE

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ABSTRACT

Limonene is a naturally occurring monoterpene commonly found in the essential oils of citrus fruits. It is widely recognized for its pleasant aroma as well as its biological properties, including antimicrobial, antioxidant, and anti-inflammatory activities. Due to the increasing problem of antimicrobial resistance, natural compounds such as limonene are being investigated as potential alternative therapeutic agents. In this study, the antibacterial and anticandidal activities of limonene were evaluated against *Staphylococcus aureus*, *Escherichia coli*, *Candida albicans*, and *Candida sp.* The antimicrobial activity was assessed using the disk diffusion method and the microdilution technique to determine the minimum inhibitory concentration (MIC). The results showed that limonene exhibited inhibitory effects against all tested microorganisms, with varying degrees of sensitivity. The activity was compared with reference antibiotics: Ampicilline for bacterial strains and Fluconazole for *Candida* species. Although the standard drugs showed stronger activity, limonene demonstrated significant antimicrobial potential, particularly against *Staphylococcus aureus* (IZ=21.15 ± 0.45 mm and MIC=0,062 mg/mL). These findings suggest that limonene could be considered a promising natural antimicrobial agent. Further studies are needed to explore its mechanism of action, toxicity profile, and potential applications in pharmaceutical or food preservation fields.

Keywords: Limonene, Bioactive molecule, antimicrobial resistance, Microbial Resistance, *Staphylococcus aureus*, Pathogenic bacteria

**ANTIMICROBIAL AND SENSORY PROPERTIES OF BIO-SOUPS ENRICHED WITH
FUSCOPORIA TORULOSA EXTRACTS**

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ABSTRACT

This study explores the antimicrobial activity and sensory properties of bio-soups enriched with medicinal mushroom extracts, specifically *Fuscoporia torulosa*. Three variants of dehydrated vegetable soups were prepared: Variant 1, a control consisting of a conventional vegetable soup; Variant 2, a vegetable soup without monosodium glutamate, but enriched with a lyophilized aqueous extract of *Fuscoporia torulosa*; and Variant 3, a vegetable soup without monosodium glutamate, but enriched with a lyophilized ethanolic extract of the same mushroom. The mushroom extracts were prepared through two methods: aqueous extraction and ethanolic extraction. Scanning electron microscopy (SEM) revealed distinct structural differences between the two extracts. Aqueous extracts exhibited rough surface structures, while ethanolic extracts showed smoother, crystalline formations. These differences were linked to the extraction method and processing temperature, which influenced the final product's microstructure. Antimicrobial testing was conducted on 12 microbial strains, including 10 bacterial strains (5 Gram-positive and 5 Gram-negative) and 2 yeast species, using the disk diffusion method. Both aqueous and ethanolic extracts exhibited significant antimicrobial activity, with the extracts from *Fuscoporia torulosa* showing superior inhibition zones compared to the control soup. After 90 days of storage, Variant 2 (aqueous extract) and Variant 3 (ethanolic extract) demonstrated significantly enhanced antimicrobial activity against various pathogens, including *Staphylococcus aureus* and *Escherichia coli*, when compared to the control variant. Sensory evaluation was performed to assess color, odor, taste, consistency, and overall acceptability. While all variants were deemed acceptable, Variant 2, enriched with the aqueous extract, received the highest sensory scores in color, taste, and overall preference. The study concludes that the incorporation of medicinal mushroom extracts into food products not only enhances their antimicrobial properties but also contributes to the sensory appeal of functional foods, presenting an innovative approach for developing healthier, bioactive food options.

Keywords: Antimicrobial activity, medicinal mushrooms, *Fuscoporia torulosa*, bio-soups, sensory properties.

SYNTHESIS, SPECTROSCOPIC CHARACTERIZATION, AND BIOLOGICAL ACTIVITY OF NOVEL HETEROCYCLIC SCHIFF BASE LIGANDS AND THEIR CO(II), NI(II), TI(III) AND TI(IV) COMPLEXES

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ABSTRACT

A series of novel heterocyclic Schiff base ligands incorporating pyrimidine, pyrazole, and coumarin moieties were synthesized and subsequently complexed with Co(II), Ni(II), and Ti(IV) ions to yield stable coordination compounds. The ligands were designed to provide multiple coordination sites through nitrogen and oxygen donor atoms, enabling the formation of chelate systems with enhanced structural stability and biological potential. The compounds were characterized by elemental (CHN) analysis, FTIR, ¹H-NMR, ¹³C-NMR, Mass spectra and UV–Vis spectroscopy. The in vitro anticancer activity was evaluated against human cancer cell lines MCF-7 (breast), HCT116 (colon), and H460 (lung). Metal complexation significantly enhanced cytotoxic activity compared to the free ligands, with the Ti(III) and Ti(IV) complexes exhibiting the highest potency, showing IC₅₀ values in the low micromolar range against HCT116 cells. In addition, the ligands and their metal complexes demonstrated notable antibacterial activity against representative Gram-positive and Gram-negative bacteria, suggesting that metal coordination improves both antimicrobial and anticancer properties. The enhanced biological effects are likely due to increased lipophilicity, improved cellular uptake, and the ability of the complexes to interact with biomolecular targets such as DNA and bacterial cell membranes. These findings highlight the potential of Co(II), Ni(II), Ti(III) and Ti(IV) heterocyclic Schiff base complexes as multifunctional agents with promising anticancer and antibacterial applications, providing a platform for further pharmacological optimization.

Keywords: Heterocyclic Schiff base; Co(II), Ni(II), Ti(III), Ti(IV) complexes; pyrimidine; pyrazole; coumarin; anticancer activity; antibacterial activity; MCF-7; HCT116; H460; Gram-positive; Gram-negative.

COPULA-BASED MULTIVARIATE CONTROL CHARTS FOR MONITORING DEPENDENT COUNT PROCESSES: APPLICATION TO CARDIOMETABOLIC DISEASES

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ABSTRACT

Effective monitoring of chronic disease patterns is essential for public health management, particularly in the presence of multiple interrelated conditions such as hypertension, diabetes, and stroke. These diseases often exhibit strong dependence structures due to shared risk factors, posing significant challenges for traditional statistical process control methods that assume independence and normality. Moreover, the discrete and overdispersed nature of such health-related count data further limits the applicability of classical multivariate control charts. This study proposes a copula-based multivariate control chart framework for monitoring dependent count processes, with a specific application to hypertension, diabetes, and stroke incidence data. The methodology utilizes flexible copula functions to capture the complex dependence structure among the three diseases, while allowing each marginal distribution to follow appropriate count models such as Poisson, Negative Binomial, or generalized discrete distributions. This separation of marginal behavior from dependence modeling enables a more realistic and robust representation of multivariate health data. A novel control statistic is constructed based on the joint distribution derived from the fitted copula model, facilitating the detection of shifts in both marginal disease incidence rates and their underlying dependence structure. The performance of the proposed control chart is evaluated through simulation studies, demonstrating improved sensitivity and reduced average run length compared to conventional methods, particularly under conditions of strong dependence and overdispersion. The proposed approach is further illustrated using a dataset comprising counts of hypertension, diabetes, and stroke cases, highlighting its practical utility in early detection of abnormal disease patterns and potential outbreaks. The results underscore the effectiveness of copula-based methods as a powerful tool for multivariate surveillance in public health systems.

Keywords: Copula models, Multivariate control charts, Hypertension, Diabetes, Stroke.

COMPUTATIONAL DEVELOPMENT OF NOVEL TRIM24-TARGETED AGENTS FOR PROSTATE CANCER THERAPY

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ABSTRACT

Prostate cancer is a vital global health concern; it is among the most prevalent cancers affecting men. While various therapeutic options are available to manage this disease, the development of resistance to existing pharmaceutical treatments highlights the critical need for new anti-prostate cancer drugs. This research seeks to evaluate the potential bioactivity of newly designed 1-(indolin-1-yl) éthan-1-one derivatives through in-silico approaches, with an emphasis on investigating their inhibitory interactions with TRIM24 PHD-bromodomain. For that purpose, combined computational approaches were employed, including 2D-QSAR, ADMET prediction, molecular docking, and Dynamic simulations. The multiple linear regression (MLR) method was utilized to conduct a quantitative structure-activity relationship analysis on a collection of 37 1-(indolin-1-yl) éthan-1-one derivatives. The analysis of 2D-QSAR results demonstrated that the inhibitory activity could be predicted with high precision, with coefficients of determination (R^2) of 0.82 and 0.78 for the training and test datasets, respectively. Furthermore, ADMET profiling revealed the drug-likeness and selection potential of the new ligands, with most showing favorable pharmacokinetics and no predicted side effects. Two of the selected ligands were subjected to docking studies to evaluate their affinity for the TRIM24 receptor (PDB: 4YAB). Ligands P3 and P4 exhibit high affinity for the target protein, with binding energies of -12.04 kcal/mol and -11.38 kcal/mol, respectively, suggesting robust interactions. Molecular dynamics simulations and MM-PBSA analysis over 100 ns, using GROMACS, were conducted to further investigate the binding stability of the selected ligands with TRIM24. In summary, ligand P3 stands out as a promising candidate for inhibiting prostate cancer, laying a strong groundwork for the development of upcoming treatments and optimization strategies.

Keywords: ADMET, Molecular Docking, Molecular Dynamics, prostate cancer, QSAR

BRIDGING THE PEDAGOGICAL GAP: AN AI-BASED SUBJECT IMPROVEMENT PLAN (AI-SIP) FOR REMEDIATION OF GENETICS MISCONCEPTIONS IN BEIRUT PUBLIC SCHOOLS

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ABSTRACT

The rapid integration of Artificial Intelligence in Education (AIED) presents a transformative opportunity to address long-standing pedagogical challenges in complex scientific disciplines. In the Lebanese public-school context, Grade 11 genetics education is characterized by persistent student misconceptions and a reliance on traditional, teacher-centered instructional methods (Osman et al., 2017; Baroudi, 2019). This study introduces and evaluates the AI-Based Subject Improvement Plan (AI-SIP), a novel, data-driven framework designed to provide personalized, adaptive scaffolding and real-time diagnostic feedback to remediate abstract conceptual errors in genetics, thereby fostering deeper conceptual understanding and critical thinking skills. Employing a robust mixed-methods approach, this research investigates the potential efficacy of the AI-SIP in enhancing academic achievement and reducing misconceptions among Grade 11 students. Furthermore, the study examines the moderating role of teacher AI readiness, conceptualized through the Technological Pedagogical Content Knowledge for AI (TPACK-AI) framework and the Technology Acceptance Model (TAM) (Skayem & El Soueidi, 2025; Lan et al., 2025). By aligning with recent strategic roadmaps, such as the CERD National AI Education Framework (2025), this research identifies how the "pedagogical gap" can be bridged through evidence-based instructional design. Preliminary analysis suggests that while AI-SIPs offer significant remedial potential, successful implementation hinges on targeted teacher professional development and addressing resource constraints within the local context. This research contributes to the global discourse on human-centered AI applications in STEM education, offering actionable insights for educational reform in developing regions. The findings aim to inform policy for sustainable AI integration and provide a scalable model for curriculum development and teacher training programs worldwide.

Keywords: AIED, Genetics Pedagogy, AI-SIP, TPACK-AI, STEM Education, Lebanon.

**TEMPERATURE-DEPENDENT NUMERICAL SIMULATION OF CIGS SOLAR CELLS
INCORPORATING A ZNS INSULATION LAYER**

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ABSTRACT

In this paper, we present a simulation of a CIGS solar cell with a ZnS buffer layer, performed using the Silvaco-Atlas simulator. However, we obtained an efficiency of 24.13%, short-circuit current of 37.81 mA/cm², an open circuit voltage of 740 mV, and a fill factor of 78.78% at was around 1.41 eV, corresponding to an x ratio of 0.5 for the CIGS solar cell using a ZnS buffer layer. We optimized the performance of the ZnS/CIGS solar cell with the improved effects of layer parameters such as thickness and acceptor densities ZnS buffer layers. In this paper, we present a simulation of a CIGS solar cell with a ZnS buffer layer, performed using the Silvaco-Atlas simulator. However, we obtained an efficiency of 24.13%, short-circuit current of 37.81 mA/cm², an open circuit voltage of 740 mV, and a fill factor of 78.78% at was around 1.41 eV, corresponding to an x ratio of 0.5 for the CIGS solar cell using a ZnS buffer layer. We optimized the performance of the ZnS/CIGS solar cell with the improved effects of layer parameters such as thickness and acceptor densities ZnS buffer layers.

KEYWORDS: Buffer layer (ZnS), CIGS, Solar cell, Optimization, Silvaco-Atlas.

**ARTIFICIAL INTELLIGENCE AND ACADEMIC INTEGRITY IN HIGHER EDUCATION:
POLICY READINESS AND CHALLENGES IN LAHORE UNIVERSITIES**

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ABSTRACT

Artificial intelligence is rapidly transforming education through applications such as automated assessment, learning analytics, and generative content tools. Alongside these advancements, serious concerns have emerged regarding economic and pedagogical integrity. The study examined how pedagogical integrity be sustained, amid increasing AI adoption in public and private industries in Lahore, Pakistan. Using a quantitative descriptive cross-sectional design, data were collected from one hundred faculty members and academic administrators across ten universities; descriptive statistics, independent sample t-tests, one-way ANOVA, and regression analysis were conducted. The results exhibit moderate AI familiarity among university faculty. There were high concerns regarding economic integrity risk, and limited institutional AI policy readiness. Faculty suggested professional development for the professional and ethical use of AI. Regression analysis showed that the presence of institutional AI policies significantly predicted lower perceived integrity risk. The findings indicate that ethical AI use, combined with pedagogy-focused assessment redesign, is critical for strengthening faculty capacity and sustaining pedagogical integrity. Practical recommendations and an integrity-cantered framework are proposed for higher education institutions.

Keywords: academic integrity; artificial intelligence; policy readiness, higher education

STRUCTURE-BASED DRUG REPURPOSING TO INHIBIT THE DNA GYRASE OF MYCOBACTERIUM TUBERCULOSIS

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ABSTRACT

Drug repurposing is an alternative avenue for identifying new drugs to treat tuberculosis (TB). Although TB can be cured with anti-tubercular drugs, the emergence of multidrug-resistant and extensively drug-resistant strains of *Mycobacterium tuberculosis* H37Rv (Mtb), as well as the significant death toll globally, necessitate the development of effective drugs to treat TB. In this study, drug repurposing approach was employed to address this drug resistance problem by screening drugbank database to identify novel inhibitors of the Mtb target enzyme, DNA gyrase. The compounds were screened against the ATPase domain of gyrase B subunit (MtbGyrB47), and the docking results showed Echinacoside, Doxorubicin, Epirubicin, and Idarubicin possess high binding affinities against MtbGyrB47. Comprehensive assessment using fluorescence spectroscopy, SPR, and CD titration studies revealed that Echinacoside as a potent binder against MtbGyrB47. Further, ATPase, and DNA supercoiling assays exhibited IC₅₀ values of 2.1-4.7 μ M for Echinacoside, Doxorubicin, Epirubicin, and Idarubicin. Among these compounds, the least MIC₉₀ of 6.3 μ M and 12 μ M were observed for Epirubicin and Echinacoside, respectively. Hence, our findings indicate that Echinacoside and Epirubicin target mycobacterial DNA gyrase, inhibit its catalytic cycle, and retard mycobacterium growth. Further these compounds exhibit potential scaffolds for optimizing novel anti-mycobacterial agents that can act on drug-resistant strains.

BINARY CUCKOO CATFISH OPTIMIZER FOR UFLP PROBLEMS

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ABSTRACT

The Uncapacitated Facility Location Problem (UFLP) is a fundamental combinatorial optimization challenge in logistics and supply chain management, classified as NP-hard. While the Cuckoo Catfish Optimization (CCO) algorithm has shown promise in continuous optimization, its application to discrete binary problems remains underexplored. This paper proposes a Binary Cuckoo Catfish Optimization (BCCO) algorithm designed to effectively solve the UFLP. To map the continuous search space of the original CCO to a binary decision space, this study implements and compares eight distinct transfer functions, categorized into S-shaped and V-shaped families. The proposed algorithm is validated using the standard OR-Library benchmark datasets (cap71–cap134), covering a range of small to large-scale instances. Experimental results demonstrate the algorithm's high robustness, achieving a 0.00% optimality gap across the majority of test cases with minimal standard deviation. Furthermore, the comparative analysis reveals that V-shaped transfer functions generally outperform S-shaped functions in terms of convergence speed and solution quality on higher-dimensional datasets. These findings indicate that the BCCO algorithm, particularly when equipped with V-shaped transfer functions, is a highly competitive and stable meta-heuristic for solving discrete facility location problems.

Keywords: UFLP, Cuckoo Catfish, Transfer Functions

INTRODUCTION

Optimization problems are used for finding the optimal value to maximize or minimize the given optimization values with certain constraints (Hu et al. 2024a; Hu et al, 2023a; Hu et al., 2023b). Numerical optimization problems are found in engineering, finance and economics. Modern day problems are often too complex and have big solution spaces making the nearly impossible to solve using traditional mathematical algorithms within a reasonable timeframe. (Kaur et al. 2020). Meta-heuristic algorithms designed inspired by natural organisms can solve these problems with low cost. Swarm Intelligence Algorithms are meta-heuristic algorithms inspired by biological populations like insects, birds and fish. Here are few examples for well known SIA's: Particle Swarm Algorithm (PSO), Simulates animal behavior like their cooperation in finding food. Members adapt their search pattern as they learn individually and as a herd. It uses a swarm mode to simultaneously search large regions in the solution space (Wang et al. 2018). Optimization of PID control parameters for marine dual-fuel engine using improved particle swarm algorithm (Hu et al. 2024b; Luo et al., 2025). Multi-objective particle swarm algorithm based on angular segmentation archive and dynamic update tactics (Lou et al. 2025) Grey Wolf Algorithm (GWA) inspired by grey wolf packs, their social hierarchy of power and their behavior while hunting like chasing, encircling, harassing and attacking. It is effective and easy to use (Faris et al. 2018). Augmented weighted K-means grey wolf optimizer: An enhanced metaheuristic algorithm for data clustering problems (Premkumar et al. 2024). A Novel Improved Grey Wolf Algorithm Based Global Maximum Power Point Tracker Method Considering Partial Shading (Gundogdu et al. 2024). Red Deer Algorithm (RDA): Inspired by the mating behavior of Scottish red deer. KM-RDA: A New Meta-Heuristic Approach for Data Clustering Problem (Thakral et al. 2024)

In binary optimization algorithms solutions are represented with 1's and 0's. Some examples are feature selection problems, 0/1 knapsack problem, wind turbine location problem, uncapacitated facility location problem. We will focus on UFLP. Here we assume that the facility capacity is unlimited. There are two costs that we will consider, facility establishment cost and shipping cost. The purpose is to find a place that will meet the requirements at minimum cost. Since UFLP is a NP-Hard problem, it is impossible to solve it on a large scale in a reasonable amount of time. So new approaches like meta-heuristic algorithms are being used

more to solve these problems. Aslan et al. proposed a Jaya algorithm with xor operator (JayaX) for UFLP. Bas, and Ulker proposed a binary social spider algorithm for uncapacitated facility location problem. Cinar and Kiran proposed a similarity and logic gate-based Tree-Seed Algorithms for binary optimization (Yildızdan and Bas, 2024). We can summarize the main contributions of this paper as:

- We propose a novel Binary Cuckoo Catfish Optimization (BCCO) algorithm designed to solve NP-hard Uncapacitated Facility Location Problem (UFLP).
- For a comprehensive transfer function analysis we implement and rigorously compare eight distinct transfer functions (four S-shaped and four V-shaped) to evaluate their influence on the mapping of continuous search space to binary decision space.
- The performance of the algorithm is validated using the widely recognized OR-Library benchmark datasets (cap71–cap134), covering a range of problem dimensions and complexities.
- We demonstrate that V-shaped transfer functions exhibit superior performance in terms of solution quality and stability compared to S-shaped functions, particularly for large-scale problem instances.

CUCKOO CATFISH OPTIMIZER (CCO)

Inspiration

The inspiration of the paper, Cuckoo Catfish needs another host to make sure their offspring survive. They try to find places with better conditions. When it is time to lay eggs, they will find the right nest, create a distraction and lay their eggs. While the host tries to collect their eggs, it will collect some of the Cuckoo catfish eggs too. The Cuckoo Catfish eggs will hatch faster and eat the hosts eggs which is improvement their survival rate (Wang et al., 2025).

CCO focuses on simulating Cuckoo Catfish behavior like their learning process by search strategy, compressed space strategy, their invasion of host nests with chaotic predation strategy, and making sure the best stays with regeneration and predation (Wang et al., 2025).

Mathematical Model

Generation of the initial population

Mathematical model for positioning the initial population with N individuals

$$x_i^d = rand \times (Ub - Lb) + Lb, \begin{cases} i = 1, 2, \dots, N \\ d = 1, 2, \dots, D \end{cases} \quad (1)$$

D represents the dimension of the problem, x_i^d represents the d -th component of the i -th individual. Ub^d and Lb^d represent the upper and lower bounds of the d -th decision variable. In order to distinguish different random numbers, the symbol of 1 dimensional random numbers between $[0,1]$ are defined as r , and the symbol of D -dimensional random numbers between $[0,1]$ are defined as R . Each individual X_i consists of D components, and all individuals form a population, which are represented by a matrix as shown (Wang et al., 2025).

$$x = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_i \\ \vdots \\ X_N \end{bmatrix} = \begin{bmatrix} x_1^1 & x_1^2 & \cdots & x_1^j & \cdots & x_1^D \\ x_2^1 & x_2^2 & \cdots & x_2^j & \cdots & x_2^D \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_i^1 & x_i^2 & \cdots & x_i^j & \cdots & x_i^D \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_N^1 & x_N^2 & \cdots & x_N^j & \cdots & x_N^D \end{bmatrix}, \begin{cases} i = 1, 2, \dots, N \\ d = 1, 2, \dots, D \end{cases} \quad (2)$$

Compressed space strategy

Cuckoo Catfish cooperate so they can narrow the space in which the prey can escape. In Eq. (3) random individuals are being united in the early iterations. X_i^{new} is the updated position of the i -th individual. X_{best} is the position of the prey which is the global optimal solution. X_r are random individuals (Wang et al., 2025).

By reducing the number of X_r the encirclement range is being reduced which helps finding more precise results shown in Eq. (4). Z_1 and Z_2 are 0–1 variable in 1-dimensional and D-dimensional, these are used to simulate natural enemies. $|rd|$ is used to describe the intensity of cooperation between populations (Wang et al., 2025).

$$X_i^{new} = X_i + Z_1 \times |rd| \times \left(\frac{X_{best} + X_{r_1}}{2} - X_{r_2} \right) + \frac{r_3}{2} \times (X_{r_3} - X_{r_4}) \quad (3)$$

$$X_i^{new} = Z_2 \times \left(X_{i_1} + |rd| \times (X_{i_1} - X_{i_2}) \right) + (1 - Z_2) \times X_i \quad (4)$$

$$X_i^{new} = X_{r_1} + |rd| \times (X_{best} - X_i + X_{r_2} - X_{r_3}) \quad (5)$$

To make sure that the algorithm doesn't get stuck, when X_i does not find a better solution and more than 80% of the population does not find a better solution, it will keep some info of the dimensional position in the next iteration (Wang et al., 2025).

$$C = 1 - It / MaxIt \quad (6)$$

Input: C, t, D, $X_{i,j}^{new}$, X_i

Output: $X_{i,j}^{new}$

```

1: if t > 0.8 * N || rand > C then
2:   for j = 1 to D do
3:     if rand < 0.2 * C + 0.2 then
4:        $X_{i,j}^{new} = X_{i,j}^{new}$ 
5:     else
6:        $X_{i,j}^{new} = X_{i,j}$ 
7:     end if
8:   end for
9: end if
    
```

Surround Search Strategy

The prey is being circled using spiral and spherical forms. X_i will check other individuals positions, when finding an individual with a better position, it will go there while using the spiral search (Wang et al., 2025).

$$X_i^{new} = \begin{cases} X_e + F \times R_1 \times \frac{step}{2} + T^n \times s \times (1 - R_1) \times |step| + V \times \frac{J_i}{It} & \text{if } mod(i, 2) = 0 \\ X_e + F \times R_1 \times \frac{step_1}{2} + T^n \times c \times (1 - R_1) \times |step| + V \times \frac{J_i}{It} & \text{otherwise} \end{cases} \quad (7)$$

$$T = \left(1 - \sin \left(\frac{\pi \times It}{2 \times MaxIt} \right) \right)^{(It/MaxIt)} \quad (8)$$

$$\theta = (1 - 10 \times i/N) \times \pi \quad (9)$$

$$c = a \times e^{(b \cdot \theta)/2} \times \cos(\theta) \quad (10)$$

$$s = a \times e^{(b \cdot \theta)/2} \times \sin(\theta) \quad (11)$$

$$E = T + r_1 \quad (12)$$

$$J_{in} = \left| \frac{1}{N} \sum_{i=1}^N \left(\frac{1}{D} \times \sum_{j=1}^D \left(\frac{X_i - X_{best}}{X_{worst} - X_{best}} \right) \right) \right| \quad (13)$$

$$J_i = \frac{1}{D} \times \sum_{j=1}^D \frac{X_i - X_{best}}{X_{worst} - X_{best}} \quad (14)$$

$$V = \begin{cases} 2 \cdot (r_1 \cdot (X_{mean} - X_i) + r_2 \cdot (X_{best} - X_i)) & \text{if } J_i < J_{in} \\ 2 \cdot (r_1 \cdot (X_{rand_2} - X_{rand_3}) + r_2 \cdot (X_{rand_1} - X_i)) & \text{else} \end{cases} \quad (15)$$

T is the shrinkage factor and is calculated as shown in Eq. (8). In the spherical wrap-around strategy a selected position of the spherical center surrounded by X_i consists of the positions of the top three individuals and the average position of the population: $RotX = [X_{best}, X_{best2}, X_{best3}, \text{mean}(X)]$. X_i will randomly select a position (represented by $RotX_r$) from $RotX$ and randomly select a X_q in Eq. (16) to perform a search around the center of the sphere. This search process can be described using Eq. (16) and the probability of CCO extracting every operator in Eq. (16) is 1/3, that is, $P(X_q = e) = 1/3$ ($e \in \{1,2,3\}$) is satisfied (Wang et al., 2025).

w is the parameter for adjusting the surround radius, as shown in Eq. (17). Rt is the rotation angle of the D dimension with a value range of $[0, 2\pi]$. Subsequently, when the fitness value of the new position X_i^{new} is better than the fitness value of the previous position X_i , the worst individuals in the population will find the circumferential behavior of X_i and be guided to the position of X_i position with a 25% chance (Wang et al., 2025).

$$X_i^{new} = \begin{cases} RotX_r + 2 \times w \times F \times \cos(Rt_1) \times \sin(Rt_2) \times (RotX_r - X_i^{new}) & X_q^{new} = 1 \\ RotX_r + 2 \times w \times F \times \sin(Rt_1) \times \cos(Rt_2) \times (RotX_r - X_i^{new}) & X_q^{new} = 2 \\ RotX_r + 2 \times w \times F \times \cos(Rt_2) \times (RotX_r - X_i^{new}) & X_q^{new} = 3 \end{cases} \quad (16)$$

$$w = 1 - \frac{e^{\frac{It}{MaxIt}} - 1}{e - 1} \quad (17)$$

For better results, when Eq. (7) is executed a certain number of times, Eq. (19) will be executed. When Eq. (16) has been executed a certain number of times, Eq. (20) will be executed (Wang et al., 2025).

$$lesp = r_1 \times X_{r_1} + (1 - r_1) \times X_{r_2} \quad (18)$$

$$X_i^{new} = \text{round}(lesp) + F \times \frac{r_1 \times R_1}{It^4} \times X_i^{new} \quad (19)$$

$$X_i^{new} = X_{(best)} \times \left(1 - \left(1 - \frac{1}{X_r} \right) \times R_1 \right) \quad (20)$$

Eq. (21) is used for a better transition between exploration and exportation (Wang et al., 2025).

$$X_i^{new} = \begin{cases} \frac{C}{t_t} \times (r_1 \times X_{best} - r_3 \times X_i) + T^2 \times \text{lev}(D) \times |Step_2| & \text{if } \text{mod}(i, 2) = 0 \\ \frac{X_{best} + X_r}{2} + De \times \left(2 \times R_1 \times Step_2 - \frac{R_2}{2} \times (De \times R_3 - 1) \right) & \text{otherwise} \end{cases} \quad (21)$$

$$\text{lev} = 0.05 \times \frac{u}{|v|^{-\beta}} \quad (22)$$

Chaotic predation strategy

As the prey notices the invasion it will adapt its movements accordingly. This movements are shown as C_y and are generated with Eq. (25). When the aggregation is less than the vigilant aggregation, the cuckoo will start the invasion which will cause the prey to collect its eggs (Wang et al., 2025).

$$X_i^{new} = \begin{cases} X_{best} + F \times S \times (X_{best} - X_i) & \text{if } J_i > J_{in} \\ X_{best} \times (1 + T^5 \times C_y \times E) + F \times S \times (X_{best} - X_i) & \text{elseif } J_i > J_{in} \times Lx \\ X_{best} \times (1 + T^5 \times Gs) + F \times S \times (X_{best} - X_i) & \text{otherwise} \end{cases} \quad (23)$$

$$Lx = |rd| \times r_1 \quad (24)$$

$$C_y = \frac{1}{\pi \times (1 + C^2)} \quad (25)$$

Death and parasitic strategy

The probability of a fish dying is named *die* and calculated using Eq. (29). A fish far away from food will have a higher chance of death and this will cause it to try harder to find food. A randomly selected value from $\{0,1\}$. $best$ represents the eggs distributed near X_{best} , Up_c and Low_c represent the maximum and minimum components of the eggs in the D dimension. When food is not enough anymore, X_i will be reborn in a random place as shown in Eq. (30). Eq. (31) makes it possible to make changes for the rebirth (Wang et al., 2025).

$$best = X_{best} \times (lev(1) \times A + |rd_1| \times (1 - A)) \quad (26)$$

$$Up_c = \max(best) \quad (27)$$

$$Low_c = \min(best) \quad (28)$$

$$X_i^{new} = r_1 \times (Up_c - Low_c) + Low_c \quad (29)$$

$$X_i^{new} = r_1 \times (Up - Low) + Low \quad (30)$$

$$X_i^{new} = \begin{cases} \text{Eq. (29) if } rand > C \\ \text{Eq. (30) else} \end{cases} \quad (31)$$

The position update strategy is shown in Eq. (32). F_i^{new} and F_i refer to the fitness of X_i^{new} and X_i . When the criteria $F_i^{new} < F_i$ is met, it means that a better place has been found. If the criteria never gets met then it means that the area has not enough food and chance of death reaches maximum (Wang et al., 2025).

$$\begin{cases} \begin{cases} X_i^{new} & \text{if } F_i^{new} < F_i \\ t = 0 \end{cases} \\ \begin{cases} X_i \\ t = t + 1 \end{cases} & \text{else} \end{cases} \quad (32)$$

Mathematical Formulation of UFLP

The Uncapacitated Facility Location Problem (UFLP) is a classic combinatorial optimization problem that involves selecting a subset of facilities to open and assigning customers to these facilities in a way that minimizes the total cost. The problem is defined by a set of potential facility locations and a set of customers. The objective is to minimize the sum of fixed costs for opening facilities and the variable costs associated with customer assignments. The mathematical model is formulated as follows:

Objective Function:

$$\text{Minimize } Z = \sum_{i=1}^m f_i y_i + \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_{ij} \quad (33)$$

Subject to:

$$\sum_{i=1}^m x_{ij} = 1, \forall j \in J$$

$$x_{ij} \leq y_i, \forall i \in I, \forall j \in J$$

$$x_{ij}, y_i \in \{0,1\}, \forall i \in I, \forall j \in J$$

Where f_i represents the fixed cost associated with opening facility. C_{ij} represents the transportation or connection cost for serving customer from facility. Y_i is a binary decision variable that equals 1 if facility is open, and 0 otherwise. X_{ij} is a binary decision variable that equals 1 if customer is assigned to facility, and 0 otherwise.

The objective function seeks to minimize the total system cost. The first constraint ensures that each customer is assigned to exactly one facility. The second constraint guarantees that customers can only be assigned to a facility if that facility is open. The third constraint defines the binary nature of the decision variables.

The pseudocode of Cuckoo Catfish Algorithm (Wang et al., 2025):

Algorithm 2: Cuckoo Catfish Optimizer (CCO)

Input: Population size N , maximum iteration MaxIt , problem dimension D

Output: The best position (X_{best}) and its fitness value (F_{best})

Initialize the random population $X_i \{0,1\}$ and calculate fitness values

Set X_{best} as best position and F_{best} as best fitness

```

3: for It = 1 to MaxIt do
4:   if t < 15 then
5:     die = 0.02 × T
6:   else
7:     die = 0.02, C = 0.8
8:   end if
9:   for i = 1 to N do
10:    if rand > C then
11:      if rand > C then
12:        Update  $X_i^{\text{new}}$  using Eq. (23)
13:      else if rand > C then
14:        Update  $X_i^{\text{new}}$  using Eq. (21)
15:      else if rand > 0.5 then
16:        Update  $X_i^{\text{new}}$  using Eq. (7) and set  $s = s + 1$ 
17:      else
18:        Update  $X_i^{\text{new}}$  using Eq. (16) and set  $z = z + 1$ 
19:        Extract an integer Q in [1, 4]
20:      end if
21:      if s > 10 Update  $X_i^{\text{new}}$  using Eq. (19) and set s = 0
22:      if z > 5 Update  $X_i^{\text{new}}$  using Eq. (20) and set z = 0

```

23:	else
24:	Update X_i^{new} using Algorithm 1
25:	end if
26:	Update X_i^{new} using Eq. (31)
27:	Update the position using Eq. (32)
28:	if $F_i^{new} < F_i$ and $== 1$ then
29:	$X_{worst} = X_i^{new}$
30:	end if
31:	end for
32:	end for
33:	return X_{best} and F_{best}

BINARY CUCKOO CATFISH OPTIMIZER

Mathematical Formulation of UFLP is modeled as a minimization problem involving a set of potential facility sites and a set of customers. The objective is to minimize the total sum of fixed setup costs for opening facilities and the transportation costs for serving customers. The mathematical formulation is defined as follows where f_i is the fixed cost of opening facility. C_{ij} is the cost of serving customer from facility. Y_i is a binary decision variable; 1 if facility is open, 0 otherwise. X_{ij} is a binary variable; 1 if customer is assigned to facility, 0 otherwise. Table 1 shows transfer function equations (Cinar & Kiran, 2018; Bas & Ulker, 2020; Yildizdan & Bas, 2024).

Table 1. Transfer Function Equations (Cinar & Kiran, 2018; Bas & Ulker, 2020; Yildizdan & Bas, 2024)

S-Shaped	S-SHAPED AND V-SHAPED TRANSFER FUNCTION
S1	$S1 = \frac{1}{1 + e^{-2x}}$
S2	$S2 = \frac{1}{1 + e^{-x}}$
S3	$S3 = \frac{1}{1 + e^{-\frac{x}{2}}}$
S4	$S4 = \frac{1}{1 + e^{-\frac{x}{3}}}$
V- Shaped	Mathematical Formula for S-Shaped Transfer Function
V1	$V1 = \tanh(x) $
V2	$V2 = \left \operatorname{erf} \left(\frac{\sqrt{\pi}}{2} x \right) \right = \left \frac{2}{\sqrt{\pi}} \int_0^{\frac{\sqrt{\pi}}{2} x} e^{-t^2} dt \right $
V3	$V3 = \left \frac{x}{\sqrt{1+x^2}} \right $

V4	$V4 = \left \frac{2}{\pi} \arctan\left(\frac{\pi}{2}x\right) \right $

UFLP Datasets

To evaluate the performance of the proposed Binary Cuckoo Catfish Algorithm, we used the cap series ranging from cap71 to cap 134 of the OR-Library, curated by J.E Beasley. The dataset is a standard benchmark for Uncapacitated Facility Location Problems. The datasets vary in dimensions and complexities. For example, the cap71 provides 16 potential facilities and 50 customers while cap131 provides 50 facilities and 50 customers. The dataset provides two matrices for each problem: the fixed setup costs required to open each facility and the connection costs associated with serving each customer from a specific facility. Since the optimal solutions for these instances are well-known in the literature, they serve as an ideal ground truth to validate the optimization capability and solution quality of our algorithm. Table 2 and Table 3 show the datasets for UFLP (Beasley, 1990; Cinar & Kiran, 2018).

Table 2. Datasets for UFLP (Beasley, 1990)

Dataset	Number of Facilities	Number of Customers	Description
cap71 - cap74	16	50	Small-scale problems. Easier to solve.
cap101 - cap104	25	50	Medium-scale problems.
cap131 - cap134	50	50	Large-scale problems. The search space (2^{50}) is very large.

Table 3. Datasets for UFLP (Beasley, 1990; Cinar & Kiran, 2018; Yildizdan & Bas, 2024)

Dataset Name	Problem Size	Optimum Value
cap71	16 x 50	932,615.75
cap72	16 x 50	977,799.40
cap73	16 x 50	1,010,641.45
cap74	16 x 50	1,034,976.98
cap101	25 x 50	796,648.44
cap102	25 x 50	854,704.20
cap103	25 x 50	893,782.11

cap104	25 x 50	928,941.75
cap131	50 x 50	793,439.56
cap132	50 x 50	851,495.33
cap134	50 x 50	928,941.80

System Configuration and Datasets

The experiments were conducted using the OR-Library UFLP benchmark datasets (cap71–cap134), originally proposed by J.E. Beasley. These datasets vary in size, ranging from small-scale to large-scale problems. All algorithms were implemented in MATLAB R2024a and executed on an Apple MacBook Pro (2019) running Windows 10 Home via BootCamp. The hardware specifications include a 9th Gen Intel Core i7-9750H CPU @ 2.60GHz, 32GB of RAM, and an AMD Radeon Pro 5500M (4GB) graphics card.

Parameter Settings to ensure a fair statistical comparison and eliminate the stochastic nature of the meta-heuristic algorithm, each transfer function (S1–S4 and V1–V4) was executed for 10 independent runs on every dataset. The population size was set to 50, and the maximum number of iterations was set to 1000. The performance of the Binary CCO algorithm was evaluated based on the Best Cost, Mean Cost, Standard Deviation, CPU Time, and the Optimality Gap (%).

Analysis of Transfer Functions on UFLP

This section presents a comparative analysis of the impact of different transfer functions on the performance of the Binary Cuckoo Catfish Optimization algorithm. As the UFLP is a discrete optimization problem, the mapping of the continuous search space to a binary domain is a critical step that directly influences the algorithm's exploration and exploitation capabilities. Eight different transfer functions were implemented to evaluate this: four from the S-shaped (Sigmoid) family and four from the V-shaped family. These functions were tested across a comprehensive set of OR-Library benchmark instances, ranging from small-scale (cap71) to large-scale (cap134) datasets. The parameters were set as: $nRuns = 10$, $MaxIt = 1000$, $nPop = 50$. The following tables and figures illustrate the experimental results, evaluating each function based on its ability to locate the global optimum (Best Cost), its convergence speed, and its algorithmic stability (Standard Deviation) across independent runs.

Table 4. Results Of Binary CCO on UFLP for S1 Transfer Function

Cap	Best	Worst	Mean	Std	Time(s)	Gap(%)
cap71	932615.76	932615.76	932615.76	0	1.1643	0
cap72	977799.41	977799.41	977799.41	0	1.144	0
cap73	1010641.48	1010641.48	1010641.48	0	1.1206	0
cap74	1034977.01	1034977.01	1034977.01	0	1.0999	0
cap101	796648.44	796648.44	796648.44	0	1.2347	0
cap102	854704.19	854704.19	854704.19	0	1.1748	0
cap103	893782.11	894573.72	893883.88	252.58	1.2479	0
cap104	928941.77	929460.98	929045.61	218.92	1.1668	0
cap131	807417.38	816436.05	812285.24	3346.48	1.5337	1.7617

cap132	877174.64	894416.17	888424.93	4926.72	1.5415	3.0158
cap134	1014443.42	1062917.54	1038273.64	15399.09	1.6626	9.2042

Table 5. Results Of Binary CCO on UFLP for S2 Transfer Function

Cap	Best	Worst	Mean	Std	Time(s)	Gap(%)
cap71	932615.76	932615.76	932615.76	0	1.1046	0
cap72	977799.41	977799.41	977799.41	0	1.1422	0
cap73	1010641.48	1010641.48	1010641.48	0	1.1349	0
cap74	1034977.01	1034977.01	1034977.01	0	1.1447	0
cap101	796648.44	796648.44	796648.44	0	1.2016	0
cap102	854704.19	854704.19	854704.19	0	1.2164	0
cap103	893782.11	893782.11	893782.11	0	1.2325	0
cap104	928941.77	928941.77	928941.76	0	1.1524	0
cap131	806058.01	813389.87	809435.54	2230.06	1.5465	1.5903
cap132	869273.42	883595.18	875657.1	4275.62	1.5207	2.0879
cap134	982921.29	1013003.88	1001156.18	9363.21	1.6312	5.8109

Table 6. Results Of Binary CCO on UFLP for S3 Transfer Function

Cap	Best	Worst	Mean	Std	Time(s)	Gap(%)
cap71	932615.76	932615.76	932615.76	0	1.1367	0
cap72	977799.41	977799.41	977799.41	0	1.1276	0
cap73	1010641.48	1010641.48	1010641.48	0	1.0803	0
cap74	1034977.01	1034977.01	1034977.01	0	1.1351	0
cap101	796648.44	796648.44	796648.44	0	1.2524	0
cap102	854704.19	854704.19	854704.19	0	1.2206	0
cap103	893782.11	893782.11	893782.11	0	1.2784	0
cap104	928941.77	928941.77	928941.76	0	1.2178	0
cap131	801348.5	810195.74	805832.89	2989.66	1.4973	0.9968
cap132	867496.13	880872.5	873615.28	4071.39	1.4921	1.8791
cap134	961076.82	1001254.68	978783.75	10930.47	1.5361	3.4593

Table 7. Results Of Binary CCO on UFLP for S4 Transfer Function

Cap	Best	Worst	Mean	Std	Time(s)	Gap(%)
cap71	932615.76	932615.76	932615.76	0	1.1094	0
cap72	977799.41	977799.41	977799.41	0	1.1355	0
cap73	1010641.48	1010641.48	1010641.48	0	1.1309	0
cap74	1034977.01	1034977.01	1034977.01	0	1.0763	0
cap101	796648.44	796648.44	796648.44	0	1.2297	0
cap102	854704.19	854704.19	854704.19	0	1.2143	0
cap103	893782.11	894008.15	893804.72	71.48	1.2197	0
cap104	928941.77	928941.77	928941.76	0	1.204	0
cap131	803931.25	813169.47	807783.1	2786.91	1.5029	1.3223
cap132	866461.17	876201.87	871230.79	2889.43	1.4396	1.7576
cap134	944533.24	991741.29	973829.2	13896.17	1.5425	1.6784

Table 8. Results Of Binary CCO on UFLP for V1 Transfer Function

Cap	Best	Worst	Mean	Std	Time(s)	Gap(%)
cap71	932615.76	932615.76	932615.76	0	1.1134	0
cap72	977799.41	977799.41	977799.41	0	1.0727	0
cap73	1010641.48	1010641.48	1010641.48	0	1.0978	0
cap74	1034977.01	1034977.01	1034977.01	0	1.0644	0
cap101	796648.44	797508.72	796734.47	272.05	1.2524	0
cap102	854704.19	854704.19	854704.19	0	1.1683	0
cap103	893782.11	894008.15	893827.32	95.3	1.1549	0
cap104	928941.77	928941.77	928941.76	0	1.2246	0
cap131	793439.54	795885.56	794924.63	723.11	1.3666	0
cap132	851495.32	851670.13	851512.8	55.28	1.4069	0
cap134	928941.77	929477.59	928995.35	169.44	1.3733	0

Table 9. Results Of Binary CCO on UFLP for V2 Transfer Function

Cap	Best	Worst	Mean	Std	Time(s)	Gap(%)
cap71	932615.76	932615.76	932615.76	0	1.1665	0
cap72	977799.41	977799.41	977799.41	0	1.1513	0
cap73	1010641.48	1010641.48	1010641.48	0	1.1247	0
cap74	1034977.01	1034977.01	1034977.01	0	1.1005	0
cap101	796648.44	797657.28	797093.44	471.16	1.1929	0
cap102	854704.19	854704.19	854704.19	0	1.1835	0
cap103	893782.11	893782.11	893782.11	0	1.1937	0
cap104	928941.77	937725.37	929820.13	2777.62	1.1486	0
cap131	793439.54	797020.49	795440.88	1354.61	1.4192	0
cap132	851495.32	854704.2	851958.1	1009.27	1.4014	0

Table 10. Results Of Binary CCO on UFLP for V3 Transfer Function

Cap	Best	Worst	Mean	Std	Time(s)	Gap(%)
cap71	932615.76	932615.76	932615.76	0	1.1342	0
cap72	977799.41	977799.41	977799.41	0	1.1126	0
cap73	1010641.48	1010641.48	1010641.48	0	1.1065	0
cap74	1034977.01	1034977.01	1034977.01	0	1.0996	0
cap101	796648.44	797508.72	796906.52	415.56	1.1278	0
cap102	854704.19	854704.19	854704.19	0	1.1472	0
cap103	893782.11	894008.15	893804.72	71.48	1.2127	0
cap104	928941.77	928941.77	928941.76	0	1.1731	0
cap131	793439.54	795894.72	794116.01	760.7	1.3803	0
cap132	851495.32	854704.2	852037.67	1044.73	1.4161	0
cap134	928941.77	929477.59	929048.93	225.92	1.3071	0

Table 11. Results Of Binary CCO on UFLP for V4 Transfer Function

Cap	Best	Worst	Mean	Std	Time(s)	Gap(%)
cap71	932615.76	932615.76	932615.76	0	1.1326	0

cap72	977799.41	977799.41	977799.41	0	1.1113	0
cap73	1010641.48	1010641.48	1010641.48	0	1.0756	0
cap74	1034977.01	1034977.01	1034977.01	0	1.0854	0
cap101	796648.44	797508.72	796820.49	362.73	1.1507	0
cap102	854704.19	854704.19	854704.19	0	1.176	0
cap103	893782.11	893782.11	893782.11	0	1.1321	0
cap104	928941.77	928941.77	928941.76	0	1.1305	0
cap131	793439.54	794299.84	793855.64	440.6	1.4576	0
cap132	851495.32	854704.2	851892.47	1016.6	1.4123	0
cap134	928941.77	929477.59	928995.35	169.44	1.3219	0

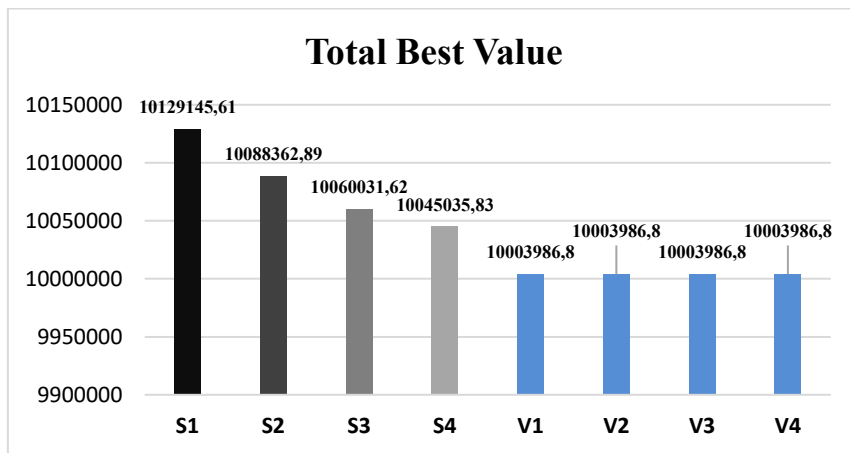


Figure 1. Total Best Value

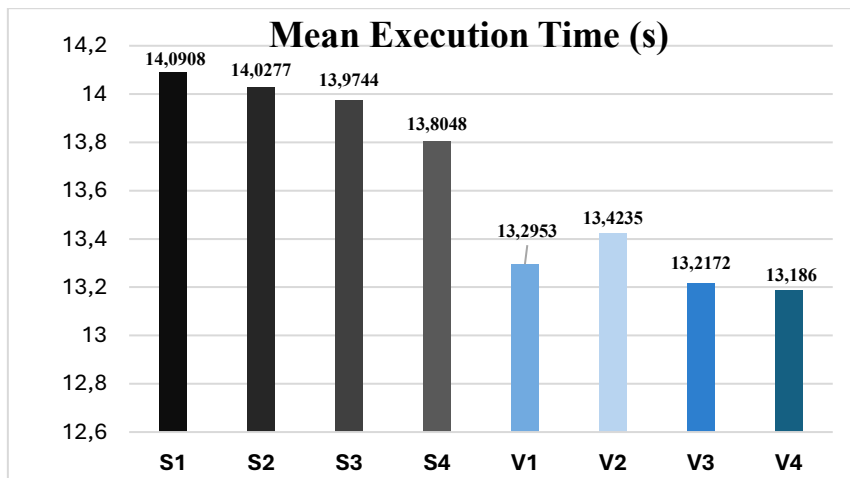
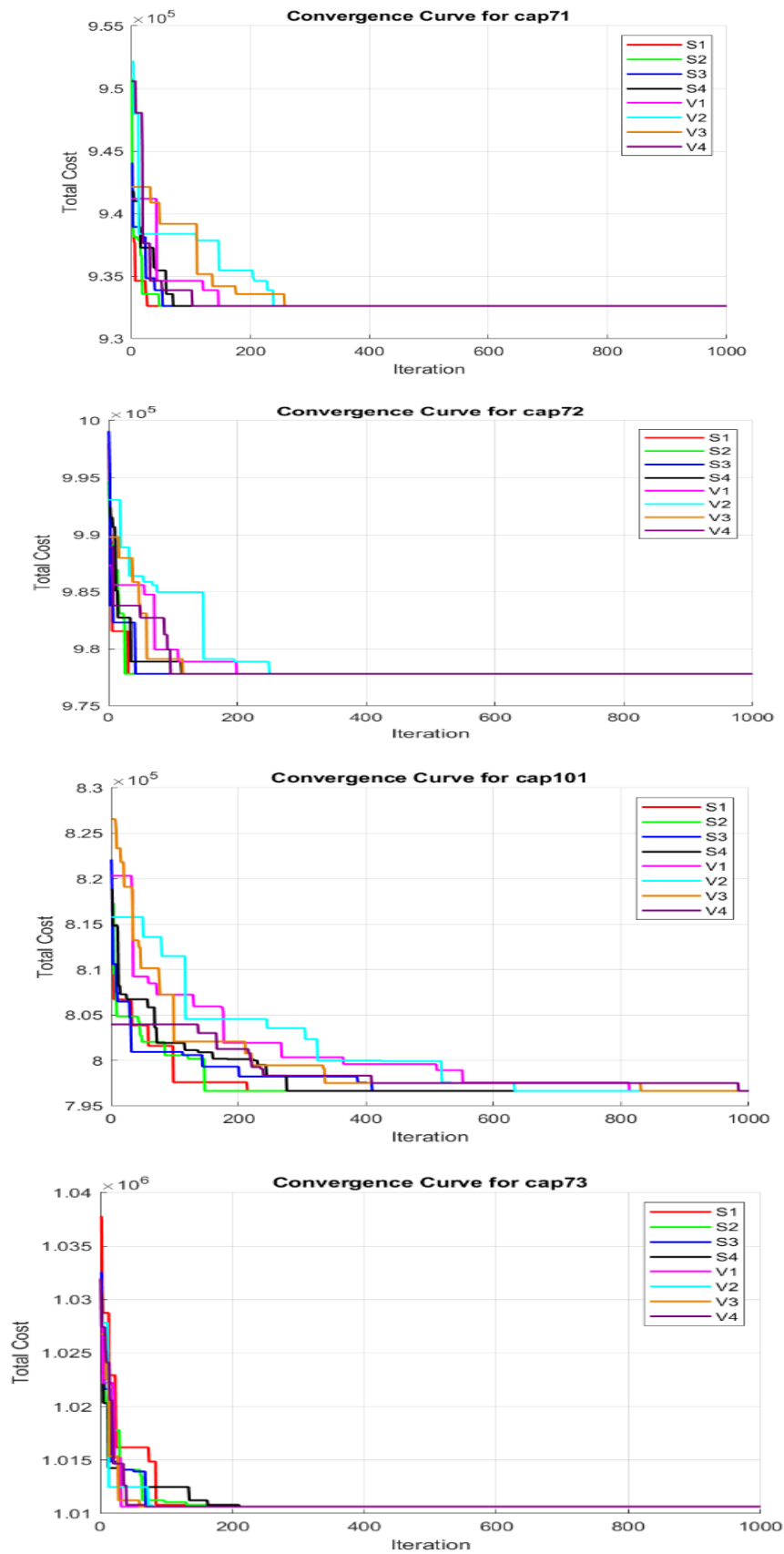
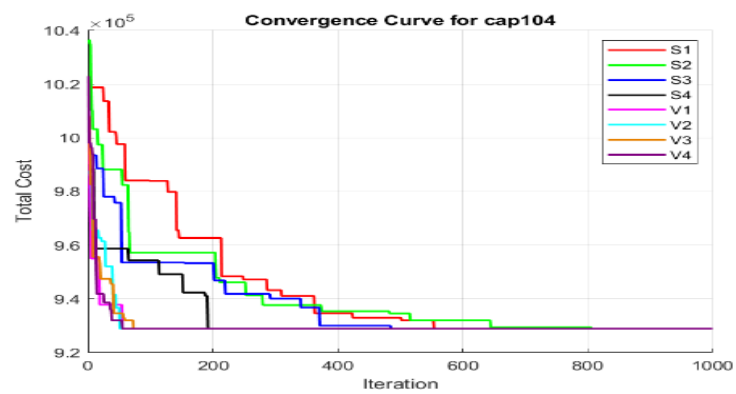
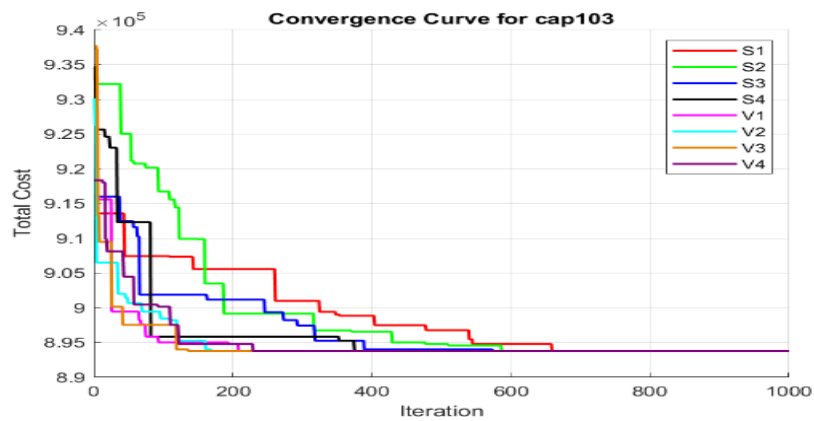
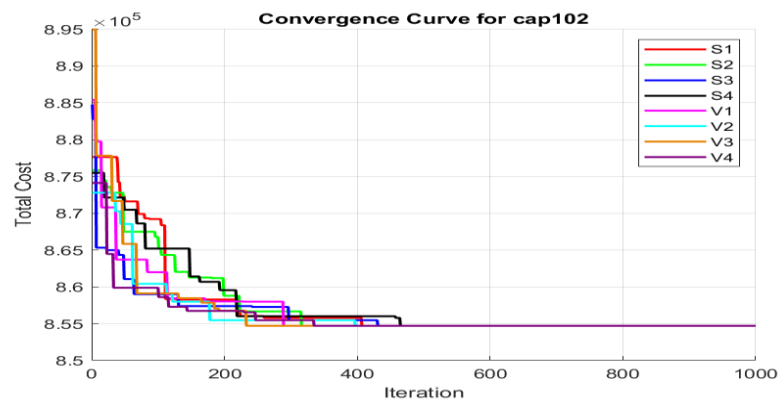
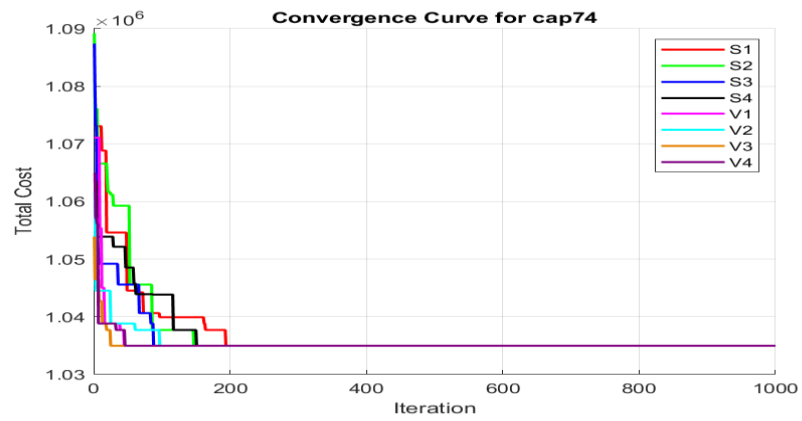


Figure 2. Mean Execution Time (s)





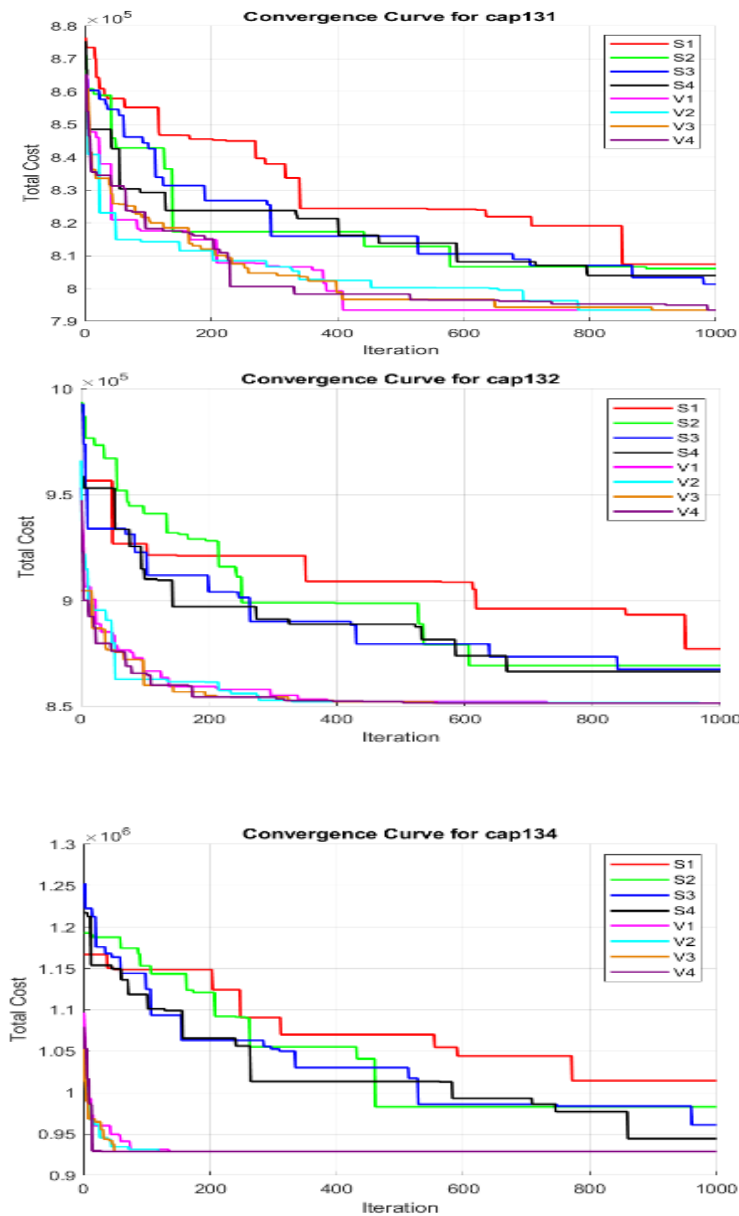


Figure 3. Convergence graphs

Evaluation of Experimental Results

Performance on the smaller datasets (cap71, cap72, cap73, and cap74), the algorithm demonstrated exceptional performance. As observed in the results table, all eight transfer functions (S1–S4 and V1–V4) successfully located the Global Optimum with a 0.00% optimality gap. The standard deviation for these instances was 0.00, indicating that the algorithm converged to the optimal solution in every single independent run. This proves the algorithm's high reliability in solving lower-dimensional UFLP problems. For the more complex datasets (cap101 through cap134), S-shaped functions managed to find the best solution in several runs but they exhibited higher instability in large scale problems like cap134. The significant gap between the best and worst costs, along with higher standard deviation values, suggests that S-shaped functions are more prone to getting trapped in local optima during the binary conversion process. V-shaped functions consistently outperformed S-shaped functions in terms of stability and average solution quality. For the most challenging instance (cap134), V-shaped functions-maintained a near-zero or zero gap with significantly lower standard deviations. This superior performance is attributed to the mechanism of V-shaped functions, which define the probability of changing a bit's value rather than forcing it to 0 or 1. This mechanism helps maintain population diversity and prevents premature convergence. A key finding in this study is the algorithm's capacity for exploration. Even in cases where the mean cost was higher the best cost often matched the theoretical optimum. This

confirms that the Binary CCO algorithm possesses the necessary search capability to locate the global optimum. However, the choice of transfer function plays a critical role in how consistently it finds that optimum. Based on the total best cost analysis and convergence behavior V-shaped functions (particularly V1 and V4) proved to be the most effective mapping strategies for the UFLP, offering the best balance between exploration and exploitation.

CONCLUSION AND FUTURE WORK

This study introduced the Binary Cuckoo Catfish Optimization (BCCO) algorithm as a robust and competitive meta-heuristic for solving the Uncapacitated Facility Location Problem (UFLP), a fundamental NP-hard challenge in logistics and supply chain management. Through extensive experimental validation using the standard OR-Library benchmark datasets (cap71–cap134), the proposed algorithm demonstrated exceptional performance, achieving a 0.00% optimality gap across the majority of test cases with minimal standard deviation.

A central contribution of this research was the rigorous comparative analysis of eight distinct transfer functions (1-4 S-shaped and 1-4 V-shaped) to evaluate their influence on mapping the continuous search space to a binary decision space. The findings indicate that while all functions performed reliably on small-scale instances, the V-shaped transfer functions (particularly V1 and V4) consistently outperformed the S-shaped family in terms of convergence speed and solution quality on higher-dimensional datasets. Specifically, S-shaped functions exhibited higher instability and were more prone to getting trapped in local optima in large-scale problems like cap134. In contrast, the V-shaped mechanism maintained superior population diversity and prevented premature convergence by defining the probability of changing a bit's value rather than forcing it toward a fixed binary state. These results confirm that the BCCO algorithm, when equipped with an appropriate V-shaped transfer function, provides an ideal balance between exploration and exploitation.

Moving forward, there are several promising avenues for future research. Given the algorithm's success in solving the UFLP, future studies should explore the application of BCCO to other discrete optimization challenges such as feature selection, the 0/1 knapsack problem, and wind turbine placement. Additionally, the performance of the algorithm could be further refined by investigating the integration of different chaotic maps or hybridizing BCCO with other local search operators to enhance its precision in even higher-dimensional search spaces.

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CLASSIFICATION OF PEAR VARIETIES USING PEAR LEAVES WITH YOLOv8

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ABSTRACT

In this study, the performance of the YOLO-based YOLOv8n-cls model was evaluated for pear cultivar classification using leaf images. In recent years, both detection- and classification-based approaches in agricultural applications have demonstrated significant success in the identification of crop diseases and the classification and detection of plant species and varieties. Within this framework, training, test and validation processes were carried out on the YOLOv8n-cls model using a dataset prepared in a controlled setup. The images were labelled according to cultivar identity with the guidance of local producers and agricultural engineers. The dataset was prepared within a closed box illuminated by LED strips, with the camera mounted at a fixed angle inside the box. Using this system, pear leaves collected in the late season (September–October) were imaged at a resolution of 1920×1080. During the training process, the model performance was analyzed using precision, recall, F1-score, and accuracy metrics, as well as top-1 and top-5 values, to validate the model performance on the test data. Recent literature indicates that classification and detection models belonging to the YOLO family have been extensively preferred in recent years, particularly due to their high accuracy and real-time processing capabilities when applied to agricultural image data. The results obtained in this study demonstrate that the YOLOv8n-cls architecture has demonstrated high classification accuracy for cultivar classification based on pear leaves. These findings suggest that YOLO-based systems can serve as fast and reliable tools in variety recognition processes within the agricultural sector; they highlight significant advantages in terms of reducing human-induced errors, validating local nomenclature, and reducing classification time.

Keywords: YOLOv8, Pear Leaf, Cultivar Classification, Agricultural Image Classification.

INTRODUCTION

The agricultural sector is one of the areas of strategic importance in terms of global food security, sustainable production and economic development. The accurate identification of plant varieties stands out as a critical requirement for production planning, increasing productivity, ensuring quality control and developing automated agricultural decision-support systems. Leaves, in particular, are structures that reflect the morphological characteristics of plants, are easily accessible, and often provide more reliable visual cues compared to other plant parts. Consequently, species and variety/cultivar identification studies based on leaf images are gaining increasing importance in precision agriculture applications.

Particularly in leaf-based studies, as morphological similarity between classes increases, the data collection and preparation process becomes even more critical. (Yang et al., 2022; Li et al., 2025; Zhang et al., 2021)

In the creation of leaf-based datasets, the data collection strategy varies according to the study's objective. In disease-focused datasets, the preservation of the healthy class and the clinically or symptomatically meaningful differentiation of diseased classes take precedence; whereas in variety/cultivar-focused datasets, due to intra-species similarity, each class must be established using samples with high representativeness.

Indeed, in the radish leaf dataset, comprising 5 classes and 2,801 images, healthy leaves were analyzed alongside four distinct disease classes (Hasan et al., 2025); in the orange HLB dataset, 649 leaves were divided into two main groups: healthy and infected (HLB) (Torres-Galván et al., 2025); whilst in the Jordan22 dataset, four different crops were organized into a total of eight classes based on their healthy and diseased states (Al-Shannaq et al., 2024). In contrast, in cultivar identification studies, 17,656 images were used for 33 varieties of pear (Li et al., 2025), 30,890 images for 118 varieties of *Camellia oleifera* (Dong et al., 2024), Over 5,000

images of 88 sweet cherry cultivars and 5,000 leaf images of 100 soya bean cultivars or elite breeding lines (Zhang et al., 2021) and 1,751 leaf images for 18 different walnut varieties (Karadeniz et al., 2024). This clearly demonstrates that as the number of classes increases, the dataset must also be scaled accordingly

Another key aspect of dataset design is the variety of devices, resolutions and capture methods. A significant portion of recent studies indicates that smartphone cameras and webcams are sufficient for dataset preparation.

For example, the Realme 9 5G was used in the radish dataset (Hasan et al., 2025), the Google Pixel 6A and iPhone XR were preferred in the BDMANGO dataset (Islam et al., 2025), and the iPhone 13 was used in the pear dataset (Li et al., 2025), a Huawei P40 was used in the Camellia oleifera study (Dong et al., 2024), and an iPhone 12 Pro Max was chosen for the Jordan22 dataset (Al-Shannaq et al., 2024). In contrast, the Fujifilm X-T4 was used in the coffee leaf dataset (Jepkoech et al., 2021), whilst the MFCIS study utilized a 600 DPI, 48-bit transmitted light scanner to capture vein and tissue details (Zhang et al., 2021). These differences demonstrate that the choice of equipment during dataset preparation is directly related to the research question and the targeted level of visual detail.

It can therefore be argued that the process of creating a leaf-based dataset is not merely a matter of collecting a large number of images. Rather, all elements—such as which leaves are selected, which device is used, and the background, angle, lighting, and validation process under which the images are captured—form part of a holistic experimental design. Indeed, in a recent study focusing on the classification of pear varieties based on leaf appearance, it was emphasized that leaves possess stable morphological features suitable for plant classification and that distinguishing pear varieties using traditional observational methods is challenging. The same study also noted that automatic classification based on leaf images offers a robust alternative to the time-consuming and error-prone manual identification process (Li et al., 2025).

Furthermore, in a remote sensing study focusing on tree species classification from aerial images, an experimental framework adapted to the YOLOv8 classification architecture was established using only the aerial image patch section of the TreeSatAI benchmark dataset. In the study, the n, s, m, l and x variants of YOLOv8 were tested; the images were resized to 288×288; and the training process was conducted over 20 epochs using SGD optimization, a learning rate of 0.01 and a batch size of 32. It has been reported that the best overall F1 scores achieved were in the region of 72% (Bayrak et al., 2023).

It is observed that studies specifically focusing on pear leaves are limited in the literature; however, various deep learning approaches have been proposed for the classification or segmentation of pear leaf diseases. For example, Wu et al. (2023) achieved high accuracy in leaf disease classification by developing a specialized segmentation network to separate pear leaves from the background. Alirezazadeh et al. (2023) demonstrated that CNN architectures integrated with CBAM improved classification performance on a pear leaf disease/stress symptom dataset. These studies indicate that deep learning methods hold significant potential for analyzing pear leaf images.

RESEARCH AND FINDINGS

In this study, a YOLO-based deep learning system was developed for the automatic classification of pear cultivars from leaf images. Classification methods are widely used in agricultural applications for disease detection, plant variety classification and species identification. In particular, models from the YOLO family stand out in real-time applications by providing both speed and high accuracy thanks to their single-stage architectures (Redmon et al., 2016).

In this study, the YOLOv8n-cls architecture was selected as the classification model. The model comprises a backbone consisting of Conv and C2f blocks that extract features from the image, and a classification head that generates class probabilities in the final stage. Whilst the Conv blocks learn basic visual patterns, the C2f blocks transform these patterns into more distinctive representations. In this study, the network was configured to distinguish between nine different pear leaf classes. Due to its lightweight architecture and computational efficiency, YOLOv8n-cls was deemed a suitable architecture for the scope of this study.

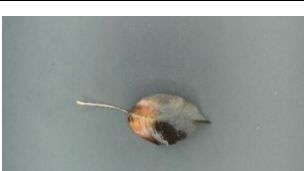
In this study, pear variety classification based on leaf images was performed using YOLOv8n-cls. Numerous studies have demonstrated that YOLO models yield successful results in plant disease detection and leaf-based analysis within the agricultural sector (Ma et al., 2023; Araaf et al., 2024; Qin et al., 2025)

Dataset:

The dataset used in this study consists of leaf images from different pear varieties. The dataset contains images that reflect the morphological differences in pear leaves and has been prepared specifically for the variety classification problem. As the correct labelling of leaf images directly affects the performance of image classification models, a careful labelling approach was followed during the dataset creation process.

In this study, a total of 1349 images across 9 different classes were captured using a Logitech StreamCam for the classification of pear leaf varieties. The leaf images were obtained at a resolution of 1920×1080 pixels using a computer and camera, with the assistance of a specific setup created after the leaves were collected from their natural environments by an Agricultural Engineer and local producers. All images were resized to 224×224 pixels, after which the dataset was split into 70% training, 20% validation and 10% test sets. The YOLOv8n-cls model was trained on the resulting datasets for 30 epochs; the models' performance was evaluated using precision, recall, F1-score and accuracy metrics. Cultivar labels were kept in their original local form.

Table 1. Sample images and class names

EXAMPLE IMAGE FOR THE CLASS	CLASSES
	CONFERANSA
	DEVECİ
	JAPON
	MARGARİT
	LİMON
	OKKACA

	SANTAMARİA
	SHİNSEKİ
	HAZİRAN GÜLÜ

RESULTS

In this study, a classification network was developed based on the YOLOv8n-cls architecture to distinguish between nine different classes of pear leaves. For each class in the dataset, the data was randomly split into training (70%), validation (20%) and test (10%) sets. Throughout the training process, the loss function decreased steadily; whilst the Top-1 accuracy was 0.444 in the first epoch, it reached 0.936 in the final epoch. During the validation phase, the Top-1 accuracy for all classes was recorded as 0.939850, and the Top-5 accuracy as 1.00.

The results obtained during the test phase are as follows: Top-1 accuracy: 0.9370, Top-5 accuracy: 1.000. For a detailed performance evaluation, precision, recall, F1-score and support metrics were calculated for each class.

Upon examining the class-based findings, it was observed that the model produced very high precision, recall and F1-score values for the Hazirangulu, Conferansa, Japon, Limon and Okkaca classes. In contrast, the most significant drop in performance was observed in the Deveci and Santamaria classes. In particular, the test results for the deveci class, where precision = 0.5625 and recall = 1.0000 were obtained, indicate that the model was successful in capturing genuine deveci examples but also predicted some examples from other classes as deveci. In the Santamaria class, precision = 1.0000 and recall = 0.5455 were found; this indicates that the model made correct decisions for the examples it predicted as Santamaria but missed a significant proportion of the actual Santamaria examples. Furthermore, Macro F1 = 0.9203 was found in the validation set and Macro F1 = 0.9177 in the test set; the Weighted F1 values were calculated as 0.9371 and 0.9385 respectively. These results demonstrate that the model generally exhibits strong performance and, given the close similarity between the validation and test results, possesses good generalisation ability. The Macro Precision, Macro Recall and Macro F1 scores indicate that the model demonstrates high and balanced performance when all classes are evaluated with equal weighting. Conversely, the fact that the Weighted Recall and Weighted F1 scores are slightly higher than the macro averages indicates that, due to the influence of support (i.e. the number of examples in each class), the model performs more strongly in some classes and relatively weaker in others. When these findings are considered together, it is evident that the model's overall classification performance is high; however, class-specific sample distributions and differences in support significantly influence performance.

Table 2. Top-1 and Top-5 accuracy results for validation and test

Split	Top1 accuracy	Top5 accuracy
Validation	0.939850	1.0
Test	0.937063	1.0

Table 3. General classification metrics for validation and test

Split	Accuracy	Precision Macro	Recall Macro	F1 Macro	Precision Weighted	Recall Weighted	F1 Weighted
Validation	0.9398	0.9293	0.9256	0.9203	0.9436	0.9398	0.9371
Test	0.9371	0.9414	0.9231	0.9177	0.9587	0.9371	0.9385

Table 4. Validation data results

Class name	Precision	Recall	F1	Support
Conferansa	0.9583	1.0000	0.9787	23.0
Deveci	0.7000	0.9333	0.8000	15.0
Hazirangulu	1.0000	1.0000	1.0000	27.0
Japon	0.9667	1.0000	0.9831	29.0
Limon	0.9608	0.9800	0.9703	50.0
Margarit	0.9697	0.9143	0.9412	35.0
Okkaca	0.9615	1.0000	0.9804	25.0
Santamaria	0.9167	0.5500	0.6875	20.0
Shinseki	0.9302	0.9524	0.9412	42.0

Table 5. Test data results

Class name	Precision	Recall	F1	Support
Conferansa	1.0000	1.0000	1.0000	13.0
Deveci	0.5625	1.0000	0.7200	9.0
Hazirangulu	1.0000	1.0000	1.0000	14.0
Japon	1.0000	0.9375	0.9677	16.0
Limon	0.9630	1.0000	0.9811	26.0
Margarit	0.9474	0.9474	0.9474	19.0
Okkaca	1.0000	0.9231	0.9600	13.0
Santamaria	1.0000	0.5455	0.7059	11.0
Shinseki	1.0000	0.9545	0.9767	22.0

In this study, a YOLOv8n-cls-based image classification model was developed to distinguish between nine different classes of pear leaves, and the model's performance was evaluated during the training, validation and test phases. Throughout the training process, a steady decrease in the loss function was observed, indicating that the model had consistently learned the fundamental patterns in the dataset. Although the reduction in training loss continued towards the final epochs, the increase in validation accuracy remained limited. This finding suggests that the model generally fits the dataset well, but that the additional gains achieved in the final stages are limited.

According to the overall performance results, the model achieved an accuracy of 0.9398 on the validation set and 0.9371 on the test set. The fact that these two values are very close to each other indicates that the model not only fits the validation data well but also maintains similar performance on unseen test data. Furthermore, on the validation set, Macro Precision = 0.9293, Macro Recall = 0.9256 and Macro F1 = 0.9203; on the test set, these values were calculated as 0.9414, 0.9231 and 0.9177 respectively. When weighted metrics are examined, the values for the validation set are Weighted Precision = 0.9436, Weighted Recall = 0.9398 and Weighted F1 = 0.9371; for the test set, these values are 0.9587, 0.9371 and 0.9385. These results indicate that the model generally demonstrates high performance, although the level of success is not distributed equally across all classes.

Similarly, the fact that the Top-5 accuracy value is 1.0000 for both the validation and test sets shows that the model retains the true class among the top candidates even in cases where it made an error in the initial prediction. When class-based results are examined, it is observed that the model performs exceptionally well in the Hazirangülü, Conferansa, Japon, Limon, and Okkaca classes. Conversely, class-based analyses reveal more pronounced error patterns, particularly in the Deveci and Santamaria classes. On the validation set, for the Deveci class, precision = 0.7000, recall = 0.9333, and F1 = 0.8000 were obtained. This result indicates that the model captures the true deveci examples to a large extent but also predicts some other classes as Deveci.

CONCLUSION AND FUTURE WORK

The findings indicate that the YOLOv8n-cls-based model is generally successful in distinguishing between nine different classes of pear leaves. In particular, the fact that the validation and test accuracy values are very close to one another demonstrates that the model possesses good generalisation ability. Overall, the model achieved 0.9398 accuracy on the validation set and 0.9371 accuracy on the test set, while Top-5 accuracy reached 1.0000 for both splits. Moreover, the Macro F1-scores of 0.9203 and 0.9177, together with the Weighted F1-scores of 0.9371 and 0.9385 for the validation and test sets, respectively, confirm that the proposed approach delivered strong overall classification performance. However, class-based analyses also showed that some cultivars, particularly Deveci and Santamaria, were more difficult to distinguish than the others.

The results of this study indicate that whilst the model's overall performance is high, there is a need for improvement in certain classes. Therefore, class-based data augmentation strategies are proposed as a first step. In particular, considering the error patterns observed in the Santamaria and Deveci classes, increasing the number of samples for these classes and expanding sample diversity could contribute to the model learning a stronger representation. Including different leaf angles, varying lighting conditions and natural appearance variations in the dataset could be particularly beneficial for the Santamaria class, which suffers from recall issues.

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A LIGHTWEIGHT QR-ASSISTED ZERO-KNOWLEDGE IDENTIFICATION PROTOCOL FOR SECURE AUTHENTICATION

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ABSTRACT

This study proposes a lightweight Zero-Knowledge authentication model supported by QR codes. The approach is based on the Schnorr authentication protocol and provides an additional security layer against replay attacks through nonce and timestamp mechanisms. The proof data generated by the prover is embedded within a QR code and transmitted to the verifier. Thus, the system enables verification of knowledge of the secret key without revealing it. Simulation results show that proof generation and verification times under a 256-bit security level are in the millisecond range. Additionally, the proof size remains constant at approximately 0.5 KB, making it suitable for practical applications in terms of QR code capacity. The findings indicate that the proposed model is applicable in mobile and low-resource systems in terms of both security and performance.

Keywords: Zero-Knowledge Proof, Schnorr Protocol, QR Code Authentication

ÖZET

Bu çalışmada, QR kod destekli hafif bir Zero-Knowledge kimlik doğrulama modeli önerilmektedir. Önerilen yaklaşım, Schnorr tabanlı kimlik doğrulama protokolünü temel almakta ve nonce ile zaman damgası mekanizmaları aracılığıyla yeniden oynatma (replay) saldırılarına karşı ek güvenlik katmanı sağlamaktadır. Kanıtlayıcı tarafta üretilen kanıt verisi QR kod içerisine gömülerek doğrulayıcıya iletilmektedir. Böylece sistem, gizli anahtarın ifşa edilmeden matematiksel olarak doğrulanmasına olanak tanımaktadır. Gerçekleştirilen simülasyon sonuçlarına göre, 256-bit güvenlik seviyesinde kanıt üretim ve doğrulama sürelerinin milisaniye seviyesinde olduğu gözlemlenmiştir. Ayrıca kanıt boyutunun yaklaşık 0.5 KB civarında sabit kaldığı ve QR kod kapasitesi açısından pratik uygulamalara uygun olduğu belirlenmiştir. Elde edilen bulgular, önerilen modelin hem güvenlik hem de performans açısından mobil ve düşük kaynaklı sistemlerde uygulanabilir olduğunu göstermektedir.

Anahtar kelimeler: Sıfır Bilgi Kanıtı, Schnorr Protokolü, QR Kod Kimlik Doğrulaması

INTRODUCTION

Secure authentication is crucial in today's mobile, distributed, and resource-constrained environments. Traditional authentication methods, such as password-based systems, one-time passwords, and certificate infrastructures, often require third-party systems to process sensitive user information. However, inadequate or poorly implemented authentication mechanisms introduce security risks, including identity theft, data leakage, and replay attacks [1-3].

Zero-Knowledge Proof (ZKP) protocols are robust cryptographic methods that enable a user to prove knowledge of confidential information without revealing it [4]. The Fiat-Shamir transformation is widely used in digital signature and authentication systems, as it converts interactive authentication protocols into non-interactive ones [5]. Schnorr-based authentication protocols, due to their mathematical security based on the difficulty of the discrete logarithm problem, are widely recognised in the literature for their security and computational efficiency in authentication and zero-knowledge proof applications [6-7]. However, their applicability in lightweight and mobile environments and their resilience to replay attacks in practical deployments remain limited.

Quick Response (QR) codes are widely used for rapid data transfer on mobile devices and in contactless authentication systems. QR-based systems are often preferred for event entry, payment, and check-in

processes. However, most existing systems require a central server for verification, which creates serious security vulnerabilities if the QR code is copied or reused [8].

Numerous studies in the literature investigate ZKP-based or QR-code-based mechanisms for identity verification, data privacy, and secure access control. In one ZKP-based study, Moya et al. presented a privacy-protected authentication system called ZKBAR-V, which integrates zero-knowledge proofs with blockchain for academic record verification [9]. In another study, Maidine et al. proposed a blockchain-based identity management architecture for verifying IoT and identity claims, aiming to reduce dependence on centralised third parties by using ZKPs [10]. Al-Karawi and Akdeniz proposed a technique combining federated learning with ZKPs for privacy-protected authentication in 5G networks [11]. In another study, Patil et al. proposed an age verification system based on ZKP. This system enables identity verification without disclosing user data by using blockchain, a decentralised identity framework (SSI), verifiable credentials, and ZKPs [12].

Research on QR codes generally focuses on secure QR code generation and verification techniques to prevent tampering or counterfeiting. In his study, Alsuhibany proposed a system that protects QR code integrity through dynamic QR code generation and digital watermark integration [13]. In another study, Abbas analysed QR code-based two-factor authentication systems, aiming to improve the existing security of QR codes and reduce the risk of unauthorised access [14]. In their research, Sarkhi and Mishra developed a deep learning-based model for detecting and classifying cyberattacks using QR codes. They focused on identifying security threats by classifying whether the QR code content is malicious [15].

There are also studies in the literature where ZKP and QR code-based applications are used together. In one such study, Gokulakrishnan et al. proposed an identity and transaction verification system that utilises ZKP to ensure trust without disclosing confidential data. In this system, users and third parties can verify the validity of evidence using a QR code-based authentication mechanism that sends queries to the server endpoint without revealing private details [16]. In another study, Raipurkar et al. proposed a blockchain-based platform where real identities of users are stored in the relevant web applications using decentralised storage. On this platform, credentials are verified using ZKP and QR codes [17].

This study proposes a lightweight QR-enabled zero-knowledge authentication protocol that integrates QR-based data transmission with a Schnorr-based, non-interactive zero-knowledge authentication protocol. The model eliminates interactive verification steps through a Fiat-Shamir transformation and protects against replay attacks using a time-based verification mechanism. The generated zero-knowledge proof components are embedded within a dynamically generated QR code, resulting in a privacy-preserving verification process with low infrastructure requirements.

The main contributions of this study are as follows:

1. Design of a lightweight, non-interactive zero-knowledge authentication protocol that can be transmitted via QR code,
2. Reduction of replay risk through a timestamp-based verification mechanism,
3. Evaluation of the compatibility of the proof size with QR code capacity.

Unlike blockchain-based identity models, this study focuses on low computational cost, minimal infrastructure requirements, and suitability for mobile environments. It therefore offers a viable secure authentication solution for IoT gateway systems, temporary access control mechanisms, and mobile authentication applications. Experimental results show that the proposed protocol provides strong cryptographic security while maintaining a sufficiently low computational load for practical applications.

PROPOSED PROTOCOL

Parameters

p is a large prime and g is a generator of the multiplicative group modulo p . The prover selects a private key $x \in \mathbb{Z}_{\{p-1\}}$ and computes the public key $y = g^x \bmod p$. The public key y is registered with the verifier before authentication.

Prover Side (Proof Generation)

The prover refers to the party that possesses the private key (x) and wishes to verify its identity without revealing it. This component generates a random value (r) using a Schnorr-based zero-knowledge identification mechanism and calculates a temporary commitment value (t) accordingly. A challenge (c) is then created by

inputting t , the nonce, and the timestamp into a hash function. Subsequently, the response value (s) is generated using r , c , and x . Throughout this process, x is never disclosed; only a mathematically verifiable proof is produced. Thus, the prover demonstrates identity without leaking information, relying on the computational hardness of the discrete logarithm problem. The generated proof is then encoded in QR format and prepared for transmission.

The prover performs the following operations in sequence:

1. Stores the private key x .
2. Generates a random value r .
3. Computes the temporary commitment value $t = g^r \bmod p$.
4. Calculates the challenge value $c = \text{Hash}(t \parallel y \parallel \text{nonce} \parallel \text{timestamp})$.
5. Calculates the response $s = r + cx \bmod (p - 1)$.
6. Embeds the proof data $\pi = (t, s, \text{nonce}, \text{timestamp})$ in JSON format into a QR code.

Verifier Side

The verifier is the validation component that mathematically checks the accuracy of the proof generated by the prover. It decodes the proof transmitted via QR code, checks the validity of the timestamp, and reconstructs the value of c using a hash function. It then tests the Schnorr validation equation $g^s = t \cdot y^c \bmod p$. If the equation holds, the proof is accepted; otherwise, it is rejected. As the verifier performs validation based solely on the public key, the system maintains zero-knowledge functionality. In addition, time tolerance control protects against replay attacks.

The verifier performs the following operations in sequence:

1. Reads the proof (π) from the QR code.
2. Performs a timestamp check.
3. Calculates the challenge value $c = \text{Hash}(t \parallel y \parallel \text{nonce} \parallel \text{timestamp})$.
4. Checks the equality: $g^s = t \cdot y^c \bmod p$.
5. Gives an Accept or Reject decision.

QR channel

A QR channel is a carrier layer that enables the transmission of generated zero-knowledge proofs over a physical or optical medium. This channel allows proof data encoded in JSON format to be transferred between two parties without a network connection. The QR mechanism does not provide cryptographic security; it only enables one-way data transmission while preserving the integrity of the proof. However, as QR codes are easily copied, there is a risk of replay, so the system implements a timestamp and nonce mechanism for freshness verification. This approach allows the QR channel to offer a practical and contactless transmission solution without compromising security.

SECURITY & PERFORMANCE ANALYSIS

Security Analysis

The proposed QR-enabled zero-knowledge authentication protocol is based on a Schnorr identification mechanism and derives its security from the computational difficulty of the Discrete Logarithm Problem (DLP). The protocol's key security features are examined below.

Completeness

If the prover knows the secret key x and follows the protocol steps correctly, the verifier will satisfy the equation $g^s = t \cdot y^c \bmod p$. This equation is derived from $s = r + cx \bmod (p - 1)$. Therefore, verification always succeeds between honest parties.

Soundness

If the attacker does not know the secret key x , satisfying the validation equation requires solving a discrete logarithm problem. The probability that an adversary can satisfy the verification equation without knowledge of the secret key is negligible under the hardness assumption of the discrete logarithm problem. As the challenge value generated by the hash function is deterministic and unpredictable, it is practically impossible for the attacker to produce a valid proof in advance.

Zero-Knowledge Property

The protocol does not reveal any information about the secret key. Extracting the secret key from the generated proof values requires solving a discrete logarithm problem. Furthermore, as the challenge value is generated using a hash function, a non-interactive version of the interactive structure (the Fiat–Shamir transformation) is applied.

Replay Attack Resistance

Due to the visually copyable nature of QR codes, replay attacks present a significant threat. The proposed model addresses this risk through two mechanisms:

A timestamp, indicating when the proof was generated, enables verification of its validity window during the authentication process. The verifier compares the timestamp in the proof with the current system time to determine if it falls within a specified tolerance range (Δ). If the time difference exceeds a predefined threshold, the proof is rejected. This method adds an extra layer of protection against delayed replay attacks. The timestamp offers temporal context, ensuring the proof is valid only within a specific time frame.

A nonce is a randomly generated, single-use value for each authentication session. Its primary purpose is to ensure that proofs generated with the same secret key and similar timing remain distinct (proof diversity). Proofs with manipulated timestamps are rejected during verification.

Performance Analysis

The protocol's performance was analysed using a Python-based simulation environment. The implementation utilises modular exponentiation operations of the Schnorr protocol and the SHA-256 cryptographic hash function for challenge generation. The analysis evaluates the computational cost of the cryptographic operations and the size of the generated proof.

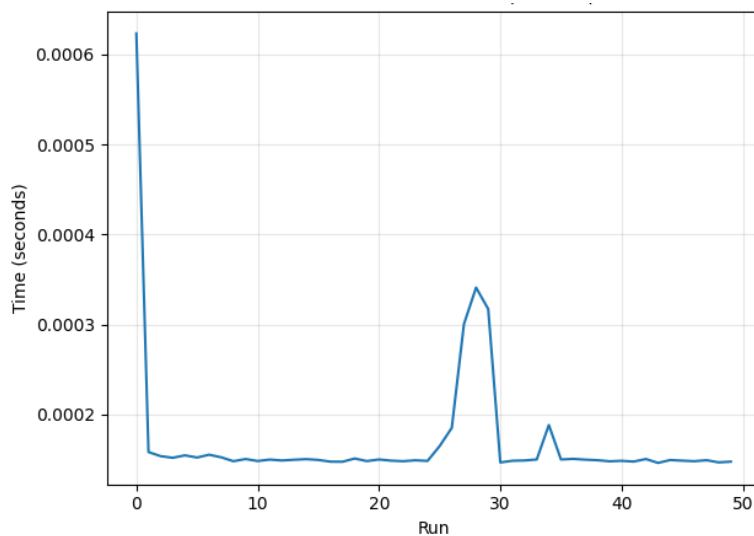


Figure 1. Proof Generation Time (256-bit)

Figure 1 shows the proof generation time on the prover side over 50 iterations. The results indicate that the generation time generally ranges from 0.00014 to 0.00018 seconds. The higher time observed in the first run is due to the costs of prime number generation and parameter initialisation. Similarly, small increases observed during some iterations may result from the variability of random number generation and modular exponentiation operations, depending on system load. Overall, the generation time is lower than or similar to the verification time. This suggests that the system is computationally lightweight on the client side and suitable for real-time authentication scenarios.

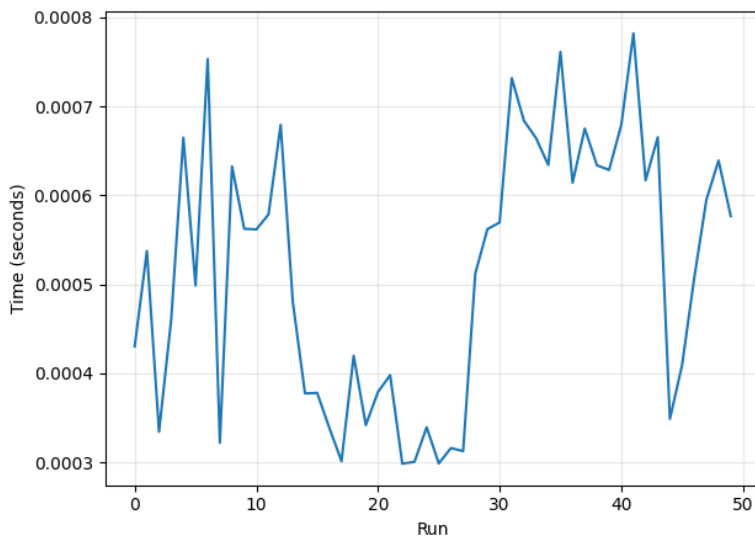


Figure 2. Proof Verification Time (256-bit)

Figure 2 shows the validation time of a zero-knowledge proof under a 256-bit security parameter over 50 independent runs. The horizontal axis indicates the number of test iterations, and the vertical axis shows the validation time (in seconds). The results indicate that the validation time ranges approximately from 0.00030 to 0.00078 seconds. Minor fluctuations in execution time are mainly attributable to system load variations, randomness in parameter generation, and Python interpreter overhead. Overall, the validation time remains below one millisecond. This demonstrates that the Schnorr-based validation process is computationally lightweight, requiring only two modular exponentiation steps and one hash calculation. This result is particularly significant for applicability to mobile or low-end verifier devices.

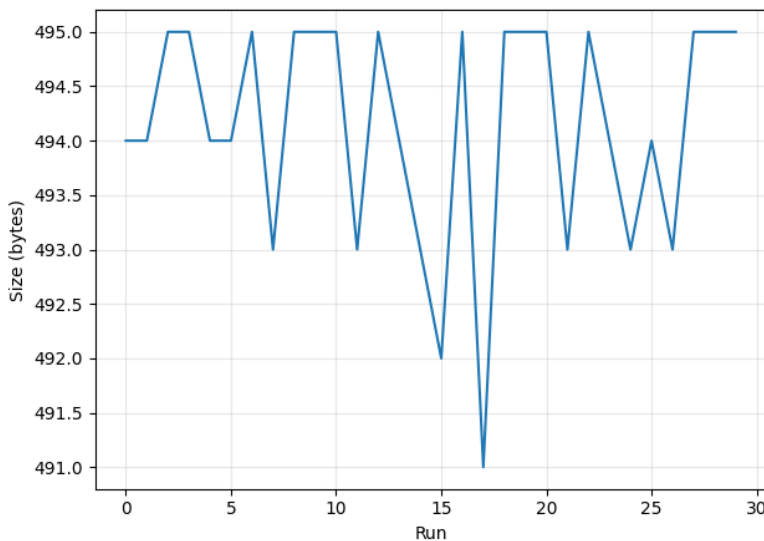


Figure 3. Zero-Knowledge Proof Size (bytes)

Figure 3 shows the size in bytes of the generated proof data after encoding in JSON format. The horizontal axis shows the different generation attempts, while the vertical axis indicates the proof size (bytes). The proof size remains constant at approximately 491–495 bytes. This result suggests that the proof structure comprises deterministic-length cryptographic parameters and that the data size does not vary significantly from sessions. This data, at approximately 0.5 KB, is well suited to QR code capacity and can be easily transmitted even with lower-version QR codes. This supports the system's applicability in practical deployment scenarios, such as physical access control and mobile authentication.

CONCLUSION

In this study, a lightweight, QR-supported Zero-Knowledge authentication protocol is designed and evaluated for performance. The proposed model employs a Schnorr mechanism based on the difficulty of the discrete

logarithm problem to enable verification without revealing the secret key. Session freshness is ensured through nonce and timestamp components, providing additional resilience against replay attacks.

Simulation results indicate that the system is suitable for practical applications, offering millisecond-level processing times and a fixed proof size. The proposed model is considered a viable solution, particularly for QR code-based physical access systems, mobile authentication scenarios, and devices with low computational capacity.

This study introduces a lightweight and practical authentication architecture suitable for QR-based verification environments. Future work will focus on integrating the model with blockchain-based identity management infrastructures, conducting scalability analyses, and performing experimental tests on real hardware. In this way, the role of the proposed approach in distributed authentication systems can be evaluated more comprehensively.

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STUDENT VIEWS ON INFORMAL EDUCATION AND SOCIAL MEDIA AND ARTIFICIAL INTELLIGENCE APPLICATIONS THAT BRING THE END OF FORMAL EDUCATION

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ABSTRACT

The formal and formal education systems of the 21st century have been powerless, helpless, ineffective and inadequate against the pressures caused by informal education, social media, the virtual world and globalization all over the world. The events and phenomena caused by the cultural, social, global and political decay on earth prevent people from benefiting from the positive effects of formal education. Schools cannot save their students from the evil and negativity of social media, virtual worlds and informal education practices. Learning individuals are uncontrollably affected by the educational processes created by informal environments. The local and universal values that humanity has created for centuries have been replaced by nonformal education practices influenced by numb brains representing corruption, violence and vulgarity that reflect all kinds of negativities. Informal education activities and organizations that do not care about any value, uncontrolled and unsupervised artificial intelligence applications have made formal and professional education ineffective, inadequate and unimportant. The aim of this research is to identify the negative effects of informal education practices, which cause schools—centers for socialization, cultural development, and personal growth—to become dysfunctional, as well as the negative impacts of the virtual world, social media, and artificial intelligence on formal education. The research is a comparative qualitative model study that aims to describe the views of higher education students regarding the ineffectiveness of formal education. In the study, a semi-structured interview form was developed by the researcher by using the opinions of academicians from information technologies, sociology, educational science and communication sciences. The study involved 10 undergraduate students from different universities. According to the research findings, university students emphasize that social media, the virtual world, informal education, and artificial intelligence are increasingly having a negative impact on formal education. According to the results of the research, although university students state that their hopes are not like that, they think that artificial intelligence applications can take over the roles of schools and teachers in the future.

Keywords: Formal Education, Formal Education, Informal Education, Social Media, Virtual World, Artificial Intelligence Applications.

FORMAL EĞİTİMİN SONUNU GETİREN İNFORMAL EĞİTİM ve SOSYAL MEDYA ile YAPAY ZEKÂ UYGULAMALARINA İLİŞKİN ÖĞRENCİ GÖRÜŞLERİ

ÖZET

21. Yüzyılın örgün ve formal eğitim sistemleri, bütün dünyada, informal eğitim, sosyal medya, sanal âlem ve küreselleşmenin neden olduğu baskılara karşı güçsüz, çaresiz, etkisiz ve yetersiz kalmıştır. Yerküre üzerinde yaşanan kültürel, sosyal, küresel ve politik çürümenin yol açtığı olaylar ve olgular, insanların formal eğitimin olumlu etkilerinden yararlanmalarını engellemektedir. Okullar, öğrencilerini, sosyal medya, sanal âlemler ve informal eğitim uygulamalarının kötülük ve olumsuzluklarından kurtaramamaktadırlar. Öğrenen bireyler, informal çevrelerin yarattığı eğitim süreçlerinden kontrolsüz bir biçimde etkilenmektedirler. İnsanlığın asırlar boyu yaratmış olduğu yerel ve evrensel değerlerin yerini, her türlü olumsuzluğu yansıtan yozlaşma, şiddet ve bayağılığı temsil eden uyuşmuş beyinlerin etkilediği nonformal eğitim uygulamaları almıştır. Hiçbir değeri önemsemeyen informal eğitim faaliyetleri ve örgütler, kontrolsüz ve denetimsiz yapay zekâ uygulamaları, formal ve profesyonel eğitimi etkisiz, yetersiz ve önemsiz hale getirmiştir. Bu araştırmanın amacı, sosyalleşme, kültürlenme ve çok kişisel gelişim merkezleri olan okulların işlevsizleşmesine neden olan informal eğitim uygulamaları ile sanal âlem, sosyal medya ve yapay zekânın formal eğitim üzerindeki olumsuz etkilerini saptamaktır. Araştırma, formal eğitimin içinde bulunduğu etkisizlikle ilgili olarak yükseköğrenim öğrenci görüşlerini betimlemeyi hedefleyen karşılaştırmalı türden nitel modelde bir çalışmadır. Araştırmada,

araştırmacı tarafından bilişim teknolojileri, sosyoloji, eğitim bilim ve iletişim bilim dallarından akademisyenlerin görüşlerinden yararlanılarak yarı yapılandırılmış görüşme formu geliştirilmiştir. Araştırmaya, farklı üniversitelerde öğrenim gören 10 lisans öğrencisi katılmıştır. Araştırma bulgularına göre, üniversite öğrencileri, sosyal medya, sanal âlem, informal eğitim ile yapay zekânın, formal eğitim üzerinde gittikçe artan oranda olumsuz etkiye sahip olduğunu vurgulamaktadırlar. Araştırma sonuçlarına göre, üniversite öğrencileri umutlarının öyle olmadığını ifade etseler de gelecekte yapay zekâ uygulamalarının okulların ve öğretmenlerin rollerini üstlenebileceğini düşünmektedirler.

Anahtar Sözcükler: Formal Eğitim, Örgün Eğitim, İnfomal Eğitim, Sosyal Medya, Sanal Âlem, Yapay Zekâ Uygulamaları.

GİRİŞ

İnsan, binlerce yıllık geçmişi ve kültürü ile yerküre üzerinde birçok medeniyet kurmuş; kültürel birikimini birçok farklı yolla başka dünyalara ve medeniyetlere, çağlara aktarmış bir varlıktır. İnsanlık, çağları aşan değişim gücüyle yerküreyi ve kendini yok etmeden 21. Yüzyıla erişmeyi başaramıştır. İnsanlar, aynı zamanda edindiği kültürel değerler ile örf ve adetlerini gelecek nesillere aktararak daha iyi bir yaşam umudunu sürekli geliştirmeye çalışmıştır. Ancak ne yazık ki insanlığın tarih boyunca edindiği değerler, kültürel birikim, yarattığı bilimsel değişim ve teknoloji; 21. Yüzyıl dünyasında daha iyi bir yaşam ve medeniyetin ortaya çıkmasını sağlayamamıştır. Emparyalizmin yol açtığı savaş ve baskılar ile dünyayı kendilerinin işgal merkezi olarak kullanan otokratik zihniyet ve rejimler, insanlığı yok etmek adeta yarış içerisinde dirler. Başta Birleşmiş Milletler olmak üzere uluslararası örgütlerin hemen hemen tamamı antidemokratik ve baskıcı rejim ve otokratik yönetimlerin kuklaları haline gelerek, dünyayı hızla yaşanmaz hale getirmektedirler.

Sosyal çürüme, teknolojik yıkım, savaşlar, antidemokratik baskı ve rejimler vb. insan eliyle toplumlara ve yerküreye verilen zarar, hiçbir dönemde 21. Yüzyılda olduğu kadar gerçekleşmemiştir. İnsanların, kendilerini daha çok geliştirmek ve öğrenme ihtiyaçlarını gidermek için oluşturdukları okul denilen sosyolojik çevreler, insanları geliştirmek yerine, öğrencilerin ve sosyal medyanın olumsuzluklarına, kötü yönlendirmelerine alet edilmiştir. Okullar, çevrelerinin aydınlanma ve değişim merkezleri olmaları gerekirken sosyal çürümüşlük alanları olmuştur. Formal eğitim merkezleri olan okullar, öğrencilerden kamuoyuna yansıyan şiddet, bencillik, başarısızlık, davranış bozuklukları, disiplinsizlik vb. görüntülerle anılır hale gelmiştir. Total toplumsal kalkınmanın itici gücü olması gereken formal, örgün ve yüz yüze eğitim merkezleri, informal eğitimin sıradanlığına, bilişim teknolojilerinin sınırsız ve kontrolsüz saldırılarına, sanal âlem ve sosyal medya uygulamalarının kötülüklerine teslim olmuştur.

Problem Durumu

Formal eğitimi her yönden en çok etkileyen eğitim türlerinden biri informal eğitimidir. Öğrencilere, formal eğitimle kazandırılan istendik bilişsel, duyuşsal, devinsel davranışların; okul çevresinde veya okul dışında yok olup kaybolmasına, önemini yitirmesine, informal eğitim çevrelerinden yayılan kötü yaşantı örnekleri, eğitim uygulamaları neden olmaktadır (Bilici, 2017; Yeşilyurt, 2020). İnfomal eğitim, okulda ya da okul dışında, hayatın her yerinde etkin olan bir eğitimidir. İnfomal eğitimin olumsuz etkilerine karşı öğrencileri koruması gerekenler, başta aileler olmak üzere bilinçli sosyal çevrelerdir.

Formal eğitimin olması gereken en önemli özelliği, insanlarda, herkes için, yerküre için olumlu ve istendik davranışlar yaratmaktır. Hangi formal ya da örgün eğitim, insanlarda, herkes için olumlu ve istendik davranışlar yaratmaktadır? Formal eğitim süreçlerinin en önemli çıkmazı, öğrencilerine, muhataplarına, insanlık yararına istendik davranışlar kazandırılmamasıdır. Formal eğitimin sonunu getiren en önemli problemler; bu eğitim türünün etkisiz, niteliksiz, başarısız ve kapsayıcılıktan yoksun performansıdır. Eğitim, her insan için öncelikle psikolojik ve sosyal olmak üzere her açıdan çok yönlü bir ihtiyaçtır. İhtiyaçlarını formal eğitimle karşılayamayan insanlar, dış dünyanın kurlsız, kanunsuz, faydasız, sosyal değer ve normlardan uzak eğitimine mahkûm edilmektedir. Eğitimi içine düştüğü çaresiz ve çözümsüz durumdan kurtaracak olanlar ise çoğulcu demokratik sosyal talepleri karşılamak zorunda olan demokratik kamu yönetimleridir.

Kamu yönetiminin, ülke genelinde, toplumun bütün kesimlerini; nonformal ve informal eğitim, kitle iletişim araçları ve sosyal medya ile sanal âlem gibi mecraların zararlı etkilerine karşı, önleyici ve koruyucu tedbirlerle bilinçlendirmesi gerekir. Kamu yönetimi, çoğulcu toplumsal kesim ve tabakaların menfaatleri çerçevesinde, halkı yönlendirici hukuksuz eğitim uygulamalarını, hukukun üstünlüğü ve çoğulcu demokratik yaşam

prensipleri çerçevesinde engellemelidir. Kamu yönetimi ile eğitim yönetimi eşgüdümlü yönetsel uygulamalar gerçekleştirerek, örgün ve formal eğitimin içinde bulunduğu etkisizlik ve başarısızlık problemlerini çözmek durumundadır.

2019 Bütün dünyada farklılıklar yaratan Covid-19 Pandemisinden sonra geleneksel eğitim anlamını yitirmiş; okul dışı eğitim dünyası çok daha fazla önem kazanmaya başlamıştır (Kırık ve Özkoçak, 2020). Okulların, okul dışı nonformal ve informal eğitimin zararlarından öğrencilerini düzenli ve sürekli olarak koruyabilmeleri için, öğrencilerine, hayatın her yerinde süreklilik arz eden istendik, olumlu ve kasıtlı davranışlar edindirmeleri gerekir. Okullar, dış çevrenin olumsuz etkilerine oldukça açık sistemlerdir. Örgün ya da formal eğitimin, kişilerin ve toplumun eğitim ihtiyaç ve taleplerini karşılayamaması, yenilik ve değişime ayak uyduramaması, küresel rekabeti kaybetmesi, yapay zekâ uygulamalarının gerisinde kalması sonucu, okulları işlevsiz hale getirmektedir. Eğitim sistemini, öğrencileri etkileyen olumsuz sosyal çevreler, informal eğitim, bilişim teknolojilerinin yanlış ve bilinçsiz kullanımı etkisiz kılmaktadır. Eğitim ve okul yönetiminin öğrencilere, uzman desteğinde, hayatın her yerinde kesintisiz biçimde kullanabilecekleri istendik davranışları kazandırabilmesi; eğitimin rol kaybına yol açmaktadır. Okulun rollerini, her türlü olumsuz davranışa açık ve alışık çevreler üstlenmektedir. Okullar işlevsiz kaldıkları durumlarda, çoğulcu demokratik ve örgütlü toplumsal tepkilerin varlığını problem olarak algılamak yerine, eleştiri kabul etmek zorundadır. Bu bağlamda, okullar, kendi performanslarıyla ilgili konularda, öğrencilerinden eleştiri almak için onlara demokratik eleştirel bilinç kazandırmak durumundadırlar. Eğitimin niteliksizliği konusunda, asıl problemlerden biri belki de en önemlisi, okulların 21. Yüzyılın demokratik ve hesap sormayı alışkanlık haline getirmiş küresel toplumlarında “kapalı sistem” özelliği sergilemeye devam etmeleridir. Okul içine kapandıkça ve açık sistem özelliği sergileyerek toplumdan koptukça önemini yitirmekte ve neredeyse kendi sonunu kendisi hazırlamaya çalışmaktadır.

Öğrencilerin formal eğitim sürecinde edindikleri davranış ve kazanımları, okul dışında, informal eğitimden etkilendikleri davranışlarla kaybetmemeleri için informal eğitimin formal eğitimle bütünleşik etkinlikler gerçekleştirmesi sağlanmalıdır (Ay Selanik, 2010; Bozdoğan, 2007; Bozdoğan, 2008; Bozdoğan ve Yalçın, 2009). Ancak hem nonformal hem de informal eğitim çoğunlukla formal eğitimin kontrol edemeyeceği davranışlar kazandırmaktadır. Bu nedenle öğrencilerin, formal eğitimde, sosyal hayatta işlevsel karşılığı olan nitelik, beceri ve yetkinlikler kazanmaları gerekir.

Amaç

Okul tür ve kademelerine göre, eğitim sisteminin amaçlarını hangi düzeyde gerçekleştirdiğinin saptanmasını sağlayıcı geniş kapsamlı araştırmalar, eğitim sistemine, okullar hakkında dönüt alma fırsatları yaratmaktadır. Eğitimin yetki, görev, işlev ve sorumlulukları yönünden denetimi, demokratik kamuoyuna hesap vermesi ile olasıdır. Bu araştırmanın amacı, formal eğitimin sonunu getiren informal eğitim ve sosyal medya ile yapay zekâ uygulamalarına ilişkin olarak üniversite öğrencilerinin algılarının hangi yönde ortaya çıktığını saptamaktır. Araştırmanın problem cümlesi aşağıdaki yönde ifade edilmiştir:

- Formal eğitimin sonunu getiren informal eğitim ve sosyal medya ile yapay zekâ uygulamalarına ilişkin olarak üniversite öğrencilerinin görüşleri nelerdir?

Yukarıdaki temel problem cümlesi doğrultusunda araştırmada, aşağıda yer verilen 5 yarı yapılandırılmış görüşme sorusuna cevap aranmıştır.

- 1. Okullarda verilen örgün, yüz yüze ve formal eğitimle kazanılan davranışlarla okul dışında, TV, radyo, sanal âlem, sosyal medya, sinema, gazete, bilişim teknolojileri ile sosyal çevrelerden vb. kazandırılan davranışlar karşılaştırıldığında, hangileri daha etkilidir? Neden?
- 2. Öğrenciler üzerinde, birer sosyal öğrenme ve formal eğitim merkezleri olan okullar mı çok daha fazla etkilidir? Yoksa aileler, arkadaş çevreleri, diğer sosyal çevreler, oyun grupları veya çok daha farklı diğer insan birlikteliklerini çağrıştıran grup dinamikleri mi daha etkilidir? Niçin?
- 3. Öğrencilere, toplumsal değerler olarak kabul edilen, “doğruluk”, “demokratiklik”, “dürüstlük”, “erdemlilik”, “yalan söylememe”, “hoşgörülülük” vb. değerler ile toplumsal norm ve kuralların kavratılmasında, eğitim merkezleri olan okullar mı daha etkilidir? Yoksa informal eğitim çevreleri, sanal âlemler, sosyal medya, sosyal çevreler vb. mi daha etkilidir? Neden?

- 4. Okullarda meydana gelen her türlü şiddet, baskı, psikolojik problemler, başarısızlık vb. durumların oluşmasında, okul dışı etkenlerden olan aile, sosyal çevre, sosyal medya, sanal âlem vb. etkili midir? Neden?
- 5. Yakın gelecekte, okulların ve öğretmenlerin yerini yapay zekânın ya da bilişim teknolojileri ile üretilen robot, mekân vb. alabileceğini düşünüyor musunuz? Neden?

Yöntem

Bu araştırma, “Formal eğitimin sonunu getiren informal eğitim ve sosyal medya ile yapay zekâ uygulamalarına ilişkin olarak üniversite öğrencilerinin görüşlerini” ortaya çıkarmak amacıyla yapılmış; karşılaştırmalı türden betimsel modelde bir çalışmadır. Araştırma, fenomenolojik yaklaşımla gerçekleştirilmiş bir çalışmadır. Fenomenolojik yaklaşım, herhangi bir olgu ya da duruma ilişkin gerçeklerin bütün açıklığıyla ortaya konulup tasarımı ve analiz edilmesini içeren araştırmalardır (Creswell ve Creswell, 2018; Creswell ve Poth, 2018). Araştırma, yüz yüze görüşme yöntemi ile gerçekleştirilmiştir. Araştırmaya, Türkiye’nin farklı üniversitelerinde lisans öğrenimi gören son sınıf öğrencileri katılmıştır.

Araştırma bağlamında öncelikle konuya ilişkin alanyazın taraması yapılmıştır. Alanyazın taraması ile birlikte okul-çevre ilişkilerinin analiz edilmesi için sosyal saha çalışmalarından sonra, araştırma için 7 sorudan oluşan yarı yapılandırılmış görüşme formu hazırlanmıştır. Formun kapsam geçerliliği ile araştırma için hangi düzeyde uygun olduğunu saptamak amacıyla eğitim bilim, iletişim bilimleri, sosyoloji ve kamu yönetim bilim alanlarından akademisyen görüşlerine başvurulmuştur. Görüş ve eleştiriler doğrultusunda, yarı yapılandırılmış görüşme formundaki soru sayısı 5 olarak şekillendirilip sonuçlandırılmıştır. Araştırmaya katılan farklı üniversitelerden öğrenciler tamamen gönüllülük esasına bağlı olarak araştırma sürecinde yer almışlardır. Görüşmeler, her öğrenciyle bire bir ve yüz yüze görüşme yöntemiyle yapılmıştır. Görüşme süreçlerine, 10 üniversite öğrencisi katılmıştır. Görüşmeler, öğrencilerin gönüllü katılımı ve kendilerinden alınan onayla yazılı kayıt altına alınmıştır. Görüşme sürecinden sonra öğrencilerin görüşlerini okuyup denetlemeleri ve böylece son kontrollerin yapılması sağlanmıştır. Görüşme uygulaması, en az 65 dakika en çok ise 120 dakika şeklinde sürmüştür.

Bulgular ve Yorumlar

“Formal eğitimin sonunu getiren informal eğitim ve sosyal medya ile yapay zekâ uygulamalarına ilişkin üniversite öğrencilerinin görüşleri” araştırmasından elde edilen veriler, öncelikle **K1, K2, K3 K10** şeklinde kodlanmıştır. Kodlanan verilerin, araştırmanın yarı yapılandırılmış görüşme formunda yer alan 5 soruya göre ayrı ayrı yapılması sağlanmıştır. Her bir sorudan sonra kategoriler tespit edilmiştir. Ayrıca sorulara göre, kategorilerin daha sade bir şekilde ifade edilmesi ve görüşlerin analiz edilmesi için temaların oluşturulması sağlanmıştır. Aşağıda araştırmanın 1. Görüşme sorusu ve buna ilişkin verilerin yer aldığı **Tablo 1** görülmektedir.

- 1. Görüşme sorusu: “Okullarda verilen örgün, yüz yüze ve formal eğitimle kazanılan davranışlarla okul dışında, TV, radyo, sanal âlem, sosyal medya, sinema, gazete, bilişim teknolojileri ile sosyal çevrelerden vb. kazandırılan davranışlar karşılaştırıldığında, hangileri daha etkilidir? Neden?”

Tablo 1. Örgün Eğitimle Kazandırılan Davranışlarla Okul Dışında Kazandırılan Davranışların Karşılaştırılmasına İlişkin Üniversite Öğrenci Görüşleri

Kodlar	Katılımcı Görüşleri
K1	“Daha fazla bilgi kirliliği ve erişimin kolaylığı açısından ikinci örnek daha olumsuz davranışlar gösterilmesini sağlayabilir.”
K2	“Sosyal medya ve gazetenin daha etkili olduğunu düşünüyorum çünkü bilgiye daha kolay ulaşırız.”
K3	“Sosyal çevre daha etkilidir. Çünkü gördüklerimiz üstümüzde etkili olur.”

K4	“Çağın getirmiş olduğu tahammülsüzlük hastalığından dolayı örgün, yüz yüze ve formal eğitimde öğrencilerin zamandan ve kısıtlanabilir ortamdan dolayı diğer saydıklarınız daha etkilidir.”
K5	“Günümüzde okul dışı faktörler davranış üzerinde daha baskındır. Sosyal medya öğrencinin günlük dilini, tüketim alışkanlıklarını daha hızlı şekillendirmektedir.”
K6	“Medya daha çok etkilidir. Çünkü sürekli maruz kalıyoruz.”
K7	“Okul dışında kazandırılan eğitim daha etkilidir. Çünkü daha etkili ve eğlencelidir.”
K8	“Sosyal medyanın daha etkili olduğunu düşünüyorum. Bunun sebebi ise günümüzde teknoloji çağını yaşamaktayız. Ve en küçükten en büyüğe, hepimizin elinde telefonlar var.”
K9	“Sosyal medya daha etkilidir çünkü günümüzde çoğu insan her şeyi sosyal medyadan öğrenmektedir.”
K10	“Sosyal medya, TV ve bilişim teknolojileri daha etkili. Çünkü günümüzde teknoloji daha ön planda olduğu için davranış kazanmada bu teknolojiler daha etkilidir.”
1.Kategoriler	“Okul dışı çevreler (2), Sosyal medya, gazete (5), Sosyal çevre (1), Okulun yetersizliğinden dolayı okul dışı çevre (2).
1. Temalar	“Sosyal medya ve okul dışı çevreler (10)”.

Araştırma bulgularına göre, üniversite öğrencileri, formal eğitimin, okul dışı çevrelerden gelen baskı ve yönlendirmeler neticesinde, öğrencilerine istedik davranış kazandırmada etkisiz kaldığını vurgulamaktadır. Üniversite öğrencileri, öğrenci davranışlarında kalıcı etkiyi okul dışı çevrelerin yarattığını belirtmektedirler. Formal, yüz yüze ve örgün eğitim öğrenci davranışlarında, sürekli ve etkili değişim yaratamamaktadır. Öğrenci davranışlarında kalıcı ve sürekli değişimi sosyal medya ve okul dışı çevrelerin sağladığı anlaşılmaktadır.

- 2. Görüşme Sorusu: “Öğrenciler üzerinde, birer sosyal öğrenme ve formal eğitim merkezleri olan okullar mı çok daha fazla etkilidir? Yoksa aileler, arkadaş çevreleri, diğer sosyal çevreler, oyun grupları veya çok daha farklı diğer insan birlikteliklerini çağrıştıran grup dinamikleri mi daha etkilidir? Niçin?” Araştırmanın 2. Görüşme Sorusuna ilişkin görüşler Tablo 2’de yer almaktadır.

Araştırma bulgularına göre, öğrenciler üzerinde asıl sosyal etkiyi, okul dışı grup dinamikleri ve çevreler yaratmaktadır. Öğrenciler, okullardan çok okul dışı arkadaş çevreleri ve aileler ile içinde bulundukları çok farklı grup dinamiklerinden etkilenmektedirler. Bulgular, öğrencilerin davranış edinimleri açısından, okul dışında, farklı insan birlikteliklerinin yer aldığı grup dinamiklerinden daha çok etkilendiğini ortaya koymaktadır.

Tablo 2. Öğrenci Davranışları Üzerinde Okul ve Okul Dışı Çevrelerin Etkilerinin Karşılaştırılmasına İlişkin Görüşler

Kodlar	Katılımcı Görüşleri
K1	“Bence grup dinamikleri daha etkilidir. Çünkü daha fazla eylem deneyim bulundurur yani grup dinamiklerinde daha aktif oluruz.”
K2	“Grup dinamikleri daha etkilidir.”
K3	“Grup dinamikleri daha etkilidir. Çünkü sosyal çevre olduğu için.”
K4	“2. Sayılan örnekler daha etkilidir. Çünkü sınırların içerisinde olmak asrın neslini boğuyor.”

K5	“Aile ve akran grupları daha baskındır. Bence gerçek hayatı, duyguları çevresinde daha etkili olmaktadır.”
K6	“Aile ve arkadaş daha etkilidir. Çünkü bu kişiler arasında gönül bağı vardır.”
K7	“Arkadaş çevresi ve gruplar. Çünkü daha eğlenceli ve kalıcıdır.”
K8	“Arkadaş çevreleri daha etkilidir. Çünkü bir kişiyi, çevresinde bulunan insanlar daha çok etkilemektedir.”
K9	“Aileler arkadaş çevreleri daha etkilidir. Çünkü sosyal hayat insana, okuldan farklı olarak tecrübe kazandırır.”
K10	“Sosyal çevreler daha çok etkilidir. Çünkü insan, oralara kendi isteğiyle daha çok gider.”
2.Kategoriler	“Okul dışı grup dinamikleri (2), Sosyal çevre içerisinde grup dinamikleri (4), Aile ve arkadaş çevresi (2), Arkadaş çevresi ve gruplar (2).
2. Temalar	“Sosyal çevreler, okul dışı grup dinamikleri, aile, arkadaş çevreleri (10).

- 3. Görüşme Sorusu: “Öğrencilere, toplumsal değerler olarak kabul edilen, “doğruluk”, “demokratiklik”, “dürüstlük”, “erdemlilik”, “yalan söylememe”, “hoşgörülülük” vb. değerler ile toplumsal norm ve kuralların kavratılmasında, eğitim merkezleri olan okullar mı daha etkilidir? Yoksa informal eğitim çevreleri, sanal âlemler, sosyal medya, sosyal çevreler vb. mi daha etkilidir? Neden?”

Araştırmanın **3. Görüşme Sorusuna** ilişkin görüş, kategori ve temalara **Tablo 3’te** yer verilmiştir. Araştırma bulgularına göre, öğrencilere, temel toplumsal değer, norm ve kuralların kavratılmasında, okullardan çok informal eğitim çevreleri, sanal âlem ve sosyal medya ile okul dışı sosyal çevrelerin etkili olduğu saptanmıştır. Değerler eğitiminde, katılımcıların yoğun olarak ve çok ciddi bir oranda okul dışı eğitim uygulamaları olan informal eğitim süreçlerini ve sosyal çevreleri işaret etmeleri dikkat çekicidir. Bu olgu değerler eğitiminin toplumsal yaşamda gerçekleşmeden okulda davranış haline getirilmesinin güç olduğunu ortaya koymaktadır. Katılımcılardan, değerler eğitiminde ailenin etkisini vurgulayanlar da mevcuttur. Okul ve ailenin birlikte değer kazandırmada önemini vurgulayan katılımcılar mevcuttur.

Tablo 3. Toplumsal Değerlerin Kazandırılmasında Okul ve Okul Dışı Çevrenin Etkisine İlişkin Görüşler

Kodlar	Katılımcı Görüşleri
K1	“İnformal eğitim çevresi daha etkilidir. Çünkü daha çok hayatın içindeyiz.”
K2	“Sosyal medya daha etkili oluyor. Ama olumsuz davranışı da kolaylıkla kazandırır.”
K3	“Elbet okul etkilidir. Ama diğerleri daha baskındır.”
K4	“İnformal eğitim merkezleri daha etkili. Çünkü daha çok rağbet görüyor.”
K5	“Bence yine informal eğitim çevreleri. Çünkü daha etkilidir.”
K6	“İnformal eğitim çevreleri. Çünkü insanlar duyduğunu değil, gördüğünü yapar.”
K7	“Herşeyden önce aile etkilidir. Okul da bu durumu destekler. Ama en etkili olan yer ailedir diye düşünüyorum. Bu konuda, davranış değiştirmenin, okullarda biraz daha zor olduğunu düşünüyorum.”
K8	“Her ikisi de etkilidir. Ama okullarda bu daha net şekilde doğrusuyla öğretilir. Sosyal çevrelerde toplumsal norm ve kuralların tersini örnek almamız da olasıdır.”

K9	“İnformal çevreler, sanal âlemler kısa süreli eğlence, başarı sağlar, anlaktır. Fakat okul, bireye etkili katkı sağlar.”
K10	“Aileler temelini atar. Okul ileri götürür. Ama bunu hayata katacak olan öğrencidir. Öğrenci gelişimini tamamlamadıysa çevre daha etkilidir.”
3.Kategoriler	“İnformal eğitimin etki ve cazibesi (4), Sosyal medya (1), Okulun etkisi; ancak okul dışı çevrenin baskınlığı (1), Aile (1), Okul ve sosyal çevreler (1), Okulun kalıcı etkisi (1), Okul ve aile (1).
3. Temalar	“İnformal eğitimin baskın ve cazip etkisi ile sosyal medya ve aileler (7), Okulun kalıcı etkisi ile aile (3).”

Araştırmanın 4. Görüşme Sorusu: “Okullarda meydana gelen her türlü şiddet, baskı, psikolojik problemler, başarısızlık vb. durumların oluşmasında, okul dışı etkenlerden olan aile, sosyal çevre, sosyal medya, sanal âlem vb. etkili midir? Neden?” Araştırmanın 4. Görüşme Sorusuna ilişkin görüş, kategori ve temalara Tablo 4’te yer verilmiştir.

Tablo 4. Okullarda Meydana Gelen Şiddet, Baskı, Psikolojik Problemler, Başarısızlık vb. Problemlerin Oluşmasında Okul Dışı Etkenlerden Aile, Sosyal Çevre, Sosyal Medya, Sanal Alem vb. Nedenlerin Etkili Olup Olmadığına İlişkin Görüşler

Kodlar	Katılımcı Görüşleri
K1	“Evet etkilidir. Çocuğun yaptığı bazı eylemler sosyal çevreden örnek alınmış hareketler olabilir. Yetişme çağındaki bir çocuğa karşı hareketlerimize çok dikkat etmeliyiz.”
K2	“Etkilidir. Örneğin ailesinde şiddet gören bir öğrenci okulda fazla hiperaktif olup arkadaşlarına saldırabiliyor.”
K3	“Evet, etkilidir. Olumsuz davranışlar sosyal medyada alenen yayınlanmakta; yaygınlaşmaktadır.”
K4	“Evet, etkilidir. Çünkü biz insanlar sosyal varlıklarız. Her türlü şeyden etkilenebiliriz.”
K5	“Elbette etkilidir. Hayatın içinde var olan bir günün; yani 24 saatin ve bu 24 saatin en az üçte birinde olduğu için maddi ve manevi rol alır.”
K6	“Okul dışı etkenler daha fazla etkilidir aile içindeki huzursuzluk veya sosyal medyadaki siber zorbalık öğrencinin psikolojik dengesini bozar.”
K7	“Etkilidir. Çünkü kişi çevresinin ortalamasıdır.”
K8	“Etkilidir. Çünkü birey ilk olarak ailede her şeyi öğrenir.”
K9	“Su sosyal medya daha etkilidir. Çünkü günümüzde insanlar sosyal medyadan daha fazla etkilenmektedir bilinçaltında daha fazla etki etmektedir
K10	“ Evet etkilidir. Çünkü herkes ailesini temsil eder.”
4.Kategoriler	“Sosyal çevre (3), Aile (3), Sosyal medya (1), Sosyal etki (1), Aile ve sosyal medya (1), Sosyal medya (1).
4. Temalar	“Aile, sosyal çevre ve sosyal medya (10).”

Tablo 4’te görüldüğü gibi aile, sosyal çevre ve sosyal medya okullarda meydana gelen şiddet, baskı, psikolojik problemler, başarısızlık vb. problemlerin oluşmasında okul dışı etkenler olarak bir sistem şeklinde çok büyük etkiler yaratmaktadırlar. Sosyal medya, aile ve sosyal çevreler, okullarda şiddet vb. kötülükler oluşturmakta birlikte olduğu gibi ikili ya da ayrı ayrı da etkiler oluşturmaktadır.

- **Araştırmanın 5. Görüşme Sorusu:** “Yakın gelecekte, okulların ve öğretmenlerin yerini yapay zekânın ya da bilişim teknolojileri ile üretilen robot, mekân vb. alabileceğini düşünüyor musunuz? Neden?” **Tablo 5’te**, yapay zekâ ya da bilişim teknolojilerinin okul ve öğretmenlerin yerini alabilme olasılığı ile ilgili görüşlere yer verilmiştir.

Tablo 5. Yapay Zekâ ya da Bilişim Teknolojileri ile Üretilen Robot, Mekân vb. Değişkenlerin Gelecekte Okul ve Öğretmenlerin Yerini Alabilme Olasılığına İlişkin Katılımcı Görüşleri

Kodlar	Katılımcı Görüşleri
K1	“Evet düşünüyorum. Bu düşünce beni ürkütse de gelecekte böyle bir durumun meydana gelmesi gelişen teknolojiyle birlikte olası bir durum. Ancak bunu istemiyorum. Çünkü okullar, öğrenciler için daha sosyal bir ortam.”
K2	“Evet. Çünkü yapay zekâ bizim yerimize her şeyi yapıyor.”
K3	“Hayır, düşünmüyorum. Yüz yüze (örgün) eğitim kadar faydalı olmayacağını düşünüyorum.”
K4	“Hayır düşünmüyorum. Çocuğun her zaman şefkate ihtiyacı vardır.”
K5	“Evet. Gidişat bunu gösteriyor.”
K6	“Evet düşünüyorum. Gelişen teknolojik bu alanlarda da kendini gösterecektir.”
K7	“Alabilir. Çünkü teknolojik gelişmeler daha çok çeşitli olduğu için daha avantajlı görülüyor.”
K8	“Bilgi aktarımı ve teknik eğitim konusunda yapay zekâ öğretmenlerden daha hızlı ve kapsamlıdır. Ancak öğretmenlik sadece bilgi aktarımı değildir. İnsan olan öğretmen, rehberlik, empati, duygusal destek ve daha fazla insani destek sunar. Bu yüzden yapay zekâ 2. planda kalacaktır.”
K9	“Evet, gelişen teknoloji ile evet böyle bir şey yaşanabilir. Fakat bir öğretmenin yerini tutamaz. Çünkü herşey bilgi vermek değildir.”
K10	“İmkânsız. Çünkü bir yapay zekâ duyguları veremez.”
5.Kategoriler	“Yapay zekâ ve bilişim teknolojilerinin okul ve öğretmen rolü alabileceği (5), Yapay zekâ ve bilişim teknolojileri örgün ve yüz yüze eğitim ile öğretmenin yerini alamaz (5).
5. Temalar	“Yapay zekâ okul ve öğretmenin yerini alacak (5), Yapay zekâ ve bilişim teknolojileri öğretmenin rolü oynayamaz (5).

Tablo 5’te yer aldığı gibi katılımcıların yarısı, yapay zekâ ile bilişim teknolojilerinin gelecekte okul ve öğretmenin yerini alabileceğini savunurken, yarısı bu görüşe katılmamaktadır. Katılmayacaklarını belirtenler de gelecekte, yapay zekâ ve bilişim teknolojilerindeki yenilik ve başdöndürücü ilerlemelerin, eğitimde değişim yaratacağına ilişkin güçlü bir beklentiye sahiptir.

Sonuç, Tartışma ve Öneriler

Formal eğitim, toplumların, devletlerin ve ülkelerin varlıklarını, sağlıklı bir şekilde sürdürebilmeleri için vazgeçilemez niteliğe sahip bir eğitimidir. 21. Yüzyıl dünyasının mevcut koşullarında, formal eğitim yerine ikame edilebilecek bir eğitim henüz yoktur. Ancak formal, yüz yüze ve örgün eğitim, varlığını başarılı bir

şekilde sürdürebilecek etkililikten yoksundur. 21. Yüzyıl dünyasının formal eğitimi, taşıdığı önemi kanıtlayabilecek performanstan çok uzak bir etkililik düzeyi sergilemektedir. Formal eğitim, demokratik toplumların varlıklarını, özellikle insan hak ve hürriyetlerine dayalı bir şekilde sağlıklı bir şekilde sürdürebilmeleri için zorunlu bir eğitim uygulamasıdır. İnsanların, sosyal birer varlık olarak, en ideal şekilde yaşamlarını sürdürmelerinde örgün eğitimin yadsınamayacak bir önemi vardır. Formal eğitim, öncelikle sosyal bir gelişim sürecidir. Formal eğitim aracılığıyla insanların çok yönlü sosyal gelişimlerinin amaçlar yönünde tamamlanması sağlanır. İnsanlar, formal eğitim aracılığıyla sosyo-kültürel, sosyo-psikolojik, sosyo-politik ve sosyo-ekonomik yönlerden gelişme imkânlarına kavuşmaktadırlar. Günümüzün formal ve örgün eğitim süreçleri, öğrencilerini, çok yönlü sosyal gelişim imkânlarına kavuşturamamaktadır. Öğrencilerin davranış değişimi daha çok okul dışı sosyal çevrelerin, farklı grup dinamiklerin yer aldığı nonformal ya da informal örgütlerin olumsuz etkileri ile şekillenmektedir. Bu araştırmadan elde edile sonuçlara göre, okul dışı çevreler ile birlikte bilişim teknolojileri ve sosyal medya uygulamalarının, öğrenciler üzerinde yarattıkları olumsuz etkiler ve davranış nedeniyle okullar etkisizliğin sınırlarına dayanmıştır. Okullar, kendilerine verilen yetki ve sorumlulukları, öğrencilerde kalıcı ve istedik davranış değişiklikleri oluşturacak şekilde gerçekleştirememektedirler.

İnformal öğrenme çevreleri ve informal ortamların, toplum yararına etkili sosyal çevreler olarak düzenlenip faaliyet göstermeleri sağlanabilir. Bu tür, amaçlı informal eğitimsel örgütlenmeler, öğrenciler için önemli katkılar sağlayan öğrenme süreçleri haline gelmektedirler (Atasoy ve Ertürk, 2008; Atkins, Velez, Goudy & Dunbar, 2008; Çavuş, Umdu Topsakal ve Öztuna Kaplan, 2016). 21. Yüzyılın okulları, öğrencileri için birer cazibe ve güç edinme merkezi olmaktan çok uzaktır (Berti, Molinari & Speltini, 2010; Bhorkar & Bray, 2018). Formal eğitim örgütleri olan okullar, öğrencilerin akademik bilişsel öğrenme ihtiyaçları ile birlikte farklı özellikler içeren gelişim ihtiyaçlarını karşılayamamaktadırlar. Bu nedenle öğrenciler, örgün, formal ve yüz yüze eğitimin sürdüğü zorunlu eğitim süreçlerinden ayrılarak, açıköğretim uygulamalarının yer aldığı okul dışı uygulama süreçlerini tercih etmektedirler (Can ve Sakallı, 2023; Çam Tosun ve Bayram, 2015; Kandemir, Koç ve Özbaş, 2024; Özalp ve Akkaya, 2026; Özbaş, 2019).

Araştırma sonuçlarına göre, aile, sosyal medya, sanal âlem ve özellikle sosyal grup ve çevrelerden oluşan grup dinamikleri, büyük oranda bir bütün olarak ya da ayrı ayrı negatif etkiler yayarak öğrencilerin toplumsal değer, norm ve kuralları edinmelerini engellemektedir. Okul dışı etkenler, öğrencilerin sosyal değer ve normları kazanmalarında güç birliği yapmış gibidir. Sosyal değer ve normların kazanılmasında okulun etkisini, aile ile birlikte önemli gören az sayıda görüş de mevcuttur. Okul dışı çevreler ve özellikle aile ile sosyal medya okulda şiddet, psikolojik baskı, başarısızlık vb. olumsuzlukların oluşmasında en önemli etkindir.

Bu araştırmadan elde edilen sonuçlara göre, üniversite öğrencileri arasında, yapay zekâ ile bilişim teknolojilerinin okullarda yönetici ve öğretmen rolü üstleneceği konusunda görüş birliği yoktur. Katılımcılar, bu bağlamda 2 karşıt görüşü temsil etmektedir. Ancak yapay zekânın öğretmenin yerini alacağına karşı çıkanlar bile yapay zekâ alanındaki değişimin eğitimde kaçınılmaz farklılıklar yaratacağını düşünmektedir.

Araştırma sonuçları doğrultusunda aşağıdaki öneriler geliştirilmiştir:

- Formal, örgün ve yüz yüze eğitimin verildiği birer sosyal öğrenme merkezi olan okulların, öğrencilerinin eğitim ihtiyaçlarını karşılayabilecek şekilde eski alışkanlıklarından sıyrılmalı, hayatla iç içe profesyonel bir eğitim çevresi haline getirilmeleri sağlanmalıdır.
- Kamu yönetimi ile eğitim ve okul yönetimlerinin, öğrenci davranışlarını yönlendiren okul dışı sosyal çevre ve grup dinamiklerinin öğrenciler üzerindeki olumsuz etkilerini elimine etmek için okullarda daha fazla sosyal ve psikolojik gelişim imkânları yaratmaları sağlanmalıdır.
- Okulların okul-aile, okul-çevre ve okul-hayat ilişkisini gerçek zemininde gerçekleştirmek için geleneksel eğitim anlayışından kurtulmaları ve öğrencilerini ilkokullardan itibaren kamu yararına örgütlü sosyal birliktelikler içerisine yönlendirmeleri temin edilmelidir.

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**AN EXAMINATION of INDIVIDUALS' PERCEPTIONS of DEMOCRATIC CULTURE and
DEMOCRATIC EDUCATION in TERMS of VARIOUS DEMOGRAPHIC VARIABLES**

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ABSTRACT

The aim of this study was to determine whether individuals' perceptions of democratic culture and democratic education differ significantly according to various demographic variables. The study is significant in that democracy is not merely an administrative structure but also a sphere of values and participation experienced in everyday life. Conducted using a comparative survey model within a quantitative research framework, the study's sample consisted of 550 participants selected on the basis of voluntarism and accessibility. Data were collected using a 28-item, five-point Likert-type measurement tool designed to assess perceptions regarding democratic life in Turkey, democratic culture, barriers to democracy, and universal democracy education, along with a Personal Information Form. Prior to data analysis, assumptions regarding missing data, outliers, normality, and homogeneity of variance were examined; for binary variables, an independent samples t-test was used, while for variables with more than two categories, one-way analysis of variance (ANOVA) and, where necessary, Welch's ANOVA with appropriate post-hoc tests were employed. The findings indicate that perceptions of democratic culture and democratic education do not differ significantly based on gender, educational level, parents' educational level, or parents' occupation; however, a statistically significant difference with a low effect size was found in favor of the student group only for the occupation variable. In conclusion, it was understood that perceptions of democratic culture and democratic education constitute a multi-layered structure shaped by educational and social contexts rather than individual demographic characteristics; it was recommended that future studies examine sub-dimensions separately, use more balanced samples, and support quantitative findings with qualitative data.

Keywords: Democratic Culture, Democratic Education, Democratic Perception, Demographic Variables.

**BİREYLERİN DEMOKRASİ KÜLTÜRÜ VE DEMOKRASİ EĞİTİMİ ALGILARININ ÇEŞİTLİ
DEMOGRAFİK DEĞİŞKENLER AÇISINDAN İNCELENMESİ**

ÖZET

Bu araştırmada, bireylerin demokrasi kültürü ve demokrasi eğitimi algılarının çeşitli demografik değişkenlere göre anlamlı biçimde farklılaşıp farklılaşmadığının belirlenmesi amaçlanmıştır. Araştırma, demokrasinin yalnızca yönetsel bir yapı değil, aynı zamanda gündelik yaşamda deneyimlenen bir değerler ve katılım alanı olması bakımından önem taşımaktadır. Nicel araştırma yaklaşımı çerçevesinde karşılaştırmalı tarama modeliyle yürütülen çalışmanın çalışma grubunu gönüllülük ve ulaşılabilirlik esasına göre belirlenen 550 katılımcı oluşturmuştur. Veriler, Kişisel Bilgi Formu ile Türkiye'de demokratik yaşam, demokrasi kültürü, demokrasi engelleri ve evrensel demokrasi eğitimine ilişkin algıları ölçmeye yönelik 28 maddelik, beşli Likert tipindeki ölçme aracı kullanılarak toplanmıştır. Verilerin analizinden önce eksik veri, aykırı gözlem, normallik ve varyans homojenliği varsayımları incelenmiş; iki kategorili değişkenlerde bağımsız örneklem t testi, ikiden fazla kategori içeren değişkenlerde tek yönlü varyans analizi ve gerekli durumlarda Welch ANOVA ile uygun çoklu karşılaştırma testleri kullanılmıştır. Bulgular, demokrasi kültürü ve demokrasi eğitimi algılarının cinsiyet, öğrenim düzeyi, anne ve baba öğrenim düzeyi ile anne ve baba mesleğine göre anlamlı biçimde farklılaşmadığını; yalnızca meslek değişkeninde öğrenci grubu lehine, düşük etki büyüklüğüne sahip anlamlı bir fark bulunduğunu göstermiştir. Sonuç olarak, demokrasi kültürü ve demokrasi eğitimi algısının tekil demografik özelliklerden çok, eğitimsel ve toplumsal bağlamla birlikte şekillenen çok katmanlı bir yapı olduğu

anlaşılmış; ileride yapılacak çalışmalarda alt boyutların ayrı ayrı incelenmesi, daha dengeli örneklemelerle çalışılması ve nicel bulguların nitel verilerle desteklenmesi önerilmiştir.

Anahtar Kelimeler: Demokrasi Kültürü, Demokrasi Eğitimi, Demokratik Algı, Demografik Değişkenler.

Giriş

Demokrasi, dar anlamda seçimler, temsil ve yönetsel kurumlar çerçevesinde tanımlanabilmekle birlikte, çağdaş eğitim ve yurttaşlık literatüründe giderek daha fazla biçimde bir yönetim tekniğinin ötesinde, gündelik yaşam içinde deneyimlenen bir toplumsal yaşam biçimi ve değerler bütünü olarak ele alınmaktadır (Avrupa Konseyi, 2021; T.C. Millî Eğitim Bakanlığı, 2018). Bu yaklaşım doğrultusunda demokrasinin sürdürülebilirliği yalnızca anayasal ve kurumsal düzenlemelerle açıklanamamakta; aynı zamanda bireylerin farklı görüşlere açık olma, kamusal müzakereye katılma, hak ve sorumluluklarını savunma, çatışmaları şiddet dışı yollarla çözme ve hukukun üstünlüğünü içselleştirme düzeyleriyle ilişkilendirilmektedir (Avrupa Konseyi, 2021). Dolayısıyla demokrasi kültürü, yalnızca siyasal sistemin biçimsel özelliklerine indirgenememekte; bireylerin bilişsel, duyuşsal ve davranışsal yönelimleriyle şekillenen çok boyutlu bir toplumsal öğrenme alanı olarak değerlendirilmektedir.

Kültürün, toplum tarafından paylaşılan anlamlar, normlar ve davranış örüntülerinden oluşan bir yapı olduğu kabul edildiğinde, demokrasi kültürünün de demokratik değerlerin gündelik etkileşimler içinde üretildiği, yeniden yorumlandığı ve sürdürüldüğü bir alan olduğu görülmektedir (Avrupa Konseyi, 2021). Bu çerçevede eğitim, yalnızca bilgi aktarımına dayalı teknik bir süreç olarak değil; bireylerin demokratik yaşam için gerekli bilgi, beceri, tutum ve değerleri kazanmalarını sağlayan temel bir toplumsallaşma mekanizması olarak işlev görmektedir (Avrupa Konseyi, 2010; UNESCO, 2015). Özellikle demokrasi eğitiminin, bilişsel farkındalık ile sınırlı kalmaması; eşitlik, adalet, çoğulculuk, farklılıklara saygı ve katılım gibi demokratik yönelimlerin birey tarafından benimsenmesini de içermesi gerektiği vurgulanmaktadır (UNESCO, 2015). Bu nedenle demokrasi kültürü ile demokrasi eğitimi arasında tek yönlü değil, karşılıklı ve dinamik bir ilişki bulunduğu; birinin diğerini besleyen ve güçlendiren bir yapı sergilediği kabul edilmektedir.

Avrupa Konseyi tarafından geliştirilen Demokrasi Kültürü Yetkinlikleri Referans Çerçevesi'nde demokrasi kültürü, değerler, tutumlar, beceriler ile bilgi ve eleştirel kavrayış boyutlarında yapılandırılmış yirmi temel yetkinlik üzerinden açıklanmıştır (Avrupa Konseyi, 2021). Bu modelde demokratik yaşamın sürdürülebilmesi için yalnızca yurttaşlık bilgisine sahip olunmasının yeterli olmadığı; aynı zamanda eleştirel düşünme, başkalarını dinleme, farklı bakış açılarını değerlendirme, çoğunluk kararları ile azınlık hakları arasında denge kurma ve kanıta dayalı tartışma yürütebilme gibi yeterliklerin de geliştirilmesi gerektiği belirtilmiştir (Avrupa Konseyi, 2021). Benzer biçimde Avrupa Konseyi Demokratik Yurttaşlık ve İnsan Hakları Eğitimi Şartı'nda, eğitim kurumlarının yalnızca demokratik değerleri öğretmesinin değil, aynı zamanda bu değerleri yönetim süreçlerinde bizzat yansıtmalarının gerekli olduğu ifade edilmiştir (Avrupa Konseyi, 2010). UNESCO'nun Küresel Vatandaşlık Eğitimi yaklaşımında da öğrenmenin bilişsel, sosyo-duyuşsal ve davranışsal alanlar üzerinden bütüncül biçimde yapılandırılması gerektiği vurgulanmış; demokratik yaşama aktif katılımın ancak bu alanların birlikte geliştirilmesiyle mümkün olacağı belirtilmiştir (UNESCO, 2015). Böylece demokrasi eğitiminin yalnızca ders içeriğiyle sınırlı bir alan olmadığı, okul iklimi, sınıf içi etkileşimler ve kurumsal katılım fırsatlarıyla birlikte anlam kazandığı ortaya konulmuştur.

Problem Durumu

Türkiye bağlamında demokrasi eğitiminin insan hakları, yurttaşlık ve demokrasi temalı öğretim programları ile okul temelli katılım uygulamaları üzerinden yapılandırıldığı görülmektedir (T.C. Millî Eğitim Bakanlığı, 2018). İlkokul 4. sınıf "İnsan Hakları, Yurttaşlık ve Demokrasi" dersi öğretim programında, kavramsal bilginin kazandırılmasının yanı sıra temel değerlerin birey tarafından içselleştirilmesi ve bunların yaşam biçimine dönüştürülmesi hedeflenmiştir (T.C. Millî Eğitim Bakanlığı, 2018). Benzer biçimde okul öğrenci meclisleri gibi uygulamalar aracılığıyla temsil, seçim, katılım ve müzakere deneyimlerinin okul yaşamı içinde somutlaştırılmasına çalışıldığı anlaşılmaktadır (T.C. Millî Eğitim Bakanlığı, 2004). Bu durum, demokrasi eğitiminin yalnızca öğretim programının bir unsuru değil, aynı zamanda okul yaşamının bütününe yayılan yaşantısal bir süreç olarak kurgulandığını göstermektedir. Nitekim uluslararası araştırmalarda da tartışmaya açık sınıf iklimi, okulda temsil ve oy verme deneyimi gibi katılım fırsatlarının yurttaşlık bilgisi ve demokratik yönelimlerle olumlu ilişkiler gösterdiği rapor edilmiştir (Schulz ve ark., 2023). Bu bulgular, demokrasi

kültürünün eğitim yoluyla yalnızca aktarılmadığını, aynı zamanda okulun gündelik ilişkiler ağı içinde yeniden üretildiğini düşündürmektedir.

Demokrasi kültürü ve demokrasi eğitimi algılarının ölçülmesinde, demokratik tutum ve demokratik değer ölçeklerinin yanı sıra yurttaşlık bilgisi, katılım yönelimi ve okul iklimi algısı gibi farklı ölçme yaklaşımlarından yararlanıldığı görülmektedir (Schulz ve ark., 2018; Karadağ ve ark., 2006). Uluslararası düzeyde IEA tarafından yürütülen ICCS çalışmaları, demokratik yurttaşlık alanındaki bilgi ve eğilimlerin standartlaştırılmış ölçümler yoluyla izlenmesine olanak tanımakta; böylece demografik gruplar arasındaki farklılıkların karşılaştırmalı olarak değerlendirilmesi mümkün hâle gelmektedir (Schulz ve ark., 2018; Schulz ve ark., 2023). Türkiye’de ise demokratik tutum, demokratik değer ve demokratik okul iklimi algısını ölçmeye yönelik ölçeklerin özellikle öğretmen adayları, öğretmenler ve üniversite öğrencileri üzerinde yaygın biçimde kullanıldığı görülmektedir (Bulut, 2006; Gömleksiz & Çetintaş, 2011; Karadağ ve ark., 2006; Baltacı & Aydın, 2019). Bu ölçme geleneği, demokrasi kültürü ve demokrasi eğitimi algısının bireysel bir özellik olmanın ötesinde, toplumsal ve kurumsal bağlamla etkileşim içinde gelişen bir yapı olduğunu göstermektedir.

Demografik değişkenlere göre farklılaşma bulguları incelendiğinde, özellikle cinsiyet, öğrenim düzeyi, meslek, gelir ve aileye ilişkin sosyoekonomik göstergelerin dikkat çekici olduğu görülmektedir. Uluslararası düzeyde ICCS 2022 bulgularında, kız öğrencilerin yurttaşlık bilgisi puanlarının erkek öğrencilere göre çoğu ülkede daha yüksek olduğu ve bu farkın çok sayıda ülkede istatistiksel olarak anlamlı bulunduğu rapor edilmiştir (Schulz ve ark., 2023). Ayrıca eşit haklar ve toplumsal cinsiyet eşitliği gibi normatif tutumlarda da kız öğrencilerin daha yüksek destek bildirdiği belirtilmiştir (Schulz ve ark., 2023). Türkiye’de ise cinsiyet değişkenine ilişkin sonuçların her çalışmada aynı yönde olmadığı; bazı araştırmalarda kadın katılımcılar lehine daha yüksek demokratik tutum puanları raporlanırken, bazı araştırmalarda anlamlı bir farklılaşmanın ortaya çıkmadığı görülmüştür (Karadağ ve ark., 2006; Baltacı & Aydın, 2019). Bu durum, cinsiyetin tek başına belirleyici olmaktan çok, okul iklimi, toplumsal deneyim ve aile kaynakları gibi değişkenlerle birlikte değerlendirilmesi gerektiğini düşündürmektedir.

Öğrenim düzeyi ve meslek değişkenleri bakımından da benzer biçimde bağlamsal bir tablo ile karşılaşılmaktadır. Demokratik bilgi, beceri ve tutumların yaşam boyu öğrenme anlayışı içinde geliştirilmesi gerektiği Avrupa Konseyi tarafından açıkça vurgulanmış olup, bu durum yükseköğretim ve yetişkin eğitimi bağlamını da kapsayacak biçimde ele alınmıştır (Avrupa Konseyi, 2010). Türkiye’de lisansüstü eğitim düzeyine sahip öğretmenlerin demokratik tutumlarının lisans mezunlarına göre daha yüksek raporlandığı; buna karşılık mesleki kıdem arttıkça demokratik tutum düzeylerinde azalma görülebildiği bildirilmiştir (Baltacı & Aydın, 2019). Bu bulgular, öğrenim düzeyinin demokratik yönelimleri destekleyebildiğini; ancak çalışma yaşamı içinde deneyimlenen kurumsal yapıların ve örgütsel iklimin bu ilişkiyi zayıflatabildiğini düşündürmektedir. Nitekim öğretmenlerin okul yöneticilerinde algıladıkları demokratik tutum ile kendi demokratik değerleri arasında pozitif ilişkiler saptanmış olması da, demokrasi kültürünün iş ve okul ortamındaki etkileşimler yoluyla biçimlenebildiğini göstermektedir (Karadağ ve ark., 2006).

Aileye ilişkin değişkenlerin de demokrasi kültürü ve demokrasi eğitimi algılarında önemli bir farklılaştırıcı olduğu anlaşılmaktadır. ICCS 2022’de ebeveyn eğitimi, ebeveyn mesleği ve evdeki kültürel kaynaklar gibi sosyoekonomik göstergelerin her birinde yüksek gruplar lehine anlamlı yurttaşlık bilgisi farkları raporlanmıştır (Schulz ve ark., 2023). Özellikle ebeveyn mesleğine dayalı göstergelerde farkların daha belirgin olduğu görülmektedir (Schulz ve ark., 2023). Türkiye’de de anne eğitim düzeyi açısından demokratik tutumlarda anlamlı farklılık bulunduğu, buna karşın baba eğitim düzeyi açısından her zaman aynı düzeyde bir farklılaşmanın ortaya çıkmadığı bildirilmiştir (Gömleksiz & Çetintaş, 2011). Ayrıca baba mesleğine göre demokratik tutumların anlamlı biçimde değişebildiği ve bu değişkenin puan varyansının dikkat çekici bir bölümünü açıkladığı rapor edilmiştir (Bulut, 2006). Bu bulgular, aile eğitim ve meslek göstergelerinin yalnızca ekonomik kaynakları değil; kültürel sermaye, kamusal kurumlarla temas ve ev içi toplumsal-siyasal etkileşim örüntülerini de yansıtabileceğini düşündürmektedir.

Gelir ve yerleşim yeri gibi değişkenler bakımından ise daha karmaşık ve bağlama duyarlı sonuçlar elde edildiği görülmektedir. Uluslararası çalışmalarda gelir doğrudan değil, daha çok sosyoekonomik arka plan göstergeleri üzerinden modellenmekte ve genel olarak yüksek sosyoekonomik grupların yurttaşlık bilgisi bakımından daha avantajlı olduğu belirtilmektedir (Schulz ve ark., 2023). Türkiye’de ise gelir düzeyi ile demokratik tutum arasındaki ilişkinin her zaman doğrusal olmadığı; bazı örneklemelerde orta ve alt gelir grubundaki katılımcıların üst gelir grubuna göre daha yüksek demokratik tutum puanları sergileyebildiği rapor edilmiştir (Gömleksiz & Çetintaş, 2011). Benzer biçimde yerleşim yeri açısından il merkezinde yaşayan öğrencilerin demokrasi kültürü ya da vatandaşlık algısı puanlarının, ilçe ve köyde yaşayanlara göre daha yüksek bulunabildiği ifade edilmiştir

(Demirbaş & Aydınöz, 2020). Bu sonuçlar, şehirleşmenin kamusal kurumlarla temas, çeşitlilik deneyimi ve katılım fırsatları üzerinden demokratik algıyı destekleyebileceğini; ancak bu ilişkinin de tek başına değil, eğitimsel ve sosyoekonomik bağlamla birlikte değerlendirilmesi gerektiğini göstermektedir.

Amaç

Demokrasi kültürü ve demokrasi eğitimi algılarının, bireyin yalnızca kişisel özelliklerine bağlı olarak oluşmadığı; cinsiyet, öğrenim düzeyi, meslek, gelir, ebeveyn eğitimi, ebeveyn mesleği ve yerleşim yeri gibi demografik değişkenlerle birlikte okul iklimi, sınıf içi etkileşimler ve katılım fırsatları gibi bağlamsal değişkenlerin ortak etkisi altında biçimlendiği anlaşılmaktadır. Bu nedenle söz konusu yapıların incelenmesinde, demografik değişkenlerin tek tek ele alınmasının yanında, bunların eğitimsel ve toplumsal bağlamla etkileşimleri içinde değerlendirilmesi daha açıklayıcı sonuçlar sağlayacaktır. Böyle bir yaklaşımın, bireylerin demokrasi kültürü ve demokrasi eğitimi algı düzeylerinin çeşitli değişkenler açısından nasıl farklılaştığını ortaya koymada daha güçlü bir kuramsal ve yöntemsel temel sunacağı düşünülmektedir. Bu araştırmada, bireylerin demokrasi kültürü ve demokrasi eğitimi algı düzeylerinin çeşitli demografik değişkenler açısından incelenmesi amaçlanmaktadır. Bu genel amaç doğrultusunda, toplam puan ve olası alt boyut puanları bakımından demografik gruplar arasında anlamlı farklılaşma olup olmadığı test edilecektir. Araştırmanın temel problemi aşağıdaki biçimde ifade edilmektedir:

- **Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları, demografik değişkenlere göre anlamlı düzeyde farklılaşmakta mıdır?**

Bu problem doğrultusunda alt problemler aşağıda sunulmaktadır:

1. Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları cinsiyete göre anlamlı düzeyde farklılaşmakta mıdır?
2. Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları iş/meslek durumuna göre anlamlı düzeyde farklılaşmakta mıdır?
3. Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları öğrenim düzeyine göre anlamlı düzeyde farklılaşmakta mıdır?
4. Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları anne öğrenim düzeyine göre anlamlı düzeyde farklılaşmakta mıdır?
5. Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları baba öğrenim düzeyine göre anlamlı düzeyde farklılaşmakta mıdır?
6. Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları anne mesleğine göre anlamlı düzeyde farklılaşmakta mıdır?
7. Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları baba mesleğine göre anlamlı düzeyde farklılaşmakta mıdır?

Yöntem

Araştırmanın Modeli

Bu araştırma, nicel araştırma yaklaşımı çerçevesinde karşılaştırmalı tarama modeli temel alınarak yürütülmüştür. Tarama araştırmalarında mevcut durum olduğu gibi betimlenmekte; ayrıca belirli değişkenlere göre oluşan alt gruplar arasında anlamlı farklılaşmaların incelenmesine de olanak sağlanmaktadır. Bu araştırmada da bireylerin Türkiye’de demokratik yaşam, demokrasi kültürü, demokrasi engelleri ve evrensel demokrasi eğitimine ilişkin algılarının cinsiyet, meslek, öğrenim düzeyi ve fakülte/öğrenim alanı gibi değişkenlere göre farklılaşıp farklılaşmadığının belirlenmesi amaçlanmıştır. Bu yönüyle araştırma, mevcut durumu ortaya koymaya ve gruplar arası puan farklılıklarını incelemeye yönelik nicel bir desen özelliği taşımaktadır (Büyüköztürk ve ark., 2024; Karasar, 2024).

Çalışma Grubu

Araştırmanın çalışma grubunu, araştırmaya gönüllü olarak katılan 550 birey oluşturmaktadır. Katılımcıların belirlenmesinde gönüllülük ve ulaşılabilirlik esas alınmıştır. Demografik dağılımlar incelendiğinde katılımcıların 302'sinin (%54,9) kadın, 248'inin (%45,1) erkek olduğu görülmüştür. Meslek değişkenine göre en yüksek oranın öğrenci grubunda (%56,4) olduğu, bunu öğretmen (%12,7), memur (%11,6) ve akademisyen (%9,1) gruplarının izlediği belirlenmiştir. Öğrenim düzeyi bakımından katılımcıların büyük çoğunluğunun üniversite düzeyinde (%95,3) olduğu saptanmıştır. Fakülte/öğrenim alanı dağılımında ise en yüksek oranın Eğitim Fakültesinde (%46,5) olduğu, bunu Fen-Edebiyat (%13,5), mezun (%11,8) ve İlahiyat (%7,1) gruplarının izlediği görülmüştür. Ayrıca incelenen değişkenlerde eksik veri bulunmadığı belirlenmiştir.

Veri Toplama Araçları

Araştırmada veriler, Kişisel Bilgi Formu ile Türkiye'de demokratik yaşam, demokrasi kültürü, demokrasi engelleri ve evrensel demokrasi eğitime ilişkin algıları belirlemeye yönelik ölçme aracı kullanılarak toplanmıştır (Özbaş ve Dildeğmez, 2026).

Kişisel Bilgi Formu

Kişisel Bilgi Formu, katılımcıların demografik özelliklerini belirlemek amacıyla hazırlanmıştır. Formda cinsiyet, meslek, öğrenim düzeyi, üniversite düzeyinde öğrenim görülmesi hâlinde fakülte ya da yüksekokul bilgisi, anne ve baba öğrenim durumu, anne ve baba mesleği, aylık gelir düzeyi ve yaşanan il gibi değişkenlere yer verilmiştir. Söz konusu değişkenler, bağımsız örneklem t testi ve tek yönlü varyans analizi kapsamında bağımsız değişkenler olarak ele alınmıştır (Özbaş ve Dildeğmez, 2026).

Türkiye'de Demokratik Yaşam, Demokrasi Kültürü, Demokrasi Engelleri, Evrensel Demokrasi Eğitimi Ölçeği

Araştırmada kullanılan ölçme aracı 28 maddeden oluşmakta ve beşli Likert tipinde yapılandırılmış bulunmaktadır. Ölçekte yanıt kategorileri "Hiç", "Az", "Orta", "Çoğunlukla" ve "Tamamen" biçimindedir. Ölçek altı boyut altında düzenlenmiştir. Bu boyutlar; Türkiye'de günlük demokratik yaşam pratikleri ve koşulları, Türkiye'de demokrasi kültürü ve demokratik yaşam, Türkiye'ye özgü antidemokratik yaşam koşulları, evrensel demokrasi kültürü ve evrensel demokrasinin ilkeleri, Türkiye'de demokrasinin sosyal, politik ve bireysel engelleri ile evrensel demokrasinin eğitimi şeklindedir. Ölçek puanlarının ilgili madde puanlarının toplamı ya da ortalaması üzerinden hesaplanabileceği anlaşılmaktadır. Yüksek puanların, ilgili boyutta daha güçlü bir algıya işaret ettiği değerlendirilmektedir. Bununla birlikte, yüklenen ölçme formunda ölçeğin geliştirilme sürecine ilişkin geçerlik ve güvenirlik katsayıları yer almadığından, bu çalışmanın yöntem metnine doğrulanmamış psikometrik değerler eklenmemiştir (Özbaş ve Dildeğmez, 2026.).

Verilerin Analizi

Verilerin analizinden önce veri seti, analiz varsayımları bakımından incelenmiştir. Bu kapsamda eksik veri durumu, aykırı gözlemler ve normallik varsayımı kontrol edilmiştir. Nicel araştırmalarda parametrik karşılaştırmalar öncesinde aykırı değerler ile dağılım özelliklerinin incelenmesi önerilmektedir. Özellikle çarpıklık-basıklık değerleri, aykırı gözlemler ve grup varyanslarının yapısı dikkate alınarak uygun analiz tekniğine karar verilmektedir (Tabachnick ve Fidell, 2013). İki kategorili bağımsız değişkenlerde grup ortalamalarının karşılaştırılması amacıyla bağımsız örneklem t testi, ikiden fazla kategori içeren bağımsız değişkenlerde ise tek yönlü varyans analizi kullanılması uygun görülmüştür. Varyans analizinde anlamlı farklılık saptanması durumunda, farkın hangi gruplardan kaynaklandığını belirlemek amacıyla varyans homojenliği sağlandığında Tukey HSD, homojenlik sağlanmadığında ise Games-Howell çoklu karşılaştırma testlerinden yararlanılması önerilmektedir. Bulguların yorumlanmasında yalnızca p değerine değil, etki büyüklüklerine de yer verilmesi uygun kabul edilmektedir. T testi için Cohen's d, varyans analizi için eta-kare değerlerinin raporlanması planlanmıştır (Field, 2024). Tüm analizlerin IBM SPSS Statistics 27 paket programında yürütülmesi ve anlamlılık düzeyinin .05 olarak alınması uygun görülmüştür (IBM Corp., 2020).

Bulgular ve Yorumlar

Bu bölümde her bir alt probleme ilişkin elde edilen betimsel istatistikler ve analiz çıktıları detaylandırılmış ve raporlanmıştır.

Alt problem 1: “Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları cinsiyete göre anlamlı düzeyde farklılaşmakta mıdır?” Araştırma problemine ilişkin bulgular **Tablo 1’de** verilmiştir.

Tablo 1. Cinsiyet Değişkenine Göre Bağımsız Örneklem İstatistikleri

Değişken	Grup	N	Ortalama	SS	Çarpıklık	Basıklık	t	sd	p	Etki Büyüklüğü	Bayes (BF10)	Güç (Power)
TOPLAM	Erkek	248	99,55	14,74	0,54	0,27	-0,48	548,00	0,632	-0,04 (Cohen's d)	0,107	0,08
	Kadın	302	100,13	13,82	0,26	-0,15						

Araştırma kapsamında, bireylerin demokrasi kültürü ve demokrasi eğitimi algıları toplam puanlarının Cinsiyet değişkenine göre anlamlı biçimde farklılaşıp farklılaşmadığı incelenmiştir. Verilerin dağılım özellikleri incelendiğinde, çarpıklık değerlerinin (0.54 ile 0.26) ve basıklık değerlerinin (0.27 ile -0.15) kabul edilebilir sınırlar içerisinde kaldığı görülmüştür. Bu nedenle normal dağılım varsayımının desteklendiği kabul edilmiştir. Levene testi sonucunda varyans homojenliğinin desteklendiği görülmüştür. Normallik ve varyans homojenliği varsayımları desteklendiği için standart t-testi uygulandı. Bu nedenle Standart T-Testi uygulanmıştır. Elde edilen bulgulara göre gruplar arasında istatistiksel açıdan anlamlı bir fark saptanmamıştır ($t(548.00) = -0.479$, $p = .632$). Betimsel istatistikler birlikte değerlendirildiğinde, Erkek ($M = 99.55$) ve Kadın ($M = 100.13$) gruplarının ortalamalarının birbirine yakın olduğu görülmüştür. Bununla birlikte, test gücünün ($1-\beta = 0.08$) ideal kabul edilen .80 düzeyinin altında kaldığı görülmüştür. Son olarak Bayesyen analiz sonucunda ($BF10 = 0.11$), mevcut verilerin sıfır hipotezini destekleme yönünde orta düzeyde kanıt sunduğu görülmüştür.

Alt problem 2: “Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları iş/meslek durumuna göre anlamlı düzeyde farklılaşmakta mıdır?” Araştırma problemine ilişkin bulgular **Tablo 2’de** verilmiştir. Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları toplam puanlarının dağılım özellikleri Meslek alt grupları bazında incelendiğinde, grupların çarpıklık değerlerinin -0.158 ile 0.749 aralığında; basıklık değerlerinin ise -2.926 ile 0.687 aralığında olduğu görülmüştür. Küçük örneklemelerde Shapiro-Wilk, orta ve büyük örneklemelerde ise çarpıklık-basıklık temelli karar ölçütleri birlikte değerlendirilmiş; alt gruplar düzeyinde normallik varsayımının kabul edilebilir düzeyde olduğu belirlenmiştir. Levene testi sonucunda varyansların homojen olmadığı görülmüş ve bu nedenle varyans eşitsizliğine daha dayanıklı olan Welch ANOVA testi uygulanmıştır. Analiz sonucunda, TOPLAM boyutunda Meslek grupları arasında istatistiksel olarak anlamlı bir fark bulunduğu belirlenmiştir ($F=2.876$; $p = 0.016^{**}$; $\eta^2=0.034$). Anlamlı farkın hangi gruplardan kaynaklandığını belirlemek amacıyla varyans homojenliği sağlanmadığından Games-Howell uygulanmıştır. Test sonucuna göre; Öğrenci grubunun betimsel ortalamasının ($\bar{x}=101.40$), Akademisyen grubuna ($\bar{x}=94.20$) göre daha yüksek olduğu ve ikili karşılaştırmanın anlamlı bulunduğu görülmüştür ($6>1$).

Tablo 2: Meslek Değişkenine Göre Toplam Puan ve Alt Boyutlarına İlişkin ANOVA Testi Sonuçları

Ölçek ve Alt Boyutlar	Meslek	N	Ort.	SS	SD	İstatistik	p	Etki Büyüklüğü	Anlamlı Fark

	Akademisyen(1)	50	94,20	10,80					
	Diğer(2)	10	98,20	24,38					
	Emekli(3)	4	101,50	8,27					
	Memur(4)	64	98,47	17,14					
TOPLAM	Serbest meslek(5)	4	88,75	7,37	9, 27.23	F=2.876	.016**	$\eta^2=0.034$	$6>1^{**}$
	Öğrenci(6)	310	101,40	13,24					
	Öğretmen(7)	70	98,83	14,90					
	İş insanı(8)	5	89,60	18,45					
	İşsiz(9)	8	104,12	10,63					
	İşçi(10)	25	101,60	15,50					

Uygulanan test: Welch ANOVA | Normallik: Sağlandı | Levene p: 0.006 | Varyans homojenliği: Sağlanmadı

Alt problem 3: “Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları öğrenim düzeyine göre anlamlı düzeyde farklılaşmakta mıdır?” Araştırma problemine ilişkin bulgular **Tablo 3’te** verilmiştir.

Tablo 3: Eğitim Düzeyi Değişkenine Göre Toplam Puan ve Alt Boyutlarına İlişkin ANOVA Testi Sonuçları

Ölçek ve Alt Boyutlar	Eğitim Düzeyi	N	Ort.	SS	SD	İstatistik	p	Etki Büyüklüğü
	5(1)	4	105,25	25,13				
	Lise(2)	15	94,93	18,32				
TOPLAM	Ortaokul(3)	4	96,75	19,35	4, 545	F=0.650	.627	$\eta^2=0.005$
	Üniversite(4)	524	99,99	14,02				
	İlkokul(5)	3	100,00	9,17				

Uygulanan test: Tek Yönlü Varyans Analizi (Standart ANOVA) | Normallik: Sağlandı | Levene p: 0.227 | Varyans homojenliği: Sağlandı

Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları toplam puanlarının dağılım özellikleri Eğitim Düzeyi alt grupları bazında incelendiğinde, grupların çarpıklık değerlerinin 0.209 ile 1.075 aralığında; basıklık değerlerinin ise -2.865 ile 2.096 aralığında olduğu görülmüştür. Küçük örneklemelerde Shapiro-Wilk, orta ve büyük örneklemelerde ise çarpıklık-basıklık temelli karar ölçütleri birlikte değerlendirilmiş; alt gruplar düzeyinde normallik varsayımının kabul edilebilir düzeyde olduğu belirlenmiştir. Levene testi sonucunda varyansların homojen olduğu görülmüş ve bu nedenle parametrik yaklaşım altında Tek Yönlü Varyans Analizi (Standart ANOVA) uygulanmıştır. Analiz sonucunda, TOPLAM düzeylerinin Eğitim Düzeyi gruplarına göre istatistiksel olarak anlamlı biçimde farklılaşmadığı belirlenmiştir ($F=0.650$; $p=0.627$; $\eta^2=0.005$).

Alt problem 4: “Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları anne öğrenim düzeyine göre anlamlı düzeyde farklılaşmakta mıdır?” Araştırma problemine ilişkin bulgular **Tablo 4’te** verilmiştir.

Tablo 4: Anne Eğitim Düzeyi Değişkenine Göre Toplam Puan ve Alt Boyutlarına İlişkin ANOVA Testi Sonuçları

Ölçek ve Alt Boyutlar	Anne Eğitim Düzeyi	N	Ort.	SS	SD	İstatistik	p	Etki Büyüklüğü
	Lise(2)	83	101,02	14,68				
	Okuryazar(3)	80	97,80	12,10				
TOPLAM	Ortaokul(4)	96	99,95	14,21	4, 544	F=0.595	0.667	$\eta^2=0.004$
	Üniversite(5)	19	99,63	18,64				
	İlkokul(6)	271	100,19	14,35				

Uygulanan test: Tek Yönlü Varyans Analizi (Standart ANOVA) | Normallik: Sağlandı | Levene p: 0.213 | Varyans homojenliği: Sağlandı

Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları toplam puanlarının dağılım özellikleri anne eğitim düzeyi alt grupları bazında incelendiğinde, grupların çarpıklık değerlerinin 0.090 ile 0.956 aralığında; basıklık değerlerinin ise -0.396 ile 0.777 aralığında olduğu görülmüştür. Küçük örneklemelerde Shapiro-Wilk, orta ve büyük örneklemelerde ise çarpıklık-basıklık temelli karar ölçütleri birlikte değerlendirilmiş; alt gruplar düzeyinde normallik varsayımının kabul edilebilir düzeyde olduğu belirlenmiştir. Levene testi sonucunda varyansların homojen olduğu görülmüş ve bu nedenle parametrik yaklaşım altında Tek Yönlü Varyans Analizi (Standart ANOVA) uygulanmıştır. Analiz sonucunda, TOPLAM düzeylerinin Anne Eğitim Düzeyi gruplarına göre istatistiksel olarak anlamlı biçimde farklılaşmadığı belirlenmiştir ($F=0.595$; $p = 0.667$; $\eta^2=0.004$).

Alt problem 5: “Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları baba öğrenim düzeyine göre anlamlı düzeyde farklılaşmakta mıdır?” Araştırma problemine ilişkin bulgular **Tablo 5’te** verilmiştir.

Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları toplam puanlarının dağılım özellikleri Baba Eğitim Düzeyi alt grupları bazında incelendiğinde, grupların çarpıklık değerlerinin 0.100 ile 0.877 aralığında; basıklık değerlerinin ise -0.664 ile 0.889 aralığında olduğu görülmüştür. Küçük örneklemelerde Shapiro-Wilk, orta ve büyük örneklemelerde ise çarpıklık-basıklık temelli karar ölçütleri birlikte değerlendirilmiş; alt gruplar düzeyinde normallik varsayımının kabul edilebilir düzeyde olduğu belirlenmiştir. Levene testi sonucunda varyansların homojen olduğu görülmüş ve bu nedenle parametrik yaklaşım altında Tek Yönlü Varyans Analizi (Standart ANOVA) uygulanmıştır. Analiz sonucunda, TOPLAM düzeylerinin Baba Eğitim Düzeyi gruplarına göre istatistiksel olarak anlamlı biçimde farklılaşmadığı belirlenmiştir ($F=0.380$; $p = 0.823$; $\eta^2=0.003$).

Tablo 5: Baba Eğitim Düzeyi Değişkenine Göre Toplam Puan ve Alt Boyutlarına İlişkin ANOVA Testi Sonuçları

Ölçek ve Alt Boyutlar	Baba Eğitim Düzeyi	N	Ort.	SS	SD	İstatistik	p	Etki Büyüklüğü
	Lise (1)	137	100,09	13,59				
	Okuryazar (2)	14	97,71	9,86				
TOPLAM	Ortaokul (3)	119	98,85	15,28	4, 545	F=0.380	0.823	$\eta^2=0.003$
	Üniversite (4)	92	100,97	14,37				
	İlkokul (5)	188	99,97	14,29				

Uygulanan test: Tek Yönlü Varyans Analizi (Standart ANOVA) | Normallik: Sağlandı | Levene p: 0.187 | Varyans homojenliği: Sağlandı

Alt problem 6: “Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları anne mesleğine göre anlamlı düzeyde farklılaşmakta mıdır?” Araştırma problemine ilişkin bulgular **Tablo 6’da** verilmiştir.

Tablo 6: Anne Meslek Değişkenine Göre Toplam Puan ve Alt Boyutlarına İlişkin ANOVA Testi Sonuçları

Ölçek ve Alt Boyutlar	Anne Meslek	N	Ort.	SS	SD	İstatistik	p	Etki Büyüklüğü
	Diğer (1)	4	91,75	14,57				
	Ev hanımı (2)	508	99,81	13,93				
TOPLAM	Memur (3)	19	99,32	18,21	4, 543	F=0.511	0.728	$\eta^2=0.004$
	Serbest meslek (4)	8	103,00	18,55				
	İşçi (7)	9	102,56	17,97				

Uygulanan test: Tek Yönlü Varyans Analizi (Standart ANOVA) | Normallik: Sağlandı | Levene p: 0.308 | Varyans homojenliği: Sağlandı

Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları toplam puanlarının dağılım özellikleri Anne Meslek alt grupları bazında incelendiğinde, grupların çarpıklık değerlerinin -0.917 ile 1.667 aralığında; basıklık değerlerinin ise -1.759 ile 3.093 aralığında olduğu görülmüştür. Küçük örneklemelerde Shapiro-Wilk, orta ve büyük örneklemelerde ise çarpıklık-basıklık temelli karar ölçütleri birlikte değerlendirilmiş; alt gruplar düzeyinde normallik varsayımının kabul edilebilir düzeyde olduğu belirlenmiştir. Levene testi sonucunda varyansların homojen olduğu görülmüş ve bu nedenle parametrik yaklaşım altında Tek Yönlü Varyans Analizi (Standart ANOVA) uygulanmıştır. Analiz sonucunda, TOPLAM düzeylerinin Anne Meslek gruplarına göre istatistiksel olarak anlamlı biçimde farklılaşmadığı belirlenmiştir (F=0.511; p = 0.728; $\eta^2=0.004$).

Alt problem 7: “Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları baba mesleğine göre anlamlı düzeyde farklılaşmakta mıdır?” Araştırma problemine ilişkin bulgular **Tablo 7’de** verilmiştir.

Tablo 7: Baba Meslek Değişkenine Göre Toplam Puan ve Alt Boyutlarına İlişkin ANOVA Testi Sonuçları

Ölçek ve Alt Boyutlar	Baba Meslek	N	Ort.	SS	SD	İstatistik	p	Etki Büyüklüğü
	Diğer(1)	141	99,61	13,00				
	Memur(2)	123	99,54	14,72				
TOPLAM	Serbest meslek(3)	101	101,35	15,56	6, 543	F=0.875	0.513	$\eta^2=0.010$
	Çiftçi(4)	52	99,73	13,01				
	İş insanı(5)	15	105,60	15,35				
	İşsiz(6)	13	101,62	18,14				

Uygulanan test: Tek Yönlü Varyans Analizi (Standart ANOVA) | Normallik: Sağlandı | Levene p: 0.451 | Varyans homojenliği: Sağlandı

Bireylerin demokrasi kültürü ve demokrasi eğitimi algıları toplam puanlarının dağılım özellikleri Baba Meslek alt grupları bazında incelendiğinde, grupların çarpıklık değerlerinin 0.002 ile 0.675 aralığında; basıklık değerlerinin ise -0.837 ile 0.553 aralığında olduğu görülmüştür. Küçük örneklemelerde Shapiro-Wilk, orta ve büyük örneklemelerde ise çarpıklık-basıklık temelli karar ölçütleri birlikte değerlendirilmiş; alt gruplar düzeyinde normallik varsayımının kabul edilebilir düzeyde olduğu belirlenmiştir. Levene testi sonucunda varyansların homojen olduğu görülmüş ve bu nedenle parametrik yaklaşım altında Tek Yönlü Varyans Analizi (Standart ANOVA) uygulanmıştır. Analiz sonucunda, TOPLAM düzeylerinin Baba Meslek gruplarına göre istatistiksel olarak anlamlı biçimde farklılaşmadığı belirlenmiştir ($F=0.875$; $p = 0.513$; $\eta^2=0.010$).

Tartışma Sonuç ve Öneriler

Bulgular bütüncül olarak değerlendirildiğinde, demokrasi kültürü ve demokrasi eğitimi algılarının incelenen demografik değişkenlerin büyük bölümünde anlamlı biçimde farklılaşmadığı, yalnızca meslek değişkeninde öğrenci grubu lehine istatistiksel olarak anlamlı ancak etki büyüklüğü sınırlı bir farklılaşmanın ortaya çıktığı görülmektedir. Bu çerçevede, cinsiyet, bireyin öğrenim düzeyi, anne ve baba öğrenim düzeyi ile anne ve baba mesleğine göre toplam puanların anlamlı biçimde değişmemesi; söz konusu algıların tekil demografik göstergelerden çok, bireyin içinde bulunduğu eğitim yaşantıları, kurumsal iklim ve demokratik katılım deneyimleriyle birlikte şekillenebilen bir yapı olduğunu düşündürmektedir. Nitekim araştırmada cinsiyet değişkeni açısından erkek ve kadın katılımcıların ortalama puanlarının birbirine oldukça yakın olduğu, t testi sonucunda farkın anlamlı olmadığı ve Bayesyen bulguların da sıfır hipotezini desteklediği görülmüştür. Bu sonucun, kız öğrenciler lehine daha yüksek yurttaşlık bilgisi ve eşitlik yönelimi rapor eden uluslararası ICCS bulgularıyla tam olarak örtüşmediği söylenebilir; ancak Türkiye bağlamında demokratik tutumun cinsiyete göre her zaman aynı yönde farklılaşmadığını gösteren araştırmalarla daha uyumlu bir görünüm sergilediği anlaşılmaktadır. Başka bir ifadeyle, bu çalışmada cinsiyetin ayırt edici bir değişken olarak öne çıkmaması, demokratik algının yalnızca biyolojik ya da toplumsal cinsiyet temelli rollerle değil, bireyin karşılaştığı eğitimsel ve toplumsal deneyimlerin niteliğiyle daha yakından ilişkili olabileceğini düşündürmektedir (Aydoğmuş & Kiraz, 2020; Baltacı & Aydın, 2019; Schulz ve ark., 2023).

Araştırmada en dikkat çekici bulgunun meslek değişkeninde ortaya çıktığı görülmektedir. Welch ANOVA sonucunda meslek grupları arasında anlamlı bir farklılık belirlenmiş, Games-Howell çoklu karşılaştırma testi bu farkın öğrenci grubu ile akademisyen grubu arasında, öğrenci grubu lehine oluştuğunu göstermiştir. Bununla birlikte eta-kare değerinin düşük olması, söz konusu farkın pratik öneminin sınırlı olduğuna işaret etmektedir. Bu bulgu, ilk bakışta eğitim düzeyi ve akademik statü yükseldikçe demokrasi kültürü ve demokrasi eğitimi algısının da artacağı yönündeki beklentiyle tam olarak uyuşmamaktadır. Ancak literatürde demokratik yönelimlerin yalnızca formel eğitim süresiyle değil, bireyin kurumsal yapılarla ilişkisi, eleştirel farkındalık düzeyi ve örgütsel deneyimleriyle de bağlantılı olduğu vurgulanmaktadır. Bu açıdan bakıldığında, öğrencilerin demokratik ilke ve değerlere daha normatif, daha idealist ve daha beklenti temelli yaklaşımları; akademisyenlerin ise demokratik yaşamın yapısal sınırlılıklarını, uygulamadaki gerilimleri ve kurumsal sorunları daha görünür biçimde değerlendirmeleri nedeniyle daha temkinli puanlar vermiş olabilecekları düşünülmektedir. Benzer şekilde, öğretmenlerde demokratik tutumların eğitim düzeyine göre artabildiği, ancak mesleki kıdem ve kurumsal deneyimin bu ilişkiyi zayıflatabildiği bildirilmiştir. Dolayısıyla bu çalışmada öğrencilerin daha yüksek puan vermesi, demokratik kültüre ilişkin algının yalnızca bilgi düzeyinin değil, rol beklentisinin ve yaşantısal konumun da bir ürünü olabileceğini göstermektedir (Baltacı & Aydın, 2019; Barrett, 2020).

Öğrenim düzeyi değişkenine ilişkin bulgular, toplam puanların farklı eğitim düzeylerine göre anlamlı biçimde değişmediğini göstermiştir. Bu sonuç, demokratik yurttaşlık yeterliklerinin eğitim süreçleri içinde geliştiğini vurgulayan kuramsal yaklaşımlarla ilk bakışta sınırlı bir uyum göstermektedir. Bununla birlikte mevcut çalışma grubunda üniversite düzeyindeki katılımcıların çok büyük bir ağırlık taşıması, alt gruplardaki kişi sayılarının oldukça dengesiz dağılması ve bazı kategorilerde gözlem sayısının çok düşük kalması, istatistiksel farkların görünür hâle gelmesini güçleştirmiş olabilir. Bu nedenle öğrenim düzeyi bakımından anlamlı farklılığın saptanmamış olması, eğitimin demokrasi kültürü ve demokrasi eğitimi algıları üzerinde hiçbir

etkisinin bulunmadığı biçiminde yorumlanmamalıdır. Daha çok, bu örneklemede varyansın daraldığı ve ölçülen yapının algı temelli özelliğinin bilişsel düzeydeki farkları zayıflatmış söylenebilir. Uluslararası araştırmalarda demokratik yurttaşlık çıktılarının okul iklimi, tartışmaya açık sınıf ortamı ve katılım fırsatlarıyla birlikte ele alındığında daha açıklayıcı sonuçlar verdiği bilinmektedir. Bu nedenle burada görülen anlamsızlık, öğrenim düzeyinin tek başına yeterli bir açıklayıcı değişken olmayabileceğini düşündürmektedir (Schulz ve ark., 2018; Schulz ve ark., 2023; UNESCO, 2015).

Anne ve baba öğrenim düzeyi ile anne ve baba mesleğine ilişkin bulguların tamamında anlamlı farklılığın saptanmamış olması da dikkate değer bir sonuçtur. Özellikle demokratik tutum ve yurttaşlık algısı literatüründe aileye ilişkin göstergelerin, kültürel sermaye ve sosyoekonomik olanakların dolaylı yansımaları olarak işlev görebildiği bilinmektedir. Bununla birlikte bu etkinin her araştırmada aynı güçte ortaya çıkmadığı, hatta bazı çalışmalarda anne-baba eğitim düzeyi ya da mesleğine bağlı farkların zayıf kaldığı görülmektedir. Mevcut çalışmada ebeveyn değişkenlerine göre anlamlı fark bulunmaması, aile arka planının demokrasi kültürü algısı üzerindeki etkisinin doğrudan değil, okul deneyimleri, yaşanan çevre, bireysel katılım olanakları ve siyasal-toplumsal etkileşimler üzerinden dolaylı olarak işliyor olabileceğini düşündürmektedir. Bu yorum, üniversite öğrencilerinin vatandaşlık algılarında cinsiyet ve yerleşim yerinin anlamlı olduğu, ancak bazı aile değişkenlerinin aynı derecede güçlü bir ayırt edici olmadığına işaret eden bulgularla uyumludur. Öte yandan öğretmen adayları üzerinde yürütülen bazı araştırmalarda anne eğitim düzeyi ve baba mesleği gibi değişkenlerin demokratik tutumları etkileyebildiği de gösterilmiştir. Dolayısıyla bu çalışmanın sonuçları, aile değişkenlerinin etkisinin bağlama duyarlı olduğunu; her örneklemede otomatik olarak ortaya çıkan bir farklılaşma beklenmemesi gerektiğini göstermektedir (Bulut, 2006; Demirbaş & Aydınöz, 2020; Gömleksiz & Çetintaş, 2011).

Genel olarak değerlendirildiğinde, bu araştırmadan elde edilen sonuçlar, demokrasi kültürü ve demokrasi eğitimi algılarının tek tek demografik değişkenlerle açıklanmasının sınırlı kaldığını; buna karşılık bireyin toplumsal ve kurumsal deneyimleriyle daha karmaşık biçimde örüldüğünü göstermektedir. Özellikle yalnızca meslek değişkeninde ve öğrenci grubu lehine küçük düzeyli bir farklılığın bulunması, demokratik algının yaş, rol, beklenti ve kurumsal deneyim ekseninde farklılaşabildiğine işaret etmektedir. Bunun yanında diğer değişkenlerde anlamlı farklılık saptanmamış olması, araştırmanın örneklem yapısı, bazı alt gruplardaki düşük sayılar ve ölçeğin algı odaklı niteliğiyle birlikte değerlendirildiğinde daha anlamlı hâle gelmektedir. Bu nedenle çalışmanın en temel sonucu, demokrasi kültürü ve demokrasi eğitimi algısının yalnızca sosyodemografik konumun bir uzantısı olmadığı; daha çok eğitim ortamlarında yaşanan katılım deneyimleri, eleştirel tartışma fırsatları ve demokratik yaşamın gündelik pratikleriyle beslenen çok katmanlı bir yapı olduğudur.

Bu çalışma kapsamında şu önerilere yer verilebilir:

- İleride yapılacak araştırmalarda, demokrasi kültürü ve demokrasi eğitimi yapısının daha ayrıntılı biçimde ortaya konulabilmesi için ölçeğin alt boyutları ayrı ayrı incelenmelidir.
- Bulguların genellenebilirliğinin artırılabilmesi amacıyla, farklı meslek gruplarını daha dengeli biçimde temsil eden ve alt gruplar arasında sayı bakımından daha homojen dağılım gösteren örneklemle çalışılmalıdır.
- Demokrasi kültürü ve demokrasi eğitimi algısının daha derinlemesine açıklanabilmesi için, nicel bulgular nitel verilerle desteklenmeli; özellikle katılımcı görüşmeleri, odak grup çalışmaları ve gözlem verileri araştırma sürecine dâhil edilmelidir.
- Gelecek çalışmalarda demokratik algının yalnızca demografik değişkenler üzerinden değil; okul iklimi, katılım deneyimi, toplumsal güven ve eleştirel tartışma ortamı gibi değişkenlerle birlikte ele alındığı daha kapsamlı araştırma desenleri kullanılmalıdır.
- Uygulama boyutunda, demokrasi eğitimi yalnızca kuramsal bilgi aktarımı ile sınırlandırılmamalı; tartışmaya açık sınıf ortamları güçlendirilmeli, öğrenci ve yetişkin gruplar için katılımcı öğrenme süreçleri yaygınlaştırılmalı ve özellikle yükseköğretimde demokratik deneyimi gündelik kurumsal yaşama taşıyan uygulamalara daha fazla yer verilmelidir.

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POLITICAL COMMUNICATION AND CAMPAIGNING IN THE AGE OF ALGORITHMS AND ARTIFICIAL INTELLIGENCE

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ABSTRACT

Political communication undergoes a substantial transformation, as the influence of artificial intelligence (AI) and algorithms has grown radically in the second quarter of the twenty-first century. The current period marks a new phase in which political debate is conducted in the cyber sphere and political discourse is largely shaped by the virtual realm. At this point, on the one hand, those engaged in political communication are consciously using artificial intelligence and algorithms in the process of designing political campaigns; on the other hand, both they and their target groups are unwittingly influenced by these technological advancements. Hence, this study examines both the transformation of the milieu in which political communication takes place and how political communication has adapted to this transformation. In this context, the focus of the study is on the structure, mechanisms and processes of discourses to which voters are exposed and the evolving content and tactics of political campaigns. To address this focus in detail, examples from diverse contexts around the world have been presented. The study found that the traditional roles of political communicators are being filled by data scientists and algorithm analysts to build data-centric campaigns. In connection with this, AI is used for hyper-personalised micro-targeting, automated content, and virtual canvassers. Furthermore, unethical practices like deepfakes and bot networks, which amplify the speed and scale of disinformation, can also be included in some cases of political campaigning. On the voters' side, algorithms foster echo chambers and prioritise emotional content, leading to the fragmentation of the shared public sphere. As voters face an excess of information about politics, they suffer from verification fatigue and cognitive exhaustion, which weakens the common ground of reality underpinning democracy. Consequently, it can be argued that electoral behaviour is the product of data-driven influence engineering rather than an exercise of individual free will.

Keywords: Political Communication, Political Campaigning, Artificial Intelligence, Algorithms.

INTRODUCTION

The groundbreaking advances in computer technology, and particularly in artificial intelligence, have brought about profound changes in many areas of life and have fundamentally transformed numerous aspects of political communication. The cyber transformation has constituted the fundamental characteristics of this era. Political debate has migrated to the cyber sphere, fundamentally altering how discourse is shaped and consumed. On the one hand, the environment in which political communication takes place has undergone a complete transformation; on the other hand, political communicators and the public are endeavouring to adapt to this new environment.

Thus, political communication in the 2020s is characterised by two intertwining dynamics. On the one hand, political actors are actively leveraging AI and algorithms to design hyper-targeted political campaigns. Conversely, both campaigners and voters are passively affected by the underlying AI-based and algorithmic architecture.

In the light of this discussion, the primary objective of this study is to examine the transformation of the political communication milieu and how political actors and voters adapt to AI-made and algorithmic architectures. The scope of research is the structure, mechanisms, and processes of political discourse in the age of algorithms and AI. Therefore, the core focus of this study becomes examining the structural shift in campaign tactics, the mechanisms of algorithmic discourse, and their ultimate impact on voter behavior and democratic realities. Thus, a methodological approach which hinges on the analysis of diverse, real-world examples and campaign contexts from around the globe has been developed.

CONSCIOUS USE: AI AS A STRATEGIC TOOL OF POLITICAL CAMPAIGNING

Hyper-personalised micro-targeting is a significant milestone in political communication, completely transforming the way communication is designed. Online political micro-targeting is a form of personalised communication that involves gathering information about individuals and displaying political advertisements specifically tailored to them based on the data collected. Political parties use micro-targeting to identify individuals who are most likely to be persuaded, and then design political messages that appeal to their values and interests (Zuiderveen Borgesius et al., 2018, p. 82). Thus, political campaigns move away from mass messaging and deliver highly specific discourse in accordance with the psychometric profiles of individual voters. On the other hand, unlike traditional political adverts on television, micro-targeting undermines data protection rights and privacy while negatively influencing the democratic process (Dobber, Ó Fathaigh & Zuiderveen Borgesius, 2019, p. 2).

For example, Facebook can position a user on the political spectrum based on the pages they like, the topics they are interested in, and the politicians they interact with. This positioning goes beyond simply left and right; it also involves understanding the individual's stance on a wide range of issues, from international migration and the social security system to environmental concerns and social equality. This big data, in turn, provides valuable insights for politicians and those running political campaigns (Sunstein, 2017, p. 3-4). Thus, predictive analytics and automation become a significant tool at the hands of political campaigners. AI is utilised in order to forecast voter turnout and automatically generate campaign content at scale.

Furthermore, virtual canvassing is a relatively new form of computer-based political communication which increases opportunities for dialogue with voters via the internet during political campaigns. AI chatbots and virtual canvassers are deployed to interact with voters in real-time, creating a human-like, persistent and personalized campaign atmosphere. According to the research conducted by Mann (2021, p. 9-10), three separate experiments have found that a campaign using chatbots to encourage voting increased voter turnout in a manner that corresponded to the perceived importance of the election. Chatbots have become an integral part of modern life, being integrated into smartphones, computers and other devices, and are now considered to be part of everyday social interactions. Just as a person might take political encouragement from family, friends or campaign volunteers seriously in their daily life, political chatbots also have the potential to influence voter behaviour.

THE STRUCTURAL TRANSFORMATION OF POLITICAL CAMPAIGN TEAMS

Across all the world's developed democracies, political parties collect voter data and design their campaigns based on it (Dommett, 2025, p. 363). A significant outcome of this trend is the shift in political communication personnel. The traditional roles of political communicators are becoming obsolete. Classic copywriters, poster designers, and field coordinators have been replaced by data scientists, algorithm analysts, and digital crisis specialists. Political campaigning is no longer merely about public relations; it is a highly technical, data-centric operation focused on behavioral modeling and content automation.

In this new political communication ecosystem, technology firms such as Google, Microsoft, Facebook, and X (formerly Twitter) have become key players in the field of political communication by gaining ground *vis-à-vis* traditional public relations firms. These firms are more dynamic players with organisational frameworks and staffing patterns that mirror the partisan character of US politics than were formerly recognised (Kreiss & McGregor, 2018).

THE DARK SIDE: UNETHICAL TACTICS AND DISINFORMATION

Synthetic media content produced with fake photos and videos or audio cloning has become the inescapable component of public discourse in today's world. Digital impersonation and the deepfake technology accompanying it have become increasingly popular in recent times due to their extreme realism and persuasiveness. Although deepfake images and videos are sometimes produced with the consent of the person in the footage, in most cases they are produced without the person's consent (Chesney & Citron, 2019, p. 1758). In political communication, hyper-realistic, manipulated media can be instrumentalised in order to damage opponents or manufacture crises during a political campaigning period.

Moreover, synthetic astroturfing has emerged as a significant problem that threatens democratic processes. Whilst astroturfing refers to the act of hiring people specifically to promote a particular belief or idea across various platforms, online astroturfing refers to the same process being carried out on the internet (Zhang, Carpenter & Ko, 2013). Online astroturfing is cheaper, easier and has the ability to reach a wider audience than traditional astroturfing carried out in a physical setting, and is far more effective. For this reason, it can be said to be far more problematic than traditional astroturfing (Kovic et al., 2018, p. 70).

Bot networks are also effective in manipulating the democratic debate culture. Political bots are software programmes designed to carry out repetitive and simple text-based duties for the purpose of computer-assisted propaganda. These bots rely on deploying automated accounts to amplify the speed and volume of online propaganda (Woolley, & Howard, 2018, p. 6), to manufacture fake public opinion or to create the illusion of grassroots support for a specific political campaign.

The proliferation of deepfakes and similar misleading content can also provide an advantage to immoral political figures. Politicians can exploit an environment of misinformation and mistrust to their own advantage by presenting damaging facts about themselves (such as a scandal) as mere ‘deepfakes’ or ‘fake news’. This can shortly be described as “misinformation about misinformation”. According to the “Liar’s Dividend” hypothesis, the level of support for political figures increases on average when they respond to a scandal with the claims of “false news” or “deepfake” compared to simply denying the scandal, offering no response, or expressing an apology (Schiff, Schiff & Bueno, 2025, p. 74). This situation will cause those involved in corruption and scandals to become even more reckless and fearless.

A significant consequence of unethical tactics in a political race is the situation of constant crisis management. These tactics force opposing campaigns into a perpetual state of reputation defense and necessitate the creation of strict digital validation mechanisms.

THE POLITICAL COMMUNICATION MILIEU AND THE PUBLIC SPHERE

Algorithmic echo chambers, which perpetuate pre-existing societal biases, are another significant element of the political communication milieu. An echo chamber is defined as an environment in which people’s beliefs, views, or political stances about a topic are reaffirmed through repeated interactions with like-minded peers or sources (Cinelli et al., 2021, p. 1). These echo chambers can function as a means to consolidate an existing perspective within a collective, thereby propelling the collective as a whole towards more radical positions (Sunstein, cited from Cinelli et al., 2021, p. 1).

Super-personalisation of information possesses the danger of fragmentation of shared reality in a society (Popowicz, 2024, p. 43). Algorithmically structured social media feeds and networks driven by social interaction can trap users within specific ideological or social identity-based narratives. This could lead to the emergence of alternative, parallel information universes, in which everyone views the opposing camp as the enemy (Chaudhari & Awate, 2026, p. 284). Unlike traditional media, which provided a shared public agenda, new media filter content on any issue individually via AI-based applications and algorithms, narrowing the common ground for debate and resulting in the fragmentation of a shared reality. Consequently, the fragmentation of shared reality with the deterioration of trust and the rise of post-truth politics undermine the public sphere’s ability to shape public opinion, thereby having a significant negative impact on the political climate and weakening democracy (Waza, 2026, p. 205).

Moreover, the milieu of political communication is often shaped by emotion. Algorithms in all social media platforms reward engagement via content centered on fear and anger. Identities of people are also highly visible in order to sharpen the differences among people. Consequently, rational debate recedes while emotional mobilization and polarization strategies come to the forefront. A study by Brady and colleagues (2017, p. 7316) revealed that the employment of moral and emotional language on X results in the rapid dissemination of specific political messages across different social media platforms. The subjects of political communication - namely, organisers of social movements, politicians, and community leaders- routinely utilise moral emotions, which may be of a positive or negative nature, in their attempts to enhance the exposure of their respective messages and to exert influence over the established norms within social networking platforms.

According to the findings of data scientist Robinson, for instance, Donald Trump’s adoption of an “off-the-cuff style” in his tweets on the X platform helped him win the presidential election. Robinson stated that “Donald Trump is an extreme example of an outsider and entertainer. Tweeting in this fast and off-the-cuff

style comes naturally to him as a part of his messaging strategy” (Bulman, 2016). According to a more recent analysis, Robinson also found that Trump posts his own rude and angry tweets from an Android smartphone. However, more strategic tweets are published by someone else using an iPhone (Griffin, 2026).

THE COGNITIVE TOLL ON THE VOTER

A significant outcome of today’s digitalised world is the information overload and verification fatigue. As social networking sites predominate in public discussion and smartphones become embedded in people’s daily lives, people are faced with a vast amount of information that they have never encountered before (Matthes et al., 2020). Voters are no longer influenced by a lack of information, but by an excess of it. This constant bombardment leads to indecision and cognitive exhaustion.

As more and more diverse content and sources become available, it becomes increasingly difficult to select and interpret relevant information. The consequence may be the information overload (IO) (Schmitt, Debbelt & Schneider, 2018, p. 1). This situation culminates in the relativisation of truth. As voters lose the ability to verify reality, they become immersed in a state of perpetual suspicion and distrust, which severely undermines the shared empirical basis required for a functioning democracy.

A significant feature of the political landscape amid an overload of information and disinformation is the sense of simulation experienced by voters. As people feel surrounded by fake conversations and manipulative imagery, they develop a tendency to “trust nothing.” The natural consequence of this situation will be the inability of society to reach agreement on even a minimum common understanding of reality. This would result in the loss of social consensus, which is one of the key pillars of democracy.

CONCLUSION: AN ILLUSION OF FREE WILL?

This study sought both to discuss how algorithm-based and AI-based technological developments have transformed the environment in which political communication takes place, and to examine how political communicators have positioned themselves in response to this transformation. Voters find themselves in a fragmented reality where the shared space for debate has disappeared. Trapped within echo chambers, they are confronted with narratives designed specifically for them and interact only with like-minded individuals. They are constantly driven towards greater ideological polarisation by political rhetoric that targets their emotions.

On the other hand, new political communication tools have provided campaigners with the means to carry out hyper-personalised micro-targeting, utilise predictive analytics and automation, and conduct virtual canvassing online. These new opportunities have resulted in campaign teams being organised around data specialists. This new era has also given rise to unethical practices, including synthetic media content created using deepfake technology, audio cloning, synthetic astroturfing, and bot networks.

At this point, it is a very important question to ask whether voter behaviour is driven by nudges designed to influence behaviour, or whether it is the result of conscious choice. The modern voter makes decisions within an algorithmically driven environment, subjected to micro-interventions and emotionally optimized content. With the concept of infocracy as a new form of today’s information capitalism, Han (2022) argued that personal freedom is exploited instead of being repressed. The belief of people in their freedom is a fallacy. The reality is that their entire lives are subject to recording for the purpose of psychopolitical control of their behaviour. In this neoliberal information regime, the function of mechanisms of power derives not from people's awareness of constant surveillance but from their illusory perception of freedom.

Consequently, the revolution in technology has ended with a profound transformation in democracy. Electoral behaviour increasingly becomes the product of data-driven influence engineering rather than the pure exercise of individual free will.

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**ORGANIZATIONAL SILENCE IN THE CONTEXT OF ARTIFICIAL INTELLIGENCE: THE
ROLE OF ALGORITHMIC AUTHORITY IN SILENCE MECHANISMS**

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ABSTRACT

Organizational silence is defined as employees deliberate withholding of work-related ideas, concerns, or suggestions, and it may have significant implications for innovation, organizational learning, and ethical decision-making processes. In the literature, this behavior is commonly explained through factors such as fear, power distance, leadership, and psychological safety. However, the integration of artificial intelligence (AI) systems into organizational decision-making processes introduces a new context for understanding silence behavior. This study conceptually examines the organizational silence literature within the context of AI-enabled work environments. In this regard, studies on employee voice and silence, psychological safety, algorithmic management, and algorithmic authority are jointly considered. In addition, a bibliometric analysis based on publications retrieved from the Scopus database is conducted to identify the general trends in the literature. The study evaluates the potential effects of algorithmic authority on silence behavior within the framework of perceived voice efficacy, perceived risk, risk to others, and perceived justice. The findings indicate that the existing literature is largely concentrated in technical domains and shows only limited integration with the organizational behavior perspective. This suggests a clear need for further research on the relationship between algorithmic authority and organizational silence.

Keywords: Organizational Silence, Employee Voice, Algorithmic Authority, Artificial Intelligence, Algorithmic Management, Bibliometric Analysis.

**YAPAY ZEKÂ BAĞLAMINDA ÖRGÜTSEL SESSİZLİK: SESSİZLİK MEKANİZMALARINDA
ALGORİTMİK OTORİTENİN ROLÜ**

ÖZET

Örgütsel sessizlik, çalışanların işle ilgili fikirlerini, endişelerini veya önerilerini bilinçli olarak dile getirmemesi olarak tanımlanmakta olup, inovasyon, örgütsel öğrenme ve etik karar verme süreçleri açısından önemli sonuçlar doğurabilmektedir. Literatürde bu davranış çoğunlukla korku, güç mesafesi, liderlik ve psikolojik güvenlik gibi faktörler üzerinden açıklanmaktadır. Ancak yapay zekâ sistemlerinin örgütsel karar alma süreçlerine entegrasyonu, sessizlik davranışının değerlendirilmesi için yeni bir bağlam sunmaktadır. Bu çalışma, örgütsel sessizlik literatürünü yapay zekâ ile desteklenen iş ortamları bağlamında kavramsal olarak incelemektedir. Bu kapsamda çalışan sesi ve sessizliği, psikolojik güvenlik, algoritmik yönetim ve algoritmik otoriteye ilişkin çalışmalar birlikte ele alınmıştır. Ayrıca literatürün genel eğilimlerini belirlemek amacıyla Scopus veri tabanından elde edilen yayınlar üzerinden bir bibliyometrik analiz gerçekleştirilmiştir. Çalışmada algoritmik otoritenin sessizlik davranışı üzerindeki olası etkileri; algılanan ses etkinliği, algılanan risk, başkalarına yönelik risk ve algılanan adalet boyutları çerçevesinde değerlendirilmektedir. Bulgular, ilgili literatürün büyük ölçüde teknik alanlarda yoğunlaştığını ve örgütsel davranış perspektifi ile sınırlı düzeyde bütünleştiğini göstermektedir. Bu durum, algoritmik otorite ve örgütsel sessizlik ilişkisine yönelik daha fazla araştırmaya ihtiyaç olduğunu ortaya koymaktadır.

Anahtar Kelimeler: Örgütsel Sessizlik, Çalışan Sesi, Algoritmik Otorite, Yapay Zekâ, Algoritmik Yönetim, Bibliyometrik Analiz

INTRODUCTION

One of the fundamental challenges in organizational life is that employees often recognize problems, risks, inefficiencies, or ethical concerns before their leaders or managers, yet choose not to communicate these observations to upper management. From an organizational behavior perspective, “organizational silence” is not merely the sum of individual and isolated decisions. Due to the perception that speaking up is neither wise nor useful, information related to problems may be withheld, and this can evolve into a collective pattern at the organizational level (Morrison & Milliken, 2000). The literature on employee silence largely rests on the assumption that voice and silence behaviors are evaluated within the context of human authorities. These authorities are socially interpretable and morally accountable. However, this assumption is increasingly being challenged as organizations begin to employ artificial intelligence systems in performance evaluation, task allocation, and critical decision-making processes (Kumar, 2026).

Contemporary work systems are increasingly carried out through AI-enabled or algorithm-based tools in processes such as reporting, evaluation, scheduling, task allocation, and even disciplinary actions. This phenomenon is commonly discussed under the concept of “algorithmic management.” These tools are capable of partially automating managerial functions and scaling monitoring and evaluation processes. This shift from interpersonal management processes to data-driven and system-mediated processes has the potential to transform how decision-making authority is structured (Nguyen & Mateescu, 2019).

This transformation is of particular importance for research on organizational silence. Traditional silence mechanisms are largely relational in nature. Employees take into account interpersonal risks and the likelihood of managerial reactions when deciding whether to speak up (Morrison, 2014). In contexts where the decision-maker is defined as an algorithmic system, a structure that is opaque, difficult to question, and often framed as objective may emerge (Lee et al., 2015). This situation can lead employees to reassess the risks and potential benefits of speaking up. In this regard, artificial intelligence can function as a technology-based authority structure, thereby transforming the nature of voice behavior. The existing literature on organizational voice and silence does not sufficiently capture the dynamics introduced by AI-enabled work environments (Kunasz, 2025). This indicates a significant gap in the literature. Lotfi Dehkharghani et al. (2023) emphasize the need for future research in this area to be developed within AI-based frameworks. In particular, with the increasing prevalence of the gig economy, platform-based forms of organizing, and algorithmic management practices, there is a growing need to adapt organizational voice and silence research to this emerging context.

The aim of this study is to extend organizational silence theory to AI-enabled work environments and to conceptually explain how perceived algorithmic authority may transform silence mechanisms. To this end, the study first synthesizes the literature on organizational silence and algorithmic management, and then proposes a conceptual framework explaining how algorithmic authority may shape different types of silence through perceived voice efficacy, perceived risk, risk to others, and perceived justice. To support this theoretical discussion, a bibliometric analysis is also presented.

CONCEPTUAL FRAMEWORK

Organizational Silence and Employee Voice

Employees generally possess a range of ideas, knowledge, and opinions aimed at improving work processes and organizational structures. However, in some situations they openly express these, while in others they may deliberately choose to remain silent. Although speaking up and withholding may initially appear as opposites, silence is not merely the absence of speech, nor is voice limited to expressing opinions on important organizational issues. Employee silence and voice are conceptualized as distinct and multidimensional constructs (Dyne et al., 2003).

Employee silence is defined as the intentional withholding of work-related evaluations from individuals perceived to have the capacity to initiate change. This definition is significant, as it emphasizes the deliberate withholding of information, the target of communication, and the idea that silence may deprive the organization of potentially valuable information (Kassandrinou et al., 2023).

Silence may manifest in different forms depending on its underlying motives. According to widely accepted classifications, employees may exhibit acquiescent silence when they believe that expressing their views will have no impact, or defensive (quiescent) silence as a self-protective strategy to avoid potential negative consequences. In addition, prosocial silence may emerge when employees withhold information in order to protect colleagues, work groups, or the organization. Some approaches conceptualize silence not only as protection- or fear-based behavior, but also as including opportunistic or strategic forms aimed at achieving individual gains. In this way, silence is understood as a multidimensional phenomenon that can serve different purposes (Dyne et al., 2003).

Across these different forms of silence, psychological safety constitutes both a fundamental condition that enables voice behavior and a critical factor that reduces fear-based silence. Psychological safety is classically defined as a shared belief that interpersonal risk-taking is safe within a team. It is directly related to whether employees feel able to speak up about mistakes, express concerns, or question decisions without fear of punishment or embarrassment (Edmondson, 1999).

Organizational silence, which prevents employees from expressing their ideas and concerns about organizational problems, can be influenced by various organizational factors (Köksal et al., 2018). Among the traditional antecedents highlighted in the voice and silence literature are leadership styles (Bulut & Meydan, 2018), leadership openness and responsiveness to feedback, hierarchical power differences, a climate of fear, and structural features that regulate upward information flow. Early conceptualizations of organizational silence emphasize that organizational and managerial practices can create perceptions among employees that speaking up is risky or futile, thereby fostering a self-reinforcing climate of silence (Morrison & Milliken, 2000).

In summary, silence mechanisms can be conceptualized as processes that explain the relationship between contextual factors (such as leadership, organizational culture, and structural features) and individuals' cognitive and affective evaluations (including perceived risk, futility, responsibility, and identification). These evaluations shape employees' motives for silence and the resulting behaviors (Morrison, 2014). This study, in turn, examines how these mechanisms are transformed in contexts where authority is experienced not through human leaders, but through AI-based decision-making systems.

Algorithmic Authority and Algorithmic Management

One of the most notable trends in recent years is the increasing reliance on algorithms in decision-making processes. Algorithms are defined as step-by-step computational instructions that generate outputs based on given inputs (Danaher, 2016). The role of algorithms in organizing information flows and shaping the visibility of certain content has been widely recognized in the literature as a significant mechanism of power and influence (Gillespie, 2014). This perspective has led to the understanding of algorithms not merely as technical tools, but as socio-technical structures that acquire meaning within social and organizational contexts. Organizations increasingly integrate algorithmic outputs into performance evaluation, reward, and sanctioning mechanisms, thereby embedding these systems into managerial processes (Lee et al., 2015; Nguyen & Mateescu, 2019). In this context, algorithmic management practices partially automate traditional managerial functions, redefine the role of human managers in decision-making processes, and signal a broader transformation in which organizational authority is reconfigured around data-driven systems (Kellogg et al., 2020).

Recent micro-level studies in the context of algorithmic authority have focused on individuals' tendency to trust the accuracy and reliability of AI-generated outputs. Research shows that trust in automation and positive perceptions of system performance lead individuals to comply more with AI recommendations, particularly in high-risk situations (Millella & Cabitza, 2026). This has important implications for silence behavior. When employees perceive decision authority as superior and unquestionable, acquiescent silence becomes more likely (Kumar, 2026).

In workplace settings, algorithmic authority is often enacted through algorithmic management systems. According to a widely accepted definition, algorithmic management refers to a set of data-driven and surveillance-based technological tools and techniques used to remotely manage the workforce. These systems enable automated or semi-automated decision-making processes. In this context, practices such as performance evaluation based on metrics, behavioral steering through rating systems, and the shaping of employee behavior through various incentives or sanctions are commonly observed (Nguyen & Mateescu, 2019).

A comprehensive and interdisciplinary synthesis on workplace algorithms suggests that algorithmic control operates through a variety of mechanisms. These include restricting available options, recommending actions, recording behaviors, evaluating performance, substituting human discretion, and rewarding or sanctioning outcomes. This indicates that algorithmic systems can evolve beyond optional decision-support tools into persistent and institutionalized infrastructures of control (Kellogg et al., 2020).

Algorithmic management is commonly conceptualized as the partial or full automation of tasks traditionally performed by human managers through technological tools, in some cases integrated with artificial intelligence. While this approach offers potential advantages such as consistency and speed, it also entails several risks, including surveillance-related stress, increased workload, ambiguity in accountability, and difficulties in monitoring and interpreting decision-making processes (Milanez et al., 2025).

AI-enabled decision systems possess two additional features that are particularly important in the context of organizational silence. First, opacity and black-box decision-making processes are prominent. Algorithmic systems may become opaque due to institutional secrecy, technical complexity, and the limited interpretability inherent in certain machine learning approaches. Opacity matters because when employees cannot understand the decision rules, they may struggle to determine what to contest, how to contest it, or whether contestation is even possible (Burrell, 2016).

Second, information and power asymmetries become salient. Field studies on platform work demonstrate that app-mediated management can generate asymmetries that structure control. While organizations maintain extensive visibility over employees, workers often have limited insight into how the system evaluates them or allocates opportunities. Such asymmetries can directly undermine employees' perceptions that speaking up is both effective and safe (Rosenblat & Stark, 2015). These characteristics suggest that algorithmic authority is not merely a new manager replacing a traditional one. Rather, it represents a qualitatively different form of authority that can transform the relationship between employees and organizations by reconfiguring accountability, sensemaking processes, and the channels through which contestation and learning occur (Lustig et al., 2016).

The Role of Algorithmic Authority in Silence Mechanisms

The organizational silence literature suggests that employees refrain from expressing their ideas and concerns when they believe that their voice will not lead to meaningful change (Morrison & Milliken, 2000; Detert & Burris, 2007). In algorithm-enabled environments, this tendency may be reinforced by the perception that algorithmic outputs are objective and superior (Gillespie, 2014). When decisions are framed as "what the system says," dissenting views may be perceived as irrational or ineffective, thereby weakening voice behavior. For this reason, it is important to conceptually explain the mechanisms through which algorithmic authority shapes silence behavior.

This section presents a conceptual framework that explains how perceived algorithmic authority shapes different types of silence. In the proposed model, algorithmic authority is conceptualized as an antecedent operating through four key mechanisms: (a) perceived voice efficacy and futility, (b) perceived risk and surveillance, (c) risk to others, and (d) perceived justice, accountability, and contestability. These mechanisms are, in turn, shaped by design and governance features such as transparency, human oversight, employee participation, and appeal/recourse mechanisms. Building on this framework, the ways in which algorithmic authority influences different forms of silence through these mechanisms are discussed in detail below.

When employees perceive algorithmic outputs as objective and grounded in expertise, they may be inclined to view their own contributions as insignificant. This tendency is consistent with the literature on *automation bias*. Individuals are more likely to defer to "what the system says" (Logg et al., 2019) and may perceive dissent as futile. Accordingly, an increase in perceived algorithmic authority is expected to amplify *acquiescent silence*—defined as the intentional withholding of voice due to low perceived voice efficacy (Pinder & Harlos, 2001; Logg et al., 2019). In this respect, perceived algorithmic objectivity is expected to weaken employees' sense of voice efficacy and thereby increase *acquiescent silence*.

Organizational relationships are built on trust, which constitutes a fundamental prerequisite for communication and collaboration. In environments where trust in the organization, managers, and colleagues is high, employees feel more comfortable expressing their thoughts and emotions. In this context, trust reduces the perceived risk associated with voice behavior (Kunasz, 2025). Opaque algorithms and intensive monitoring

can increase employees' perceived risk of negative consequences and the associated fear (Edmondson, 1999; Rosenblat & Stark, 2016; Kellogg et al., 2020). Edmondson (1999) demonstrates that low psychological safety—that is, a heightened perception of personal risk—can increase silence. In algorithmically managed environments, employees may assume that questioning data-driven decisions could be harmful to them, particularly when algorithmic rules are unclear (Rosenblat & Stark, 2016). Accordingly, perceived algorithmic surveillance and opaque control are expected to increase defensive (fear-based) silence. *In this respect, algorithmic opacity and surveillance are expected to heighten employees' perceived risk and thereby reinforce defensive silence.*

In addition to these mechanisms, employees' perceptions of risk to others may also influence silence behavior. *Prosocial silence* is defined as the intentional withholding of information by individuals in order to prevent organizational or interpersonal harm (Knoll & van Dick, 2013). Unlike fear- or resignation-based forms, this type of silence is driven by motivations to protect the interests of others. Considering the multidimensional nature of organizational trust, meaningful relationships may exist between trust in colleagues and silence behaviors. Some findings suggest that *prosocial silence* may be negatively associated with organizational trust (Kunasz, 2025). In this context, when employees believe that speaking up may harm others, they may refrain from raising issues, resulting in *prosocial silence*. For instance, platform workers may avoid reporting problematic situations to prevent triggering algorithmic evaluations or sanctions, and may adapt their behavior accordingly (Rosenblat & Stark, 2016; Kellogg et al., 2020). Although such behaviors have not yet been sufficiently examined directly in the context of artificial intelligence and algorithmic management, the literature on collective silence and prosocially motivated silence provides indirect support for this mechanism. Therefore, this phenomenon can be conceptually situated within the domain of *prosocial silence*. Accordingly, perceived risk to others is expected to increase *prosocial silence* by strengthening employees' motivation to prevent potential harm.

Systems that provide explanations for decision processes and allow for contestation and human intervention can reduce silence. Lee et al. (2019) show that elements of *procedural justice* in algorithmic evaluation processes—particularly *outcome control*—enhance perceived fairness, whereas transparency alone is insufficient. Increased *perceived justice* is widely regarded in the literature as a key antecedent of employee voice behavior (Colquitt et al., 2001; Detert & Burris, 2007). Perceptions of justice may play a significant role in understanding individuals' silence within organizational contexts (Meydan et al., 2015). Accordingly, mechanisms that strengthen perceptions of fairness in algorithmic decision-making processes may indirectly increase employees' willingness to speak up. However, the provision of transparency alone may not be sufficient to resolve legitimacy concerns surrounding algorithmic decisions within organizations. In particular, challenges may arise in the justification and acceptance of decisions (Mirbabaie et al., 2025). In this context, the presence of feedback mechanisms that signal that voice is acknowledged within algorithmic systems is expected to reduce both *acquiescent* and *defensive silence*. Accordingly, enhanced *perceived justice* through *algorithmic transparency* and *contestability* is expected to increase voice behavior and reduce silence.

In this context, four propositions have been developed to serve as the basis for hypotheses, with the aim of systematically examining the effects of perceived algorithmic authority on different types of organizational silence. The proposed model assumes that algorithmic authority shapes employees' silence behaviors through perceived voice efficacy, perceived risk, and perceived justice. In addition, governance mechanisms such as algorithmic transparency and contestability are expected to weaken these relationships and promote employee voice. The four propositions developed to systematically present the effects of perceived algorithmic authority on different types of silence are presented below.

P1: An increase in perceived algorithmic authority reduces employees' perceived voice efficacy and, in turn, increases acquiescent (submissive) silence.

P2: Increased algorithmic opacity and surveillance practices raise employees' perceived risk, thereby increasing defensive (fear-based) silence.

P3: Employees' perceptions that speaking up may harm others increase prosocial silence behavior.

P4: The presence of algorithmic transparency and contestability mechanisms increases perceived justice, thereby reducing silence tendencies and promoting employee voice.

METHOD

To support the conceptual framework of this study, a bibliometric analysis was conducted. Bibliometric analysis is a widely used method for systematically examining the structure, trends, and thematic relationships within a given research field (Zupic & Čater, 2015; Donthu et al., 2021). The dataset was obtained through a search conducted in the Scopus database, which is frequently preferred in bibliometric studies due to its broad coverage and interdisciplinary scope (Donthu et al., 2021). During the search process, the keywords *employee voice*, *silence*, *speaking up*, *algorithm*, *artificial intelligence*, and *digitalization* were used to capture the relationship between employee voice and silence behavior and AI- and algorithm-based systems.

In the first stage, a search conducted in the Scopus database on March 15, 2026, yielded a total of 1,383 publications. The dataset spans the period from 1975 to 2026. Unlike conventional filtering approaches, no subject area restriction was applied in this study in order to preserve the interdisciplinary nature of the literature. In the second stage, to maintain the academic rigor of the study, only publications classified as *articles*, *conference papers*, and *book chapters* were included, reducing the dataset to 1,252 records. Finally, a language filter was applied, and only English-language publications were retained, resulting in a final dataset of 1,250 publications. The dataset was analyzed in the R environment using the *bibliometrix* package. Bibliometrix (Version 5.2.1) is a comprehensive tool developed for scientific mapping and bibliometric analysis and is widely used in the literature (Aria & Cuccurullo, 2017). Within this scope, keyword frequencies, co-occurrence relationships, and thematic mapping were examined to explore the conceptual structure of the field in an exploratory manner.

Due to the polysemous nature of the terms *silence* and *voice*, the dataset also included studies from biological and technical domains. Therefore, prior to analysis, a limited data cleaning and filtering procedure was applied to reduce terms that were not directly relevant to the research context.

FINDINGS

Keyword Frequency Findings

The keyword frequency analysis conducted on the filtered dataset indicates that themes related to artificial intelligence and machine learning remain dominant in the literature. *Artificial intelligence* (23) and *machine learning* (16) emerge as the most frequently occurring concepts. In contrast, concepts directly related to the organizational context, such as *employee voice* (5), *silence* (9), and *spiral of silence* (4), appear with relatively lower frequencies. This suggests that the literature on organizational silence and employee voice occupies a limited space within the broader AI research domain.

In addition, technical terms such as *voice activity detection*, *speech enhancement*, and *speech processing* appear with relatively high frequencies. This indicates that the dataset partially includes studies from engineering and speech processing fields. Overall, the findings confirm that the AI literature is predominantly concentrated along a technical axis, while the organizational behavior perspective—particularly employee voice and silence—remains limited and fragmented.

Keyword Co-occurrence Network

The keyword co-occurrence analysis conducted on the filtered dataset reveals that the artificial intelligence literature is predominantly concentrated around technical concepts, with only limited intersections with behavioral themes. Within the network structure, *artificial intelligence* occupies a central position and is connected to concepts such as *decision making*, *behavioral research*, and *social media*. In contrast, clusters formed by terms such as *machine learning*, *natural language processing*, and other network- and communication-related concepts indicate that the literature is largely organized along a technical axis. Despite the filtering procedures, the continued presence of certain biological and engineering-related terms in the network suggests that the polysemous nature of the concepts *silence* and *voice* has led to the inclusion of studies from multiple disciplines within the dataset. Overall, the findings demonstrate that the artificial intelligence literature remains only partially and fragmentedly integrated with the organizational behavior perspective. The resulting keyword co-occurrence network is presented in Figure 1.

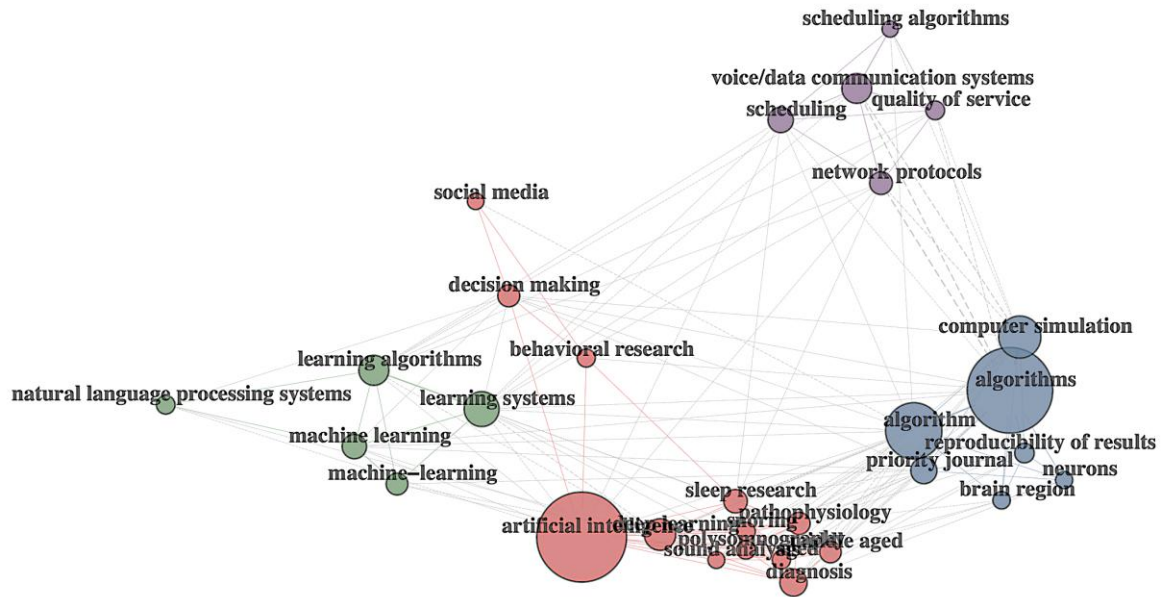


Figure 1. Keyword Co-occurrence Network

Thematic Mapping Analysis

The thematic mapping analysis indicates that the artificial intelligence literature is primarily concentrated around *artificial intelligence* and *machine learning* as motor themes. In contrast, concepts directly related to the focus of this study, such as *voice behavior* and *algorithmic bias*, are positioned within the basic themes. This suggests that, although these concepts are strongly connected to the field, they remain underdeveloped. Furthermore, concepts associated with organizational behavior, such as *rationalized knowledge hiding*, appear as emerging but not yet fully developed themes. This finding highlights the limited presence of the organizational perspective within the broader artificial intelligence literature. The findings indicate that the artificial intelligence literature has matured around technical themes, whereas behavioral topics such as employee voice and organizational silence remain emerging and fragmented research areas. The resulting thematic map is presented in Figure 2.

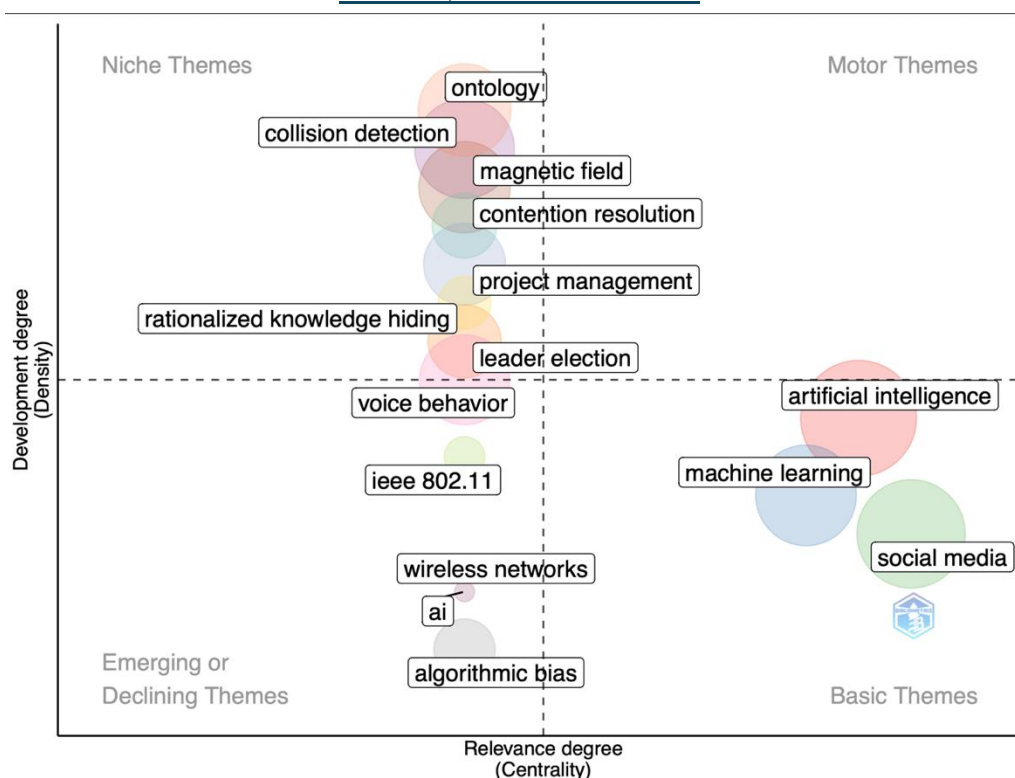


Figure 2. Thematic Map

DISCUSSION

This study aims to extend the organizational silence literature into AI-enabled work environments by conceptually examining how perceived algorithmic authority may transform employees' silence behaviors. The findings and the proposed theoretical framework suggest that algorithmic management systems function not only as mechanisms of efficiency and control but also as a powerful source of authority that shapes employee voice behavior.

The findings of the bibliometric analysis reveal a significant gap in the existing literature. While studies on artificial intelligence and algorithmic systems are largely concentrated in technical and engineering domains, behavioral concepts such as organizational silence and employee voice remain underrepresented. This indicates the presence of an interdisciplinary blind spot and strengthens the potential contribution of the conceptual framework proposed in this study.

When the four propositions are considered together, it becomes evident that algorithmic authority shapes silence behavior not as a unidimensional construct, but through multiple underlying mechanisms. The first proposition suggests that the perception of algorithmic outputs as objective and data-driven may lead employees to view their own contributions as insignificant, thereby fostering acquiescent silence. The second proposition indicates that algorithmic opacity and intensive surveillance mechanisms may weaken employees' perceptions of psychological safety, thereby triggering defensive silence. The third proposition points out that employees' evaluations that speaking up may harm others can strengthen prosocial silence motivations. The fourth proposition, in turn, demonstrates that algorithmic transparency and contestability mechanisms have the potential to reduce silence behavior by enhancing perceptions of justice.

This framework shows that, while the core assumptions of traditional silence theory—such as relational risk, psychological safety, and perceived voice efficacy—remain valid in the context of algorithmic authority, the way these mechanisms operate is transformed. In the presence of human managers, employees are able to interpret interpersonal dynamics, anticipate managerial reactions, and rely on social cues. However, when interacting with algorithmic systems, the absence of such interpretive processes may leave employees facing heightened uncertainty and feelings of helplessness.

This study has several important limitations that should be considered in future research. First, the study is conceptual in nature, and the proposed relationships have not been empirically tested. Second, the bibliometric

analysis was limited in scope due to the nature of a conference paper and was based solely on the Scopus database. The selection of keywords and filtering criteria may also have influenced the coverage of the literature. In addition, the rapid development of artificial intelligence technologies requires that the findings be interpreted within a dynamic context that may evolve over time.

The findings and limitations of this study offer important implications for practitioners, policymakers, and researchers. Considering the impact of algorithmic authority on organizational processes, practitioners should evaluate algorithmic systems not only as tools of efficiency but also in terms of their behavioral effects. In this regard, increasing transparency and explainability, institutionalizing mechanisms for contestation and feedback, and preserving human oversight through hybrid decision-making systems are of critical importance. From a policy perspective, binding standards for transparency and accountability in algorithmic decision-making processes should be established, employees' rights to contest algorithmic decisions should be regulated, and human oversight should be mandated in critical decision contexts. From a research perspective, future studies should focus on developing measurement scales for perceived algorithmic authority, empirically testing the proposed model, examining dynamic effects through longitudinal and multilevel research designs, and addressing cultural and sectoral differences.

CONCLUSION

This study reconceptualizes the organizational silence literature within the context of AI-enabled work environments and conceptually establishes the role of algorithmic authority in shaping employee behavior. The findings suggest that algorithmic systems function not only as technical tools but also as a new form of authority that influences employees' voice and silence behaviors.

The proposed propositions indicate that algorithmic authority may shape silence behavior along four key dimensions: reduced perceived voice efficacy, increased perceived risk, evaluations of risk to others, and the presence of justice and contestability mechanisms. In this respect, the study provides a systematic explanation of how organizational silence is reproduced in AI-enabled work environments and extends organizational silence theory through a socio-technical perspective. Moreover, by challenging the human-centered assumptions in the existing literature, it offers a novel theoretical contribution. As also indicated by the bibliometric findings, the limited and fragmented representation of this relationship in the current literature highlights that the proposed conceptual framework provides a valuable starting point for future research.

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**EXAMINING THE EFFECTIVENESS OF VIRTUAL REALITY-ASSISTED
PSYCHOEDUCATION ON ANXIETY IN EARTHQUAKE SURVIVORS: A QUALITATIVE
STUDY²**

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ABSTRACT

Earthquakes cause not only physical destruction but also mental health problems at both individual and societal levels, underscoring the importance of psychosocial interventions in the post-earthquake period. This study aimed to examine the effects of cognitive behavioral therapy (CBT)-based virtual reality (VR)-assisted psychoeducation on anxiety levels in earthquake survivors. The study was conducted using a qualitative design. The sample consisted of 16 adult earthquake survivors affected by the February 6, 2023 Kahramanmaraş-centered earthquakes who were residing at a Temporary Accommodation Center. Participants were assigned to a VR-assisted psychoeducation group (n=16). The psychoeducation group received 10 sessions of CBT-based psychoeducation once a week, with VR content integrated at the end of each session. Thematic analysis was used for data analysis. Ethical committee and institutional approvals were obtained prior to the study, and written informed consent was collected from all participants. The mean age of participants in the VR-assisted psychoeducation group was 36.12 ± 7.25 years; half held university degrees, 62.5% were married, all were female, and all had lost a close relative in the earthquake. The data were categorized under five themes: physical side effects associated with VR use, anxiety responses, triggering of traumatic memories, coping, control and exposure experience, and achievement and empowerment. At the conclusion of the study, VR-assisted psychoeducation was found to have positive effects on participants' immediate emotional responses, reducing negative emotions and increasing positive ones. Furthermore, the intervention was determined to be effective in reducing anxiety levels.

Keywords: Earthquake, Virtual Reality, Psychoeducation, Anxiety Level

**DEPREMZEDELERDE SANAL GERÇEKLİK DESTEKLİ PSİKOEĞİTİMİN KAYGI
ÜZERİNDEKİ ETKİNLİĞİNİN İNCELENMESİ: NİTEL ÇALIŞMA**

ÖZET

Depremler yalnızca fiziksel yıkıma değil, aynı zamanda bireysel ve toplumsal düzeyde ruh sağlığı sorunlarına da yol açmaktadır; bu durum, deprem sonrası uygulanacak psikososyal müdahalelerin önemini ortaya koymaktadır. Bu araştırma, depremzedelerde bilişsel davranışçı terapi (BDT) temelli sanal gerçeklik (SG) destekli psikoeğitimin anksiyete düzeyi üzerindeki etkilerini incelemek amacıyla yürütülmüştür. Araştırma nitel olarak gerçekleştirilmiştir. Örneklemi, 6 Şubat 2023 Kahramanmaraş merkezli depremlerden etkilenen ve Geçici Konaklama Merkezi'nde yaşayan 16 erişkin depremzede oluşturmuştur. Katılımcılar SG destekli psikoeğitim 16 kişilik bir grup olarak belirlenmiştir. Psikoeğitim grubuna haftada bir kez 10 oturum BDT temelli psikoeğitim verilmiş ve her oturum sonunda SG içerikleri kullanılmıştır. Verilerin analizinde tematik analiz yöntemi kullanılmıştır. Araştırma için etik kurul ve resmi kurum izinleri alınmış, katılımcılardan yazılı onam alınmıştır. Araştırmada SG destekli psikoeğitim grubuna dahil edilen katılımcıların yaş ortalaması $36,12 \pm 7,25$; yarısı üniversite mezunu, %62,5'i evli, tamamı kadın ve depremde yakınına kaybetmiştir. Araştırmada elde edilen veriler beş temaya göre kategorize edilmiştir. Bu temalar: sanal gerçeklik uygulamalarına bağlı fiziksel yan etkiler, anksiyete-kaygı tepkileri, travmatik anıların tetiklenmesi, baş etme, kontrol ve maruz kalma deneyimi, başarı ve güçlenmedir. Bu araştırmanın sonunda, SG destekli psikoeğitimin katılımcıların

²Bu çalışma TÜBİTAK 1001 Programı kapsamında (Proje No: 323K009) desteklenmiştir.
This study was supported by TÜBİTAK under the 1001 Program (Project No: 323K009).

anlık duygusal tepkileri üzerinde olumlu etkiler oluşturarak negatif duyguları azalttığı ve olumlu duyguları artırdığı tespit edilmiştir. Bununla birlikte, yapılan müdahalenin kaygıyı azaltmada etkili olduğu belirlenmiştir.

GİRİŞ

Türkiye, tarih boyunca büyük depremlerin meydana geldiği, yüksek sismik aktiviteye sahip Anadolu Plakası üzerinde; dünyanın en önemli deprem kuşaklarından biri olan Alp-Himalaya kuşağı üzerinde yer almaktadır. Türkiye’de 1900-2023 yılları arasında can ve mal kaybına neden olan 269 deprem meydana gelmiştir. Kahramanmaraş’ın Pazarcık ve Elbistan ilçelerinde 9 saat arayla gerçekleşen 7.7 ve 7.6 büyüklüğündeki depremler, şiddet ve kapsadığı alan açısından yakın tarihte eşi benzeri olmayan felaketler olarak nitelendirilmektedir. Bu depremler sonucunda 50 binden fazla insan hayatını kaybetmiş, yarım milyondan fazla bina hasar görmüş, iletişim ve enerji altyapısı zarar görmüş ve önemli maddi kayıplar yaşanmıştır (Kahramanmaraş ve Hatay Depremleri Raporu, 2023). Ayrıca, yaşanan iki büyük depremin hemen ardından Malatya merkez üslü 6.0, 5.8 ve 5.7 büyüklüğünde üç deprem daha meydana gelmesi, mevcut hasarı daha da artırmıştır (Malatya Deprem Bilgi Notu, 2023).

Depremin yıkıcı ve karşı konulamaz etkileri, mağdurların sıklıkla korku, çaresizlik ve dehşet gibi tepkiler vermesine yol açmaktadır (Aker vd., 2014). Deprem sonrasında görülen yaralanmış ya da ölmüş insanlar, yıkılan binalar, artçı sarsıntılar ve sosyal destek ağlarının zayıflaması tekrarlayan travmaların yaşanmasına zemin hazırlamaktadır (Altınöz ve Kaptanoğlu, 2018; Yıldırım, 2021). Nitekim toplum temelli çalışmalarda afeti yaşayanlar arasında psikiyatrik bozukluk gelişme oranı %10-30 arasında değişmekte olup Marmara Depremi (1999) sonrasında Travma Sonrası Stres Bozukluğu (TSSB) görülme sıklığı %25 olarak saptanmıştır (Tural vd., 2004). Bu nedenle afetten etkilenmiş bireylere yönelik psikososyal müdahalelerin hızla planlanması ve uygulanması büyük önem taşımaktadır (Morganstein vd., 2016).

Alan yazın incelendiğinde travmayla ilişkili ruhsal bozukluklara müdahalede ilaç tedavisinin yanı sıra psikoeğitimin etkinliğine dair veriler bulunmaktadır (Yıldız vd., 2023; Lotzin vd., 2023; Sangraula vd., 2020; Gümüş ve Deniz, 2020). Psikoeğitim, bireylerin psikolojik stres ve travmayı anlamalarına, başa çıkma becerilerini geliştirmelerine ve duygusal destek almalarına yardımcı olur. Travma sonrası psikoeğitim programlarında sıklıkla Bilişsel Davranışçı Terapi (BDT) temelli yaklaşımlardan yararlanıldığı görülmektedir; bunun temel nedeni, travmatik deneyimlerin ardından artan olumsuz bilişlerin semptomları harekete geçirmesidir (Ehlers ve Clark, 2000). Nitekim yapılan çalışmalarda, okul temelli psikoeğitimin ergenlerdeki kaygı ve korkuyu azalttığı (Tanaka vd., 2019), depremden etkilenen bireylere uygulanan psikoeğitimin stresle baş etme düzeyinin artmasında etkili olduğu (Sangraula vd., 2020) ve kısa psikoeğitimin çocuklarda afete bağlı travma etkisini azaltabildiği (Fukuchi, 2019) bildirilmiştir.

Sanal Gerçeklik (SG) teknolojisi, klinik psikoloji alanında giderek artan bir kullanım alanı bulmaktadır. Sanal Gerçeklik Maruz Bırakma Terapisinin (SGMT) sosyal anksiyete, fobiler ve TSSB başta olmak üzere kaygı bozukluklarının tedavisindeki etkinliği meta-analitik çalışmalarla da kanıtlanmıştır (Chesham vd., 2018; Fernández-Álvarez vd., 2019; Schroeder, 2022). SG, bireylerin bilgisayar ortamında hazırlanan simüle edilmiş alanlara tamamen kapılmasını sağlayarak sesli düşünmeye teşvik etmekte, zorlu koşullarda sergilenecek davranışları ve yaşanacak duyguları ortaya koymaktadır (Zhang vd., 2021; Feng vd., 2020). Alan yazın incelendiğinde SG’nin deprem bağlamında yalnızca tatbikat ve eğitim amaçlı kullanıldığı görülmekte; SG destekli psikoeğitimin depremzedelerle yürütülen herhangi bir psikososyal müdahale programına entegre edildiği bir çalışmaya rastlanmamaktadır (Feng vd., 2020; Lu vd., 2020; Lovreglio vd., 2018). Bu durum, mevcut araştırmayı alanyazındaki önemli bir boşluğu dolduran özgün bir çalışma hâline getirmektedir.

Ulusal alan yazında SG destekli müdahalelerin sosyal kaygı, psikolojik belirtiler ve sosyal fobi üzerindeki etkililiğini inceleyen çalışmalara rastlanmakla birlikte (Özbay, 2017; Özer vd., 2022; Bilge vd., 2020; Aksoy, 2023), depremzedelere yönelik hiçbir çalışmanın yer almadığı görülmektedir. Bu bağlamda, BDT temelli SG destekli psikoeğitimin depremzedelerin anksiyete düzeylerini azaltmadaki etkililiğini derinlemesine görüşme tekniğiyle ortaya koyan bu araştırma, ulusal alan yazındaki ilk çalışma olma niteliği taşımaktadır.

Bu bağlamda, proje kapsamında depremzedelerin yaşadıkları travmatik olay sonrası sanal gerçeklik destekli psikoeğitimin anksiyete düzeyine etkisinin araştırılması amaçlanmıştır.

YÖNTEM

Araştırmanın Tipi: Bu araştırma, derinlemesine görüşme tekniğinin kullanıldığı nitel bir çalışmadır.

Araştırmanın Yapıldığı Yer ve Özellikleri: Araştırma, Şubat 2024-Nisan 2025 tarihleri arasında Malatya'nın Battalgazi ilçesinde kurulan Teknokent Geçici Konaklama Merkezi'nde yaşayan erişkin bireylerle yürütülmüştür. Söz konusu merkez, İnönü Üniversitesi Teknopark bahçesinde yaklaşık 180.000 metrekairelik alanda kurulmuş olup depremzedelere temel yaşam koşulları sağlayan bir konteyner kent niteliği taşımaktadır.

Araştırmanın Evren ve Örneklemi: Araştırmanın evrenini Teknokent Geçici Konaklama Merkezi'nde yaşayan erişkin depremzedeler oluşturmaktadır. Nitel araştırma geleneğine uygun olarak örneklem amaçlı örnekleme yöntemiyle belirlenmiştir. Çalışmaya katılım kriterleri: 6 Şubat 2023 depreminden doğrudan etkilenmiş olmak, merkezde ikamet etmek, araştırmaya gönüllü katılmayı kabul etmek ve psikiyatrik tanı geçmişinin bulunmaması olarak belirlenmiştir. Bu kriterler çerçevesinde 16 erişkin katılımcıya ulaşılmıştır.

Kişisel Bilgi Formu: Bu form araştırmacılar tarafından alanyazın taranarak geliştirilmiş olup yaş, cinsiyet, eğitim durumu, gelir durumu, meslek, medeni durum, bakmakla yükümlü olduğu kişi sayısı, daha önce deprem yaşama durumu gibi sosyodemografik özellikler ile evin hasar durumu, yakınıni kaybetme ve yakınlık derecesi, enkaz altında kalma, depremde dolayı mal varlığını ve işini kaybetme gibi depreme bağlı oluşan yeni durumlarını saptamak için sorulan toplam 14 sorudan oluşmaktadır (Kurt ve Gülbahçe, 2019, James vd., 2020, Taşçı ve Özsoy, 2021).

Verilerin Toplanması: Bu araştırmanın verileri Malatya Teknokent Geçici Konaklama Merkezi'nde kalan depremzedelerden Şubat 2024 - Nisan 2025 tarihleri arasında toplandı. Bireylere psikoeğitim uygulandı; her bir psikoeğitim oturumunun sonunda SG içerikli bir uygulama yapıldı. Bireylerde depremin yarattığı duyguların tespit edilmesi, psikoeğitim oturumlarında ve SG uygulamalarında kişiye özgü bu duyguların işlenmesi yoluyla anksiyete düzeylerinin düşürülmesi hedeflendi. Veriler, araştırmacılar tarafından yüz yüze görüşme yöntemiyle 25-30 dakikada toplandı.

Sanal gerçeklik destekli, 10 oturum olarak planlanan psikoeğitim programı, haftada bir kez olmak üzere 60 dakikalık oturumlar şeklinde yürütüldü. Psikoeğitimin ilk oturumu tanışma ve grup kurallarını, son oturumda ise vedalaşmayı içerdiği için, SG içerikleri ikinci oturumdan dokuzuncu oturuma kadar kullanıldı. Oturumların sonunda verilen SG içerikleri hakkında üyelerin geri bildirimlerini almak amacıyla SG geri bildirim formları (SG deneyimlerine ilişkin soruların ve yanıt verebilmeleri için boşlukların yer aldığı kağıt) üyelere dağıtıldı ve bu formları evde doldurmaları istendi. Bu formda aşağıda yer alan sorular bulunmaktadır.

- SG deneyimi esnasında neler hissettiniz?
- SG deneyiminiz sırasında aklınızdan hangi tür düşünceler geçti?
- SG deneyimi tamamlandıktan sonra kendinizle ilgili neleri fark ettiniz?

Araştırmaya katılanlara uygulamalar ev ödevleri şeklinde verildi ve sonraki oturumlarda takip edilmek üzere kullanıldı.

BULGULAR

Tablo 1. Katılımcıların Tanıtıcı Özellikleri

Özellik	Kategori	Psikoeğitim Grubu (S=16)
Yaş	Ortalama (SS)	36.12± 7.25
Cinsiyet	Kadın	16 (%100)
Medeni Durum	Evli	10 (%62.5)
	Bekar	6 (%37.5)
Eğitim	Lise	8 (%50)
	Üniversite	8 (%50)
Çalışma Durumu	Çalışıyor	2 (%12.5)
	Çalışmıyor	14 (%87.5)

Gelir	İyi	2 (%12.5)
	Orta	12 (%75)
	Kötü	2 (%12.5)
Hasar Durumu	Orta Hasarlı	2 (%12.5)
	Yıkık/Acil Yıkılacak	8 (%50)
Enkaz Altında Kalma	Evet	16 (%100)
	Hayır	0.0
Yakın Kaybı	Evet	16 (%100)
	Hayır	0.0
İş Kaybı	Evet	6 (%37.5)
	Hayır	10 (%62.5)

Bu çalışmada, depremzede bireylere yönelik Sanal Gerçeklik (SG) destekli psikoeğitim uygulamalarına ilişkin katılımcı geri bildirimleri beş ana tema altında toplandı. Bunlar;

Tema 1: Sanal Gerçeklik Uygulamalarına Bağlı Fiziksel Yan Etkiler

Tema 2: Anksiyete -Kaygı Tepkileri

Tema 3: Travmatik Anıların Tetiklenmesi

Tema 4: Baş Etme, Kontrol ve Maruz Kalma Deneyimi

Tema 5: Başarma ve Güçlenme

Sanal Gerçeklik Uygulamalarına Bağlı Fiziksel Yan Etkiler

Katılımcıların sanal gerçeklik (SG) uygulamaları sırasında en sık bildirdikleri fiziksel belirtiler baş dönmesi, mide bulantısı, göz kararması ve terlemeydi. Özellikle ilk haftalarda ve hareketli, kapalı alan içeren senaryolarda bu belirtilerin daha yoğun yaşandığı gözlemlendi.

Doğa yürüyüşü, labirent, rafting ve hazine avı senaryolarında bazı katılımcılar uygulamayı yarıda bırakmak zorunda kaldıklarını ifade ettiler.

“Başım döndü, mide bulantısı yaşadım, o yüzden yarım bıraktım.” (C. A.)

“Sallanma nedeniyle çok baş dönmesi oldu, gözümü kapattım.” (R. B.)

Buna karşın, yoga ve voleybol gibi daha durağan ve sosyal içerikli senaryolarda fiziksel yan etkilerin belirgin biçimde azaldığı gözlemlendi.

Anksiyete- Kaygı Tepkileri

SG senaryoları katılımcılarda farklı düzeylerde kaygı ve anksiyete tepkileri oluşturmuştur. Kaygı tepkileri özellikle:

- Kapalı alanlar (labirent, dar geçit)
- Yükseklik (dağ tırmanışı)
- Su ve düşme hissi (rafting, köprü sahneleri)

Gibi uyaranlar karşısında artış göstermiştir.

Bazı katılımcılar, sanal ortamın gerçek olmadığı bilgisini kendilerine hatırlatarak kaygılarını düzenlemeye çalıştıklarını belirtti.

“Burası gerçek değil diye kendime telkin verdim.” (S.K.)

“Gerçek olmadığını bildiğim için ilerleyebildim.” (R. B.)

Travmatik Anıların Tetiklenmesi

Bazı senaryoların, özellikle labirent ve kapalı alan içeren uygulamaların, katılımcıların deprem sonrası yaşadıkları travmatik anıları tetiklediği görüldü.

“Depremden sonra apartmanın tuğlalarını görmüştük; labirentin duvarları o anı hatırlattı.” (K. K.)

Bu durum bazı katılımcılarda çarpıntı, nefes darlığı ve yoğun kaygı tepkilerine yol açtı.

Baş Etme, Kontrol ve Maruz Kalma Deneyimi

Katılımcılar, zorlu senaryolar sırasında kaygı yaşadıklarını, ancak uygulamayı tamamladıklarında baş etme becerilerinin arttığını ifade ettiler. Telkin sesleri, nefes egzersizleri ve hedefe odaklanma gibi unsurlar katılımcıların süreci tamamlamasında etkili oldu.

“Telkin konuşmasıyla nefes aldım ve rahatladım.” (S.A.)

“Devam ettim ve sonunda başardım.” (C.A.)

Başarma ve Güçlenme

Özellikle dağ tırmanışı, hazine avı ve voleybol senaryolarında katılımcılar yoğun biçimde başarma, güçlenme ve özgüven artışı yaşadıklarını ifade ettiler.

“Zirveye ulaşmayı başardım.” (S. A.)

“Sandığa ulaşmak her şeye rağmen mutlu etti.” (C. A.)

Aynalı oda senaryosunda ise katılımcıların kendilik algısı, öz-şefkat ve farkındalık temalarına vurgu yaptığı görüldü.

“Kendimi affettim ve kendimle barıştım.” (S. K.).

TARTIŞMA

Çalışmanın sonuçları, SG tabanlı müdahalelerin bu hassas grupta hem riskler hem de terapötik potansiyel barındırdığını göstermektedir.

Katılımcıların baş dönmesi, mide bulantısı ve göz kararması gibi fiziksel yan etkiler bildirmeleri, literatürde tanımlanan “SG hastalığı” ile uyumludur. Bu etkilerin özellikle hareketli ve kapalı alan senaryolarında artması, görsel-vestibüler uyumsuzlukla açıklanabilirken, daha durağan içeriklerde azalması literatürde desteklenmektedir. Bununla birlikte, SG deneyiminin yalnızca fiziksel değil, aynı zamanda duygusal tepkileri de tetiklediği görülmektedir.

SG senaryolarının kapalı alan, yükseklik ve su gibi uyaranlar karşısında kaygı ve anksiyete tepkilerini artırdığı belirlendi. Bu durum, sanal ortamın güçlü bir varlık hissi oluşturmasıyla ilişkilidir. Katılımcıların sanal ortamın gerçek olmadığını bilerek kendilerine telkin vermeleri, bilişsel yeniden yapılandırma ve duygu düzenleme süreçlerinin aktif olarak kullanıldığını göstermektedir. Bununla birlikte, bazı senaryoların travmatik anıları tetikleyebildiği de gözlemlendi. Görsel ve mekânsal ipuçlarının gerçek yaşantılarla çağrışım kurması, akut stres tepkilerine yol açabilmektedir.

Ancak bu tetiklenme riski uygun bir yapılandırma ile terapötik bir fırsata dönüşebilmektedir. SG’nin kontrollü yapısı, bireylerin kaygı uyandıran uyaranlara güvenli bir biçimde maruz kalmasını ve baş etme becerilerini geliştirmesini desteklemektedir. Katılımcıların süreç sonunda rahatlama ve başarıma hissi bildirdikleri, sanal ortamın gerçek olmadığını kendilerine hatırlatarak duygu düzenleyebildikleri ve bu süreçte anksiyete düzeylerinin azaldığı saptanmıştır.

SONUÇ ve ÖNERİLER

Bu çalışmada, depremzedelerde sanal gerçeklik destekli psikoeğitimin kaygı üzerindeki etkileri nitel veriler ışığında incelenmiştir. Elde edilen bulgular, yapılan müdahalenin kaygıyı azaltmada etkili olduğunu göstermiştir.

SG destekli psikoeğitim, maruz bırakma ve bilişsel yeniden yapılandırma temelli bir öğrenme ortamı sunmaktadır. Bununla birlikte, SG uygulamalarında içerik yoğunluğunun ve senaryo tipinin bireysel özelliklere göre uyarlanması, olası fiziksel yan etkileri ve kaygı tetiklenmesini en aza indirmek açısından önem taşımaktadır. Gelecek araştırmalarda, bireylerdeki anksiyeteyi azaltmaya yönelik eğitim müdahalelerinde SG desteğinin entegre edilmesi ve SG desteğinin kullanılması önerilmektedir.

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**MOBILE HEALTH APPLICATIONS IN CHRONIC DISEASE MANAGEMENT: A REVIEW OF
THE LITERATURE FROM THE LAST FIVE YEARS (2020–2025)**

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ABSTRACT

The management of chronic diseases encompasses multidimensional requirements, including medication adherence, lifestyle modifications, regular monitoring, and continuous access to healthcare services. In meeting these needs, digital health technologies, particularly mobile health applications, have become critical tools in recent years. As of 2024, there are approximately 35,000–41,000 health and medical applications on the Apple App Store and 36,000–57,000 on the Google Play Store. This rapid growth clearly demonstrates the strategic importance of mHealth in healthcare delivery. This review aims to systematically present the current evidence regarding mobile health applications used in chronic disease management, based on studies published between 2020 and 2025 in the Elsevier/ScienceDirect, Web of Science (WoS), Google Scholar, and Scopus databases. This review is based on a comprehensive literature search conducted across four major academic databases, covering studies published between January 2020 and March 2025. Systematic reviews on diabetes management report that smartphone applications reduce HbA1c levels by an average of 0.79 percentage points. Studies evaluating digital interventions for hypertension management reveal that mHealth tools can reduce systolic/diastolic blood pressure by an average of 140/50 mmHg. Randomized controlled trials of integrated mHealth interventions that address both diabetes and hypertension report improved clinical outcomes for both conditions. Studies using mHealth platforms in randomized controlled trials demonstrate reductions in symptom burden and improvements in quality of life. The high heterogeneity among studies in terms of sample characteristics, disease types, and outcome measures assessed complicates systematic comparison. High user dropout rates and methodological inadequacies in monitoring long-term engagement limit the understanding of applications' effectiveness in real-world conditions. Therefore, longitudinal studies with adequate follow-up periods are necessary to understand the dynamics of adoption and long-term use.

Keywords: Diabetes, Hypertension, Chronic Obstructive Pulmonary Disease, Disease Management, Biomedical Technology

1. INTRODUCTION

Chronic diseases are one of the most significant public health challenges worldwide. According to World Health Organization (WHO) data, about seventy-one percent of all deaths are caused by chronic diseases. This proportion is expected to rise in the coming years (WHO, 2025). Chronic conditions such as diabetes, hypertension, and COPD require patients to stick to long-term pharmacological treatments, lifestyle changes, and regular clinical evaluations. These demands call for patients to manage their health and for the healthcare system to provide sustainable support.

The rapid global proliferation of smartphone use in recent years has positioned digital health technologies as instruments for integration into healthcare delivery. In this context, the concept of "mobile health" (mHealth) encompasses the full range of digital health interventions—including health information delivery, disease monitoring, medication reminders, symptom recording, and remote patient–physician communication—delivered via smartphones, tablets, and wearable devices (Balkaya, 2025). The World Health Organization defines mHealth as "medical and public health practice supported through mobile devices," and considers it a core component of eHealth (electronic health).

The COVID-19 pandemic substantially accelerated the global adoption of mHealth by rapidly increasing demand for remote healthcare services. During this period, applications such as tele-monitoring, digital rehabilitation, and remote medication management began to be incorporated into standard care protocols across numerous health systems (Balkaya, 2025). Furthermore, figures from application marketplaces concretely reflect this growth: as of 2024, between 35,000 and 41,000 health and medical applications are reported to be

available on the App Store, and between 36,000 and 57,000 on Google Play Store. This rapid growth, however, raises important questions of quality and efficacy that extend beyond mere quantitative expansion. It is known that only a small fraction of the applications currently available in mobile app stores have been developed on the basis of clinical evidence, while the vast majority have been designed without supervision by any health professional. Moreover, research examining the effectiveness of mHealth interventions has yielded inconsistent results due to methodological heterogeneity, short follow-up durations, and variation in sample characteristics. This situation clearly highlights the need for a systematic evaluation of the field.

This review systematically examines studies published between January 2020 and March 2025 to discuss the effectiveness, strengths, and limitations of mHealth applications for chronic disease management, as well as future research priorities. While focusing primarily on diabetes mellitus, hypertension, and COPD, the review also includes findings on general chronic disease management.

2. METHOD

2.1. Literature Search Strategy

This study was designed as a systematic literature review covering academic studies published between January 2020 and March 2025. The search was conducted across four major academic databases: Elsevier/ScienceDirect, Web of Science (WoS), Google Scholar, and Scopus. The search strategy incorporated the following keywords and their combinations using Boolean operators (AND/OR): "mobile health," "mHealth," "smartphone application," "chronic disease management," "diabetes," "hypertension," "COPD," "medication adherence," "self-management," and "digital health intervention."

2.2. Inclusion and Exclusion Criteria

The inclusion criteria were as follows: (1) English-language articles in peer-reviewed journals between January 2020 and March 2025; (2) studies with adult patients with diabetes, hypertension, or COPD; (3) studies using smartphone or tablet apps in any intervention arm; (4) studies with randomized controlled trial (RCT), systematic review, or meta-analysis designs; (5) studies reporting measurable outcomes such as HbA1c, blood pressure, quality of life, symptom burden, or medication adherence.

Exclusion criteria were: studies on non-primary chronic conditions, like acute illnesses or mental disorders; SMS-based interventions that did not use applications; conference abstracts and editorials; and narrative reviews without raw data.

2.3. Data Extraction and Quality Assessment

The following information was systematically extracted from each study: publication year, study design, sample size, target disease, intervention type, follow-up duration, and reported clinical outcomes. The methodological quality of randomized controlled trials was assessed using the Cochrane Risk of Bias Tool (RoB 2). Systematic reviews were evaluated using the AMSTAR-2 (A MeaSurement Tool to Assess Systematic Reviews) criteria.

3. RESULTS

3.1. Mobile Health Applications in Diabetes Management

Diabetes mellitus constitutes the chronic disease category in which mHealth interventions have been most extensively studied. A meta-analysis comprehensively evaluating the effect of mHealth applications on HbA1c in patients with type 2 diabetes included 41 randomized controlled trials and found that mHealth-based interventions reduced HbA1c levels by 0–0.6% compared with control groups (Versluis et al., 2025).

Another meta-analysis reviewed 27 studies on diabetes-specific mHealth apps published between January 2008 and October 2020 (Eberle et al., 2021). The mean difference in HbA1c was -0.63 (95% CI: -0.93 to -0.32) for type 1 diabetes, and -0.54 (95% CI: -0.80 to -0.28) for type 2. These studies also found that mHealth use supported better self-care and self-efficacy (Eberle et al., 2021; Versluis et al., 2025).

A further study, a systematic review, examined RCTs published up to April 18, 2024, and evaluated the effect of mobile application interventions on HbA1c in patients with type 2 diabetes (Tang et al., 2024). According

to the review findings, studies with an intervention duration of 6 months or more demonstrated a mean reduction in HbA1c of 0.52 points, indicating that clinical efficacy increases with longer intervention duration.

A meta-analysis focused on elderly patients with diabetes (Azevedo et al., 2024). It included 7 RCTs and 490 participants and found a statistically significant reduction in HbA1c (Hedges' $g = -0.40$; 95% CI: -0.75 to -0.06). For type 1 diabetes, another meta-analysis showed a reduction of -0.25 in HbA1c (Wang et al., 2019). However, one of the greatest challenges in developing mobile applications for patients with diabetes is ensuring sustained engagement with the application. Long-term follow-up studies report that approximately 80% of users of a diabetes monitoring application discontinue use within 1 week (Deniz-Garcia et al., 2023). Lack of motivation, technical difficulties, user fatigue, and the burden of daily data entry are identified as the primary reasons for discontinuation (Deniz-Garcia et al., 2023). This high dropout rate raises serious questions regarding the extent to which the favorable findings obtained from short-term RCTs can be generalized to real-world conditions.

3.2. Mobile Health Applications in Hypertension Management

Hypertension continues to be one of the most important modifiable risk factors for morbidity and mortality in cardiovascular disease. According to WHO data, approximately 1.28 billion adults worldwide carry a diagnosis of hypertension, and only forty-five percent of these individuals achieve adequate blood pressure control (WHO, 2024). MHealth applications are increasingly being considered as a promising tool to bridge this treatment gap.

A meta-analysis examining the effect of interactive mHealth interventions on blood pressure management synthesized findings from RCTs and demonstrated that the net change in systolic blood pressure (SBP) was -3.85 mmHg (95% CI: -4.74 to -2.96 ; $I^2=22.8\%$) and in diastolic blood pressure (DBP) was -2.19 mmHg (95% CI: -3.16 to -1.23 ; $I^2=29.4\%$) (Lu et al., 2019). The degree of homogeneity observed supports the reliability of these findings.

In a two-arm study conducted in China with 297 patients with hypertension, participants used the mHealth application "Blood Pressure Assistant" for 6 months, which provided vital sign recording, access to educational materials, and self-management reminders (Liu et al., 2023). Significant improvements were observed in the intervention group, and the mHealth-based approach was reported to support health-promoting behaviors, including medication adherence, a low-salt diet, and physical exercise (Liu et al., 2023).

3.3. Mobile Health Applications in COPD Management

Chronic obstructive pulmonary disease (COPD) is a complex chronic condition characterized by a significant symptom burden, recurrent exacerbations, and loss of functional capacity. Pulmonary rehabilitation (PR) is among the interventions with the strongest evidence base in COPD management; however, access to center-based PR programs is frequently restricted by factors such as transportation difficulties, geographic distance, low patient motivation, and inadequate insurance coverage. In this context, smartphone-based pulmonary rehabilitation programs are emerging as an accessible alternative.

A systematic review and meta-analysis in this area examined RCTs published between January 2007 and June 2023 that compared mobile application-based PR with conventional center-based PR (Chung et al., 2024). This meta-analysis evaluated differences in the six-minute walk test (6MWT) distance, measuring exercise capacity; COPD Assessment Test (CAT) scores; the modified Medical Research Council (mMRC) dyspnea scale; and quality-of-life indicators (Chung et al., 2024). The study demonstrated that mobile application-based PR produced outcomes clinically equivalent to those of center-based programs and emphasized that mHealth-based pulmonary rehabilitation constitutes a robust alternative, particularly for patients residing in remote areas (Chung et al., 2024).

A systematic review providing a comprehensive assessment of mHealth applications in COPD evaluated multiple outcomes, including exacerbation frequency, quality of life, physical function, dyspnea, physical activity, and self-efficacy (Shaw et al., 2020). The findings indicate that mHealth adds value, particularly for symptom monitoring and access to educational materials. Nevertheless, the review noted that statistically significant evidence for certain primary outcomes—particularly reductions in hospital admissions—was not yet sufficiently robust.

4. DISCUSSION

The studies within the scope of this review indicate that mHealth applications offer statistically and clinically significant benefits in chronic disease management. In the field of diabetes, it is noteworthy that multiple meta-analyses consistently report effects on HbA1c that are clinically comparable to those achievable as an adjunct to pharmacological treatment. In hypertension, even modest but significant reductions in blood pressure may be considered of sufficient magnitude to reduce the risk of cardiovascular events at the population level over the long term. In COPD, particularly in the context of pulmonary rehabilitation, mHealth-based approaches demonstrate the potential to deliver outcomes equivalent to those of center-based programs for patients unable to access them.

Evaluation of the studies within the scope of this review clearly reveals significant methodological challenges in the field. Chief among these is high methodological heterogeneity. Marked differences across studies in sample characteristics, disease severity, intervention components, follow-up durations, and outcomes assessed make direct comparative analyses difficult. This heterogeneity, frequently characterized by high I^2 values in meta-analyses, complicates the interpretation of pooled effect estimates.

The second major area of concern pertains to user dropout rates and long-term engagement. Dropout rates reported in studies utilizing mHealth applications are at worrying levels. A systematic review reported a mean dropout rate of 49% in real-world observational studies and 40% in RCTs (Deniz-Garcia et al., 2023). The third area of concern relates to short follow-up durations. The majority of existing studies have been evaluated over follow-up periods of 3 to 12 months—a timeframe that does not adequately illuminate the long-term clinical efficacy, sustainability, and potential washout effects of mHealth interventions. Given that the effectiveness of digital behavioral change interventions tends to diminish over time, longitudinal studies with follow-up periods of at least 18–24 months are of considerable importance.

The fourth area of concern encompasses the lack of standardization. The marked differences among studies in application designs, feature sets, user interfaces, and intervention protocols make systematic comparison across studies extremely challenging. Furthermore, the failure of many studies to report application characteristics and intervention components in sufficient detail makes it difficult to identify the mechanisms underlying effectiveness. Inadequate reporting regarding safety, privacy, and data management standards also emerges as a distinct concern.

In light of the gaps in the existing evidence base and the methodological limitations identified, future research should focus on specific priorities. First, the need for long-term longitudinal studies is clear. In this regard, it is recommended that studies with a follow-up duration of at least 18–24 months be planned. Such a timeframe will allow not only the evaluation of clinical outcomes but also the monitoring of user engagement and the documentation of the trajectory of intervention effects over time (patterns of persistence or attenuation).

Second, the development of standardized reporting frameworks emerges as a critical necessity. Establishing standardized reporting guidelines for application features, intervention components, user engagement metrics, and safety and privacy protocols will enhance comparability across studies and support more robust, comprehensive systematic analyses.

The third priority focuses on disadvantaged populations. Studies conducted in groups that are underrepresented in existing research—such as elderly individuals, populations with low digital literacy, and populations in low- and middle-income countries—will more accurately reflect the real-world accessibility of mHealth.

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CONFIRMATORY FACTOR ANALYSIS OF THE TURKISH VERSION OF THE SECOND LANGUAGE LEARNING GRIT (L2-GRIT) SCALE

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ABSTRACT

The Second Language Grit Scale (L2-Grit Scale), developed by Teimouri and colleagues to assess the tenacity of English as a Foreign Language (EFL) learners in their second-language acquisition, was translated into Turkish by Uştuk and Erarslan. An exploratory factor analysis was conducted to assess the adoption of the Second Language Grit Scale into Turkish. A limitation of the study employing exploratory factor analysis is the absence of a confirmatory factor analysis of the scale. This research aims to evaluate the two-factor theoretical framework of the Second Language Learning Grit Scale, translated into Turkish, by confirmatory factor analysis. The scale assesses a domain-specific personality trait that gauge's individuals' consistency and perseverance in pursuing long-term objectives in second language acquisition. Prior research employed an exploratory factor analysis of the Turkish version of the measure, yielding a two-component structure. The structural model requires validation to ensure the scale is applicable in research. Confirmatory factor analysis was conducted to assess the scale's structural validity, using data from 343 students enrolled in university preparatory classes. The model in the study was evaluated using AMOS on a nine-item scale. The study's findings indicate the following model fit indices: $\chi^2/df = 2.35$, GFI = .971, AGFI = .938, CFI = .988, TLI = .981, and RMSEA = .063. These numbers demonstrate that the model has a satisfactory level of fit. The findings support the two-factor structure of the Turkish version of the L2-Grit scale and demonstrate its structural validity. Nevertheless, the second factor comprises three items rather than four, as shown in the English scale. The adaptation of the nine-item scale into two dimensions has confirmed that the Turkish version has two factors and eight items.

Keywords: Confirmatory factor analysis, grit scale, L2-Grit, second language acquisition, scale validity.

INTRODUCTION

Individual differences are regarded as a primary variable in elucidating learning success in second language acquisition. Among these individual differences, perseverance has become a significant focus of research in the psychology of language learning. Perseverance is characterized by a tendency to maintain consistency and sustained effort towards long-term objectives (Duckworth et al., 2007). When research on the concept of perseverance in learning and teaching processes began, it initially focused on broad studies of academic achievement. As research on perseverance evolved, it was analyzed as a discipline-specific framework in studies. The construct of Second Language Grit, which emerged from learning English as a second language, shows learners' determination to continue learning despite difficulties.

The Second Language Grit Scale (L2-Grit Scale), developed by Teimouri and colleagues, is intended to measure grit among English as a Foreign Language (EFL) learners in their second-language learning (Teimouri et al., 2020). The adaptation of this scale into Turkish employed exploratory factor analysis; however, the lack of confirmatory factor analysis is a notable limitation of the study (Uştuk & Erarslan, 2023). It is essential to perform confirmatory factor analysis (CFA) alongside exploratory factor analysis (EFA) when validating a scale. Teimouri and colleagues developed L2 grit, which has two factors: Perseverance of Effort and Consistency of Interest. In the Turkish adaptation study by Uştuk and Erarslan, an exploratory factor analysis yielded a two-factor, nine-item structure derived from the original scale (Uştuk & Erarslan, 2023). The analyses revealed that the internal consistency coefficients for the Turkish-adapted scale were 0.90 for the Perseverance of Effort dimension, 0.88 for the Consistency of Interest dimension, and 0.84 for the overall scale. These numbers show that the scale is very reliable. However, exploratory factor analysis is merely one way to determine the potential factor structure. Confirmatory factor analysis is essential for validating the

theoretical model. Consequently, the present study focuses on the following research question: Is the two-factor theoretical structure of the L2-Grit scale validated within the Turkish sample?

THEORETICAL FRAMEWORK

Grit and Learning a Language

Recent research has examined the concept of grit. Perseverance is regarded as significantly impactful on academic progress and accomplishments across multiple life domains (Kırkıç, 2022). "Passion and perseverance" for long-term goals is what grit means. People who are determined think that success does not come from brief bursts of hard work, but from doing things repeatedly. Learning a language is a long-term process that requires repetition. Perseverance is one of the personal traits needed to ensure continuity. Grit is considered a significant individual difference variable, particularly in second language acquisition. Research indicates that the two essential elements of grit, "perseverance of effort" and "consistency of interest," are vital in the language acquisition process (Duckworth et al., 2007). In this context, it has been established that students who exhibit a high degree of perseverance attain greater academic success in language acquisition, demonstrate a higher self-perception of competence in their evaluations, and exhibit enhanced resilience in overcoming challenges encountered during the learning process (Sudina & Plonsky, 2021). In the same way, studies across diverse groups have shown a strong, positive link between perseverance and success in learning a foreign language, and that perseverance is an essential predictor of success (Ding, Wu, & Ming, 2025). Moreover, comprehensive evaluations underscore that perseverance is a crucial psychological asset in language acquisition, sustaining motivation, dedication to the learning process, and the attainment of long-term objectives (Zhao & Wang, 2023). In this context, recognizing that language acquisition is an inherently prolonged and ongoing endeavor, perseverance emerges as a crucial factor for individuals to maintain their learning trajectory and achieve success (Henry, 2023).

The Second Language Grit Scale

Teimouri and colleagues developed the Second Language Grit Scale, which comprises 9 items and 2 factors. Uştuk and Erarslan adapted it into Turkish (Uştuk & Erarslan, 2023). The Second Language Grit scale differs from the general grit scale, focusing on actions related to learning a second language. There are nine items on the scale, and it is two-dimensional: The first dimension, "Perseverance of effort" means not giving up while learning, and the second dimension, "Consistency of interest" means staying interested in learning a language. The exploratory factor analysis performed in the adaptation study revealed that these two factors accounted for almost 70% of the total variance. However, according to the psychometric literature, a scale should be tested using confirmatory analysis to be considered valid.

METHOD

Research Model

The research used confirmatory factor analysis, which should have been conducted in the preceding adaptation study, as recommended by Özdamar (2017) for scale development. Confirmatory factor analysis within the framework of structural equation modeling was used to test the scale's structural validity.

Study Group

The study's participants are students enrolled in the English preparatory program at a foundation university. Participants were selected through convenience sampling and volunteered to participate in the research.

Table 1. The Demographic Characteristics of Participants in the Study

Demographic Characteristics		Frequency	Percentage (%)
Gender	Female	205	59,8
	Male	138	40,2

Class Level	A1	203	59,2
	A2	71	20,7
	B1	50	14,6
	B2	19	5,5
Faculty	FoE&NS	124	36,2
	FoB&MS	115	33,5
	FoH&SS	82	23,9
	Other	22	6,4
	Total	343	100
Other: FoE, FoL, FoIS, FoHS, FoSS			
FoE: Faculty of Education; FoL: Faculty of Law; FoH&SS: Faculty of Humanities and Social Sciences; FoIS: Faculty of Islamic Sciences; FoB&MS: Faculty of Business and Management Sciences; FoE&NS: Faculty of Engineering and Natural Sciences; FoHS: Faculty of Health Sciences; FoSS: Faculty of Sports Science			

The study group comprises 205 (59.8%) females and 138 (40.2%) males, categorized by gender; 203 (59.2%) in preparatory class level A1, 71 (20.7%) in A2, 50 (14.6%) in B1, and 19 (5.5%) in B2; and 82 (23.9%) from the Faculty of Political Sciences, 115 (33.5%) from the Faculty of Economics and Administrative Sciences, 124 (36.2%) from the Faculty of Business Administration, and 22 (6.4%) from other faculties.

Data Collection

The data were gathered from students enrolled in the English preparatory program class at a foundation university. The researchers informed students about the study, and those who wanted to take part completed paper-based questionnaires.

Data Analysis

The L2-Grit Scale has 9 Likert-type items. The tool assesses two latent constructs: "Perseverance of Effort" (5 items) and "Consistency of Interest" (4 items). The Turkish adaptation study utilized AMOS software for confirmatory factor analysis. The maximum likelihood estimate technique has been employed. To ensure normality responses from participants who violated it were excluded, and analyses were performed using the responses of the remaining 343 participants who upheld normality.

FINDINGS

Model Fit Indices

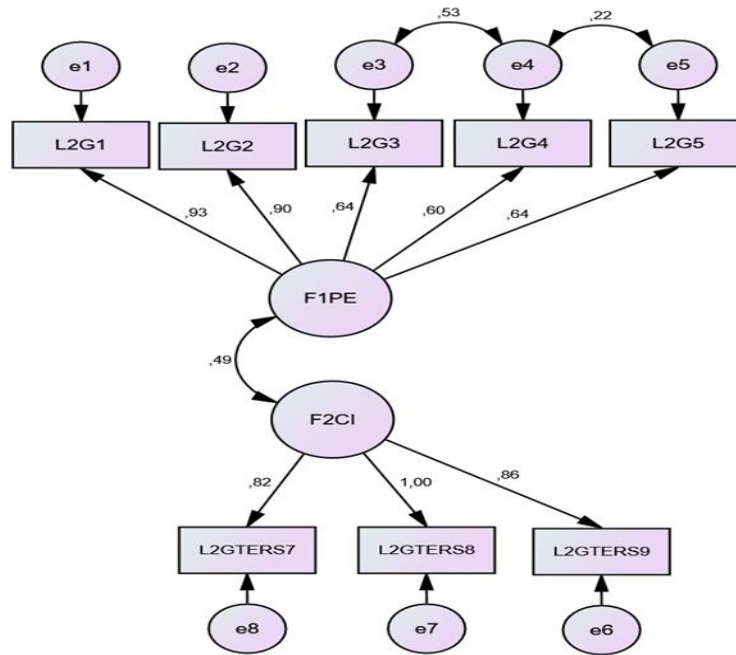


Figure 1. Path Diagram of the DFA Results of the L2 Grit Scale

When examining the factor loadings between dimensions and items, it is observed that the loadings are generally above .70. Loadings above .70 indicate a perfect structure (Çokluk et al., 2012). The fit values of the scale are provided in Table 2.

Table 2. DFA Model Fit Indices

Fit Goodness Values	Ideal Fit Goodness Values	Acceptable Fit Values	Calculated Fit Values for the Model	Goodness of Fit Result
χ^2/df	$0 \leq \chi^2/df \leq 3$	$3 < \chi^2/df \leq 5$	2.35	Perfect
GFI	$0.95 \leq GFI \leq 1.00$	$0.90 \leq GFI < 0.95$	.971	Perfect
AGFI	$0.90 \leq AGFI \leq 1.00$	$0.85 \leq AGFI < 0.90$	.938	Perfect
CFI	$0.95 \leq CFI \leq 1.00$	$0.90 \leq CFI < 0.95$	.988	Perfect
TLI	$0.95 \leq TLI \leq 1.00$	$0.90 \leq TLI < 0.95$	.981	Perfect
RMSEA	$0 \leq RMSEA \leq 0.05$	$0.05 < RMSEA \leq 0.08$	.063	Acceptable
RMR	$0 \leq RMR \leq 0.05$	$0.05 < RMR \leq 0.08$	.027	Perfect

(İlhan & Çetin, 2014, p.31)

Table 2 presents the results of the confirmatory factor analysis (CFA), indicating that the model fits well overall. The chi-square/degrees of freedom ratio ($\chi^2/df = 2.35$) is within the optimal range, indicating a good fit. The absolute fit indices GFI (.971) and AGFI (.938) are both in the good-to-excellent fit range, supporting strong model-data fit.

The incremental fit indices indicate that the CFI (.988) and TLI (.981) are both above 0.95, indicating that the model fits very well. The RMSEA (.063) from the error-based fit indices falls within the acceptable range, indicating that the model has a reasonable level of error. Also, the RMR value (.027) is less than 0.05, indicating that the discrepancies between the observed and estimated covariance matrices are quite small, suggesting an excellent fit.

In general, all fit indices are within acceptable ranges, and most are at the perfect fit level. These results show that the proposed measurement model fits the data very well and that its structural validity is quite strong (İlhan & Çetin, 2014).

Table 3. t-test outcomes comparing groups based on the gender variable

	Gender	N	Mean	Sd	t	df	p
L2G1	Male	138	3,9275	,77965	1,100	341	,272
	Female	205	3,8293				
L2G2	Male	138	3,6884	,79046	,007	341	,995
	Female	205	3,6878				
L2G3	Male	138	3,8768	,92376	-,112	341	,911
	Female	205	3,8878				
L2G4	Male	138	3,7536	,90264	-1,233	341	,218
	Female	205	3,8732				
L2G5	Male	138	3,5652	,86249	,460	341	,646
	Female	205	3,5220				
L2GRVRS7	Male	138	4,5000	,64199	-1,627	268,707	,105
	Female	205	4,6244				
L2GRVRS8	Male	138	4,6232	,75651	,243	341	,808
	Female	205	4,6049				
L2GRVRS9	Male	138	4,6014	,74029	,082	341	,935
	Female	205	4,5951				

Table 3 shows the results of the independent-samples t-test conducted to determine whether participants' responses to the L2-Grit scale items differed by gender. The study found no statistically significant difference between female and male participants across all evaluated items ($p > .05$). When examining the groups' average scores, small differences are evident in several areas. However, these differences do not reach statistical significance. Overall, responses to the L2-Grit scale do not show significant gender differences. This finding shows that grit levels are similar for both female and male participants and that the scale functions similarly for both groups.

Table 4 presents the results of the Kruskal-Wallis H test, which was conducted to determine whether participants' responses to the L2-Grit scale items vary by class level.

Table 4. The Kruskal-Wallis H test compares groups based on the class level variable

	Class Level	N	Mean Rank	Kruskal-Wallis H	df	p
L2G1	A1	203	17.66	2.037	3	.565
	A2	71	175.44			
	B1	50	181.92			
	B2	19	147.39			
	Total	343				
L2G2	A1	203	171.85	.468	3	.926
	A2	71	172.55			
	B1	50	176.59			
	B2	19	159.47			
	Total	343				
L2G3	A1	203	167.38	3.113	3	.375
	A2	71	18.39			
	B1	50	186.48			
	B2	19	151.84			
	Total	343				
L2G4	A1	203	167.96	2.541	3	.468
	A2	71	169.89			
	B1	50	191.39			
	B2	19	172.00			
	Total	343				
L2G5	A1	203	171.62	.274	3	.965
	A2	71	169.08			
	B1	50	177.90			
	B2	19	171.42			
	Total	343				

L2GRVRS7	A1	203	166.30	9.740	3	.021
	A2	71	19.22			
	B1	50	183.86			
	B2	19	133.61			
	Total	343				
L2GRVRS8	A1	203	167.79	9.132	3	.028
	A2	71	194.07			
	B1	50	17.31			
	B2	19	138.92			
	Total	343				
L2GRVRS9	A1	203	172.47	6.083	3	.108
	A2	71	184.39			
	B1	50	166.46			
	B2	19	135.29			
	Total	343				

Table 4 presents the results of the Kruskal-Wallis H test, which assesses differences among groups based on the class-level variable. The analysis indicates no statistically significant differences among the groups for the variables L2G1 ($p = .565$), L2G2 ($p = .926$), L2G3 ($p = .375$), L2G4 ($p = .468$), L2G5 ($p = .965$), and L2GRVRS9 ($p = .108$), as all p-values exceed .05. In contrast, significant differences were observed between groups at the class level for the variables L2GRVRS7 ($H = 9.740$, $p = .021$) and L2GRVRS8 ($H = 9.132$, $p = .028$; $p < .05$). This suggests a substantial disparity among at least one group regarding the pertinent factors.

Table 5 displays the results of the Kruskal-Wallis H test, which was performed to determine whether participants' responses to the L2-Grit scale items vary by class level.

Table 5. The Kruskal-Wallis H test comparing groups based on the faculty variable

	Faculty	N	Mean Rank	Kruskal-Wallis H	df	p
L2G1	FoE	14	161,00	1,978	4	0,740
	FoH&SS	82	164,16			
	FoB&MS	115	170,92			
	FoE&NS	124	177,61			
	OTHER	8	200,19			
	Total	343				
L2G2	FoE	14	146,68	1,609	4	0,807
	FoH&SS	82	170,65			
	FoB&MS	115	169,63			
	FoE&NS	124	177,77			
	OTHER	8	174,63			
	Total	343				
	FoE	14	157,71			

L2G3	FoH&SS	82	170,84	1,487	4	0,829
	FoB&MS	115	175,37			
	FoE&NS	124	173,38			
	OTHER	8	139,13			
	Total	343				
L2G4	FoE	14	179,50	0,613	4	0,962
	FoH&SS	82	174,88			
	FoB&MS	115	168,21			
	FoE&NS	124	171,67			
	OTHER	8	188,88			
L2G5	Total	343		3,174	4	0,529
	FoE	14	155,75			
	FoH&SS	82	177,00			
	FoB&MS	115	170,23			
	FoE&NS	124	168,92			
L2GRVRS7	OTHER	8	222,38	1,519	4	0,823
	Total	343				
	FoE	14	156,14			
	FoH&SS	82	177,69			
	FoB&MS	115	171,04			
L2GRVRS8	FoE&NS	124	172,34	0,411	4	0,982
	OTHER	8	150,00			
	Total	343				
	FoE	14	160,46			
	FoH&SS	82	171,41			
L2GRVRS9	FoB&MS	115	174,06	2,714	4	0,607
	FoE&NS	124	172,16			
	OTHER	8	166,13			
	Total	343				
	FoE	14	177,39			

The results indicate no statistically significant variation in the faculty variable across all items ($p > .05$). When examining rank means, several faculties show slight disparities, but these differences are not statistically significant. For instance, it is significant that the OTHER and FoE&NS groups have higher mean ranks on certain items; however, this does not indicate a substantial difference. In general, the faculty in which the participants studied did not have a significant effect on their L2-Grit levels. This finding suggests that grit is distributed similarly across students from different academic disciplines, demonstrating interdisciplinary consistency.

Table 6 shows the reliability coefficients (Cronbach's alpha) for the L2-Grit scale and its sub-dimensions.

Table 6. The scale and its sub-dimensions' reliability coefficients

Reliability	PE	.878
	CI	.915
	L2GRIT	.884

The results indicate that the reliability coefficients for the Perseverance of Effort (PE) are $\alpha = .878$, for Consistency of Interest (CI) are $\alpha = .915$, and for the overall scale (L2-GRIT) are $\alpha = .884$. Upon examination of these numbers, it is observed that all reliability coefficients are above .70, indicating a high level of internal consistency for the scale. In particular, the CI sub-dimension, with a coefficient exceeding 0.90, indicates an exceptionally high degree of reliability for this dimension. The reliability coefficients for the PE sub-dimension

and the overall scale score are high. The L2-Grit scale is a reliable measurement instrument for its sub-dimensions and overall score, with the research data demonstrating robust internal consistency.

DISCUSSION

This study thoroughly examined the psychometric features of the Turkish version of the L2-Grit Scale using confirmatory factor analysis (CFA), group comparisons, and reliability assessments. The results indicated that the scale demonstrates strong evidence for both construct validity and internal consistency. The DFA results revealed that the two-factor structure (Perseverance of Effort and Consistency of Interest) showed a good fit to the data. The predominance of fit indices at an excellent level (CFI = .988; TLI = .981), along with the remaining indices within acceptable thresholds, suggests that the model effectively represents the theoretical framework. This finding aligns with Duckworth's hypothesized two-dimensional structure of grit. The definition of grit by Duckworth and colleagues (2007) as perseverance and passion for long-term objectives corresponds with the factor structure shown in this study. Nevertheless, the present findings also align with research on second language acquisition. The L2 grit framework indicates that individual differences are a crucial factor in language acquisition (Teimouri et al., 2020). The strong model fit achieved in this study substantiates that L2 grit is a valid construct within the Turkish context as well.

The results for the gender variable indicate that L2-Grit levels do not differ significantly between female and male participants. This finding corresponds with research indicating that grit may be a personality trait mostly independent of demographic factors (Duckworth & Quinn, 2009). Nevertheless, while some research has indicated minor gender-related differences, these discrepancies are typically inconsistent and context-sensitive. In the analyses conducted at the class level, significant differences were observed only in some reverse-coded items. The higher mean ranks of A2 and B1 students indicate that individuals acquiring the language at an intermediate level may have an advantage in sustained motivation. This situation aligns with Dörnyei's motivation theories, which propose that motivation in language acquisition may follow a variable trajectory rather than a linear progression (Dörnyei, 2005). Nonetheless, the absence of notable differences across class levels indicates that grit is predominantly an autonomous, more consistent trait. Results for the faculty variable also indicated that L2-Grit levels did not differ significantly across academic disciplines. This situation suggests that grit is not context-dependent but rather an individual trait, uniformly distributed among students across different disciplines. This finding aligns with prior research demonstrating the multidisciplinary validity of grit.

Reliability analyses indicate that the scale exhibits strong internal consistency ($\alpha = .878-.915$). In particular, the Consistency of Interest subscale has a value exceeding .90, indicating that this dimension assesses a highly homogeneous structure. The results exceed the reliability thresholds ($\alpha > .70$) recommended in psychometric assessments, strongly supporting the scale's reliability (Kline, 2016). Overall, this study's results demonstrate that the Turkish version of the L2-Grit Scale is a valid and reliable measurement instrument. The scale's consistent results across different demographic groups offer indirect evidence for measurement invariance. The study contributes to both scale development literature and research on individual differences in second language acquisition.

CONCLUSION

This study thoroughly assessed the psychometric properties of the Turkish version of the L2-Grit Scale, demonstrating that it is a valid and reliable assessment instrument. The confirmatory factor analysis results substantially validated the two-factor structure of the scale (Perseverance of Effort and Consistency of Interest), demonstrating a high level of model fit with the data. Analysis of demographic characteristics indicates that L2-Grit levels do not significantly vary by gender, class level, or faculty variables. This reinforces the idea that grit is a more stable individual trait rather than being influenced by contextual or demographic factors. The lack of significant differences in gender and faculty factors suggests that the scale yields consistent measurements across various groups. The data at the class level reveal that variance is limited to only a few reverse-coded items, suggesting that although the overall structure of grit remains intact, certain dimensions may change during the learning process. Reliability analyses have demonstrated that the scale has high internal consistency across its sub-dimensions and overall score. Upon evaluating these findings collectively, it can be stated that the Turkish version of the L2-Grit Scale is a robust measurement instrument suitable for both research and practical applications.

RECOMMENDATIONS

The scale's validity and reliability can be reassessed across different universities, age groups, and educational levels. Validation can thus be conducted using various samples. Moreover, Future studies may be conducted to test the scale's measurement invariance.

LIMITATIONS

One limitation of this study is that the sample exclusively comprises students enrolled in the English preparatory program at a foundation university. This limitation may restrict the generalizability of the findings. A further limitation is the uneven distribution of participants across class levels. The number of participants at the A1 level is markedly higher than at other levels, while those at the B2 level are very scarce.

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**MIDDLE AND HIGH SCHOOL TEACHERS' CURRICULUM LITERACY
AND TEACHER SELF-REGULATION³**

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ABSTRACT

This research aims to examine the levels of curriculum literacy and self-regulation skills of middle and high school teachers. In the study, a descriptive survey model and a quantitative research method were used. Data were collected from 325 teachers working in middle and high schools in the Küçükçekmece district of Istanbul during the 2019–2020 academic year. Of the teachers participating in the study, 194 are middle school teachers, and 131 are high school teachers. Due to the COVID-19 pandemic, data were collected via a Google Form rather than face-to-face interviews. The data collection process utilized the "Personal Information Form," the "Teacher Self-Regulation Scale" developed by Çapa-Aydın, Sungur, and Uzuntiryaki, and the "Curriculum Literacy Scale" for teachers developed by Kahramanoğlu. Data analysis was conducted using an independent t-test. The teachers participating in the study indicated that they fully engaged in self-assessment, goal setting, intrinsic interest, expertise goal orientation, self-instruction, self-evaluation, self-response, and help-seeking, and mostly engaged in emotional control. However, some did not engage in performance goal orientation. Teachers stated that they are quite proficient in the foundations, elements, and structural features of the curriculum, as well as in curriculum literacy. The structural characteristics of the curriculum for teachers working in middle schools are higher than those for teachers working in high schools. However, it was determined that the "foundations of the curriculum," "elements of the curriculum," and the overall scale do not differ across school types. The research was conducted at the middle school and high school levels. The same research can also be applied at the preschool, elementary school, and even university levels. The study employed convenience sampling. Future studies can be designed using more comprehensive sampling methods to yield more generalizable results.

Keywords: Curriculum, Teacher Self-Regulation, Program Development, Program Literacy

**ORTAOKUL VE LİSE ÖĞRETMENLERİNİN ÖĞRETİM PROGRAMI OKURYAZARLIĞI
İLE ÖĞRETMEN ÖZDÜZENLEMESİ**

ÖZET

Bu araştırmanın amacı, ortaokul ve lise öğretmenlerinin öğretim programı okuryazarlığı düzeyleri ile öğretmen özdüzenleme becerilerinin incelenmesidir. Çalışmada nicel araştırma yöntemlerinden biri olan betimsel tarama modeli kullanılmıştır. Veriler 2019-2020 öğretim yılı içerisinde İstanbul ilinin Küçükçekmece ilçesinde ortaokul ve liselerde görev yapan 325 öğretmenden toplanmıştır. Araştırmaya katılan öğretmenlerden 194 kişi ortaokul öğretmeni ve 131 kişi ise lisede görev yapan öğretmenlerdir. Verilerin toplanmasında yüz yüze veri toplamak yerine, veriler COVID-19 pandemisi nedeniyle Google Form üzerinden toplanmıştır. Verilerin toplanmasında “Kişisel Bilgi Formu”, Çapa-Aydın, Sungur ve Uzuntiryaki tarafından geliştirilen “Öğretmenlerin Öz Düzenleme Ölçeği” ve Kahramanoğlu tarafından

³ Bu çalışma ikinci yazarın danışmanlığında birinci yazar tarafından hazırlanan tezsiz yüksek lisans projesinden üretilmiştir. This study was derived from a master's thesis completed by the first author under the supervision of the second author.

geliştirilen öğretmenlerin “Öğretim Programı Okuryazarlığı Ölçeği” kullanılmıştır. Veri analizi: Veri analizi bağımsız t testi ile yapılmıştır. Çalışmaya katılan öğretmenler öz değerlendirmelerinden hedef belirlemeye, içsel ilgiye, uzmanlık hedef oryantasyonuna, öz talimata, öz değerlendirmeye, öz tepkiye, yardım aramaya tümüyle; duygusal kontrole çoğunlukla katıldıklarını, performans hedefi yönelimine bir bölümüyle katılmadıklarını belirtmişlerdir. Öğretmenler öğretim programının temellerine, öğretim programının öğelerine, öğretim programının yapısal özelliklerine ve genel olarak öğretim programı okuryazarlığına yönelik oldukça yeterli olduklarını belirtmişlerdir. Okulda görev yapan öğretmenlerin öğretim programının yapısal özellikleri lisede görev yapan öğretmenlerden daha yüksektir. Buna karşın, “öğretim programının temelleri”, “öğretim programının öğeleri” ve ölçek toplamında okul türüne göre farklılık göstermediği tespit edilmiştir. Araştırma ortaokul ve lise düzeyinde yapılmıştır. Aynı araştırma okul öncesi, ilkokul ve hatta üniversite kademelerinde de uygulanabilir. Araştırma kolayda örnekleme yapılmıştır. Daha kapsamlı örnekleme yöntemleri ile daha genellenir sonuçlar elde edilecek çalışmalar tasarlanabilir.

Anahtar Kelimeler: Öğretim Programı, Öğretmen Öz düzenlemesi, Program Geliştirme, Program Okuryazarlığı.

INTRODUCTION

Teaching, which contributes to learning in schools, is a crucial activity carried out by teachers. One of the primary reference documents guiding teachers during instruction is the curriculum. Achieving the objectives outlined in the curriculum depends on the teacher's understanding of it. Additionally, teachers must possess the skills to plan, design, and implement the teaching process independently. A teacher's ability to understand the curriculum is related to their “curriculum literacy.” Yılmaz and Kahramanoğlu state that if teachers are curriculum literate, they can understand the curriculum's objectives and, consequently, its other components (Yılmaz & Kahramanoğlu, 2021, p. 179). The ability to recognize curricula, develop a critical perspective, and provide commentary on the implementation process can be considered curriculum literacy (Keskin, 2020, cited in Yılmaz & Kahramanoğlu, 2021, p. 179). Curriculum literacy is a teacher's ability to understand and analyze the curriculum using higher-order thinking skills. Teachers who are curriculum literate can understand the official curriculum. In other words, for curricula to be reflected in the teaching-learning process, teachers must understand and interpret them. This, in turn, depends on teachers being curriculum literate (Kahramanoğlu, 2019, p. 829).

In recent years, teacher self-regulation has emerged in the literature as a characteristic that influences teaching quality. Teacher self-regulation refers to the strategies teachers use to manage their teaching environments. Accordingly, teacher self-regulation can be viewed as an active process through which teachers direct and sustain their own metacognitive abilities, motivation, and effective teaching strategies. In short, teacher self-regulation is the process by which teachers effectively plan, manage, and sustain their metacognitive abilities, strategies, and motivation (Capa-Aydın, Sungur, & Uzunıtyaki, 2009, p. 346).

Curriculum literacy requires teachers to be both knowledgeable and skilled. Additionally, they must develop strong self-regulation to effectively utilize their knowledge and skills. A teacher's ability to organize, plan, and implement the teaching process by following the curriculum's steps will facilitate students' achievement of their goals. It is assessed that, in addition to being curriculum literate to understand the curriculum for successful teaching, teachers must also possess teacher self-regulation to implement it. In this context, the research problem is: “What are the levels of curriculum literacy and teacher self-regulation among middle school and high school teachers?” Additionally, the study sought answers to the following questions:

1. What are the levels of curriculum literacy and teacher self-regulation among middle school and high school teachers?
2. Do the levels of curriculum literacy and teacher self-regulation among middle school and high school teachers differ significantly according to the type of school they work at?

METHOD

In this study, the descriptive survey model is used as a quantitative research method. The survey model is a research method that examines a sample representative of a large population. This model allows for research in a manner suitable for both univariate and correlational analysis (Karasar, 2008). Data regarding middle school and high school teachers' curriculum literacy and teacher self-regulation were collected, the current situation was identified, and these two teacher characteristics were described.

Study Group

The study population consists of 3,753 teachers working in middle and high schools in the Küçükçekmece district of Istanbul during the 2019–2020 academic year. Calculations determined the sample size to be 349; to enhance the study's power, a target of 700 participants (double the sample size) was set, but due to the COVID-19 pandemic, the study was completed with 346 participants. Of these, 145 were high school teachers, and the remaining 201 were middle school teachers. Since 21 teachers did not complete the survey, they were excluded from the analysis, and the study was conducted based on responses from 325 teachers. The study group consisted of 162 (49.8%) women and 163 (50.2%) men, 22 (6.9%) married and 99 (30.5%) single, 194 (59.7%) middle school teachers and 131 (40.3%) high school teachers.

Table 1: Demographic Characteristics of Teachers Participating in the Study

Demographic characteristics		Frequency	Percentage
Gender	Female	162	49.8
	Male	163	50.2
School Type	Middle School	194	59.7
	High School	131	40.3
Marital Status	Married	226	69.5
	Single	99	30.5
Total		325	100

The study group consists of 162 (49.8%) women and 163 (50.2%) men, 226 (69.5%) are married, and 99

(30.5%) single, 194 (59.7%) middle school teachers and 131 (40.3%) high school teachers.

Data Collection Tools

The "Teachers' Self-Regulation Scale," developed by Capa-Aydın, Sungur, and Uzuntiryaki (2009), was used as the primary data collection tool. The six-point Likert-type scale is rated as follows: (1) Strongly Disagree, (2) Mostly Disagree, (3) Partially Disagree, (4) Partially Agree, (5) Mostly Agree, and (6) Strongly Agree. Items (2, 8, 14, 24, 28, 30) of the scale pertain to goal setting; items (45, 46, 47, 48, 49) pertain to intrinsic interest; items (36, 39, 40, 41, 43) pertain to performance goal orientation; (37, 38, 42, 44) items: expertise goal orientation; (3, 11, 18, 25) items: self-direction; (7, 9, 16, 33, 35) items: emotional control; (15, 19, 29, 34) items: self-evaluation; (4, 6, 12, 22) items: self-reaction; (17, 21, 27) items: help-seeking, comprising nine subscales. Cronbach's alpha coefficients were .86 for the goal-setting subscale, .85 for the intrinsic interest subscale, .78 for the performance goal orientation subscale, .67 for the mastery goal orientation subscale, .78 for the self- instruction subscale, .73 for the emotional control subscale, .62 and .66 for the self-reaction subscale, and .78 for the help-seeking subscale. In this study, Cronbach's alpha coefficients were found to be .78 for the goal-setting subscale, .72 for the intrinsic interest subscale, .81 for the performance goal orientation subscale, .61 for the expertise goal orientation subscale, .63, .72 for the emotional control subscale, .56 for the self-evaluation subscale, .60 for the self-reaction subscale, and .75 for the help-seeking subscale. Based on the results, the scale is reliable and suitable for research, as indicated by the sample data.

The scale developed by Kahramanoğlu (2019) to determine teachers' competency levels regarding curriculum literacy was used. The scale was designed as a 5-point Likert scale. The scale was rated as follows: (5) very competent, (4) quite competent, (3) competent, (2) incompetent, (1) not at all

competent. There are no reverse-scored items in the scale. The scale's KMO value was found to be .911, and the Bartlett test was determined to be statistically significant ($\chi^2 = 2778.876$, $df = 253$, $p < .01$). The scale consists of a three-factor structure explaining 50.34% of the total variance. The Cronbach's Alpha coefficient for the first dimension, consisting of 7 items, is .80; for the second dimension, consisting of 8 items, the Cronbach's Alpha coefficient was .84; for the third dimension, consisting of 8 items, the Cronbach's Alpha coefficient was .80; and for the total scale, the Cronbach's Alpha coefficient was .92. In this study, the Cronbach's alpha coefficients were calculated as .92 for the "Foundations of the Curriculum" subscale, .93 for the "Elements of the Curriculum" subscale, .93 for the "Structural Characteristics of the Curriculum" subscale, and .97 for the total scale. Based on the results, the scale is reliable and suitable for use in research based on the sample data.

Data Analysis

The 6-point Likert scale prepared for the teachers' self-regulation scale was divided into six equal parts, and the corresponding score ranges for each option were as follows: 1–1.83 "strongly disagree"; 1.84–2.67 "mostly agree"; 2.68–3.50 for "partially disagree"; 3.51–4.33 for "partially agree"; 4.34–5.16 for "mostly agree"; and 5.17–6.00 for "strongly agree"; The 5-point Likert scale developed to determine teachers' proficiency levels regarding curriculum literacy is divided into five equal parts, with the corresponding score ranges as follows: 1–1.79 "not at all proficient"; 1.80–2.59 "not very proficient"; 2.60–3.39 as "sufficient"; 3.40–4.19 as "quite sufficient"; and 4.20–5.00 as "very sufficient." To determine whether the data followed a normal distribution, skewness and kurtosis were examined; the results are presented in Tables 2 and 3.

Table 2. Skewness and Kurtosis Values for the Teachers' Self-Regulation Scale

Dimensions	<i>N</i>	<i>M</i>	<i>SD</i>	Skewness		Kurtosis	
				Value	SEM	Value	SEM
Target Setting	325	5.20	.52	-.173	.135	-.454	.270
Intrinsic Interest	325	5.47	.54	-1.215	.135	1.179	.270
Performance Target	325	3.41	1.06	-0.175	.135	-0.597	.270
Specialization Goal	325	5.42	.55	-.899	.135	.435	.270
Self-Directed Learning	325	5.28	.52	-.587	.135	.661	.270
Emotional Control	325	4.86	.60	-.392	.135	.668	.270
Self-Assessment	325	5.21	.49	-.425	.135	.586	.270
Self-Reaction	325	5.22	.64	-1.060	.135	1.272	.270
Search for Help	325	4.87	.74	-.455	.135	.035	.270

As shown in Table 2, the normality test for the teachers' scores in the sample group on the self-regulation scale indicates that the kurtosis and skewness values are within the ± 1.5 range.

Table 3. Skewness and Kurtosis Values of the Scale for Determining Teachers' Competence Levels in Curriculum Literacy

Dimensions	N	M	SD	Skewness		Kurtosis	
				Value	SEM	Value	SEM
Foundations of the Curriculum (FC)	325	3.52	.69	.127	.135	-.734	.270
Curriculum Components (CC)	325	3.64	.71	.287	.135	-.874	.270
Structural Characteristics of the Curriculum (SCC)	325	3.51	.77	.099	.135	-.798	.270
Total Scale (TS)	325	3.56	.69	.216	.135	-.799	.270

As shown in Table 3, the normality test conducted to assess the normal distribution of the teachers' scores in the sample group on the scale measuring their proficiency in curriculum literacy indicates that the values of kurtosis and skewness are within the ± 1.5 range. According to Tabachnick and Fidell (2013), skewness and kurtosis values within the ± 1.5 range are considered acceptable for normality. Based on this statement, the scale scores were assumed to be normally distributed, and the analyses were conducted accordingly. Means and standard deviations were calculated for both scales and their subscales, and an independent samples t-test was used to analyze group differences.

FINDINGS

Findings and Interpretation Regarding the First Sub-Problem of the Study

The data obtained regarding the first sub-problem of the study, “What is the level of curriculum literacy and teacher self-regulation among middle school and high school teachers?” are presented below.

Table 4: Arithmetic Mean and Standard Deviation Values for the Subdimensions of the Teacher Self-Regulation Scale

Dimensions	N	M	SD
Goal Setting	325	5.20	.52
Intrinsic Interest	325	5.47	.54
Performance Goal Orientation	325	3.41	1.06
Expertise Goal Orientation	325	5.42	.55
Self-Directed Learning	325	5.28	.52
Emotional Control	325	4.86	.60
Self-Assessment	325	5.21	.49
Self-Reaction	325	5.22	.64
Help Search	325	4.87	.74

As shown in Table 4, when examining the subscales of the teachers' self-assessment scale, the mean score for the “goal setting” subscale was 5.20; the mean score for the “intrinsic interest” subscale was 5.47; the mean score for the “performance goal orientation” subscale was 3.41, the mean score for the “expertise goal orientation” subscale was 5.42, the mean score for the “self- instruction” subscale was

5.28, the mean score for the “emotional control” subscale was 4.86, the mean score for the “self-evaluation” subscale was 5.21, the mean score for the “self-response” subscale was 5.22, and the mean score for the “help-seeking” subscale was 4.87. Based on these findings, teachers indicated that they fully agreed with self-assessment, goal setting, intrinsic interest, expert goal orientation, self-instruction, self-evaluation, self-response, and help-seeking; they mostly agreed with emotional control; and they partially disagreed with performance goal orientation.

Table 5: Arithmetic Mean and Standard Deviation Values for the Subdimensions of the Scale Determining Teachers’ Competence Levels Regarding Curriculum Literacy

Dimensions	N	M	SD
Foundations of the Curriculum (FC)	325	3.52	.69
Elements of the Curriculum (EC)	325	3.64	.71
Structural Characteristics of the Curriculum (SCC)	325	3.51	.77
Total Scale (TS)	325	3.56	.69

As shown in Table 5, when examining the scale and subscales used to determine teachers’ competency levels regarding curriculum literacy, the mean score for the “foundations of the curriculum (FC)” subscale was 3.52; the mean score for the “Elements of the Curriculum (EC)” subscale was 3.64; the mean score for the “structural characteristics of the curriculum (SCC)” subscale was 3.51; and the mean score for the total scale (TS) was 3.56. Based on these findings, teachers indicated they were quite competent in the fundamentals, elements, structural characteristics, and general curriculum literacy.

Findings and Interpretation Regarding the Second Sub-Problem of the Study

The data obtained regarding the second sub-problem of the study, “Do teachers’ self-regulation skills and curriculum literacy levels differ significantly according to the school type variable?” are presented in Table 6.

Table 6: t-Test Results for Teachers’ Self-Regulation Scale Subscale Scores by School Type Groups

Dimensions	Groups	N	M	SD	SEM	t test		
						t	df	p
Goal Setting	Middle	194	5.22	.49	.04	.945	323	.345
	High School	131	5.16	.56	.05			
Internal Motivation	Middle	194	5.46	.53	.04	-.254	323	.800
	High School	131	5.48	.55	.05			
Performance Goal Orientation	Middle	194	3.21	1.03	.07	-4.064	323	.000
	High School	131	3.69	1.03	.09			
Expertise Goal Orientation	Middle	194	5.41	.54	.04	-.385	323	.701
	High School	131	5.44	.57	.05			

Self-Instruction	Middle	194	5.32	.48	.03	1.702	323	.090
	High School	131	5.22	.55	.05			
Emotional Control	Middle School	194	4.81	.64	.05	-1.677	323	.094
	High School	131	4.92	.54	.05			
Self-Assessment	Middle	194	5.21	.46	.03	.141	323	.888
	High School	131	5.21	.53	.05			
Self-Report	Middle	194	5.21	.59	.04	-.357	323	.721
	High School	131	5.24	.71	.06			
Search for Help	Middle	194	4.88	.74	.05	.457	323	.648
	High School	131	4.84	.75	.07			

As shown in Table 6, the results of the independent samples t-test conducted to determine whether there was a significant difference in teachers' mean self-regulation scale scores based on the school Type variable revealed a significant difference in favor of high school teachers between the scores of the performance goal orientation subscale [$t(323) = -4.064$; $p < .05$], a significant difference was found in favor of high school teachers. According to the results, high school teachers have higher performance goal orientation and self-regulation than middle school teachers. In contrast, no significant differences were found in the goal setting subscale [$t(323) = .945$; $p > .05$], the intrinsic interest subscale [$t(323) = -.254$; $p > .05$], the expertise goal orientation subscale [$t(323) = -.385$; $p > .05$], the self-instruction subscale [$t(323) = 1.702$; $p > 0.05$], the emotional control subscale [$t(323) = -1.677$; $p > .05$], the self-evaluation subscale [$t(323) = .141$; $p > .05$], self-reaction subscale [$t(323) = -.357$; $p > .05$], and help-seeking subscale [$t(323) = .457$; $p > .05$], an independent groups t-test was conducted based on teachers' school type; the results indicated that the differences between the groups were not significant.

Table 7: Results of the t-Test for the Scores of the Subdimensions of the Scale for Determining Teachers' Competence Levels in Curriculum Literacy, by School Type Groups

Dimensions	Groups	N	M	SD	SEM	t test		
						t	df	p
Foundations of the Curriculum (FC)	Middle School	194	3.57	.67	.05	1.638	323	.102
	High School	131	3.44	.71	.06			
Curriculum Components (CC)	Middle School	194	3.68	.69	.05	1.159	323	.247
	High School	131	3.58	.73	.06			
Structural Characteristics of the Curriculum (SCC)	Middle School	194	3.60	.71	.05	2.546	323	.011
	High School	131	3.38	.85	.07			
Total Scale (TS)	Middle School	194	3.62	.65	.05	1.904	323	.058
	High School	131	3.47	.74	.06			

As shown in Table 7, an independent-samples t-test was conducted to determine whether there was a significant difference in the mean scale scores on the curriculum literacy competency scale across school types. The results revealed a significant difference in favor of teachers working in middle schools on the "structural characteristics of the curriculum (SCC)" subscale [$t(323) = 2.546$; $p < .05$]. According to the results, middle school teachers scored higher on the structural characteristics of the curriculum than high school teachers. In contrast, for the "Foundations of the Curriculum" (FC) subscale [$t(323) = 1.638$; $p > .05$], the "Elements of the Curriculum" (EC) subscale [$t(323) = 1.159$; $p > .05$], and the total scale score [$t(323) = 1.904$; $p > .05$] were found to show no significant differences between the groups.

RESULTS AND RECOMMENDATIONS

Analysis of the research findings revealed that middle school and high school educators exhibit elevated levels of self-regulation abilities and curricular literacy. Upon evaluating the subscales of the "Teacher Self-Regulation Scale," middle school and high school educators expressed complete agreement with "goal setting," "internal motivation," "expertise goal orientation," "self-instruction," "self-evaluation," "self-response," and "seeking help," as well as "emotional control"; conversely, they exhibited partial disagreement with "performance goal orientation." Analysis of the sub-dimensions of the "Curriculum Literacy Scale" revealed that middle school and high school educators demonstrated high proficiency in "the fundamentals of the curriculum," "the elements of the curriculum," "the structural characteristics of the curriculum," and overall curriculum literacy.

The self-regulation skills and curriculum literacy levels of middle school and high school teachers were determined as follows, according to the school type variable: When considering the sub-dimensions of the "Teacher Self-Regulation Scale," a significant difference in "performance goal orientation" was found in favor of high school teachers. According to the results, high school teachers' "performance goal-oriented self-regulation" is higher than that of middle school teachers. In contrast, it was found that "goal setting," "intrinsic interest," "expertise goal orientation," "self-instruction," "emotional control," "self-evaluation," "self-response," and "seeking help" did not differ based on the type of school where teachers were employed. According to the findings, middle school teachers scored higher on the "structural characteristics of the curriculum" than high school teachers. In contrast, no differences were found by school type for "foundations of the curriculum," "elements of the curriculum," or the total scale score.

A review of the literature revealed no comprehensive study examining the relationship between middle and high school teachers' self-regulation skills and their levels of curriculum literacy. Studies on this topic could be conducted based on various variables such as age, the most recent educational institution attended, years of professional experience, employment status, etc. The study is limited to the Küçükçekmece district of Istanbul. For this reason, it is recommended that the study be replicated across different provinces or districts, using different samples. Since teacher self-regulation and curriculum literacy are important for all teachers, the study can be applied nationwide in Turkey. The study was conducted at the middle school and high school levels. The same study could also be applied at the preschool, elementary school, and even university levels. Convenience sampling was used in this study. Studies designed with more comprehensive sampling methods could yield more generalizable results.

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**STRATEGIC APPROACHES TO SUSTAINABLE AVIATION EDUCATION: A
THEORETICAL ANALYSIS OF GLOBAL POLICY FRAMEWORKS**

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ABSTRACT

In line with global sustainability goals, the aviation industry is redefining its environmental responsibilities and necessitating the transformation of education systems. Contemporary aviation education requires a comprehensive approach that goes beyond the mere transfer of technical knowledge, incorporating multidimensional components such as environmental awareness, digital competencies, and behavioral change. The limited number of studies in the literature addressing the systematic integration of these components into educational policies and curricula is noteworthy. This study aims to identify the fundamental elements of sustainable aviation education and to explain pathways for their integration into educational policies. The research is based on a systematic document analysis and comparative examination of policy documents and strategic frameworks published by international regulatory bodies, including International Civil Aviation Organization, European Union Aviation Safety Agency, Federal Aviation Administration, and International Air Transport Association. The findings indicate that sustainability within regulatory documents is not limited to reducing environmental impact, but is also directly associated with operational continuity, workforce resilience, and digital transformation. The study proposes six key approaches for sustainable aviation education: Digital Learning Ecosystems, Simulation-Based Learning, AR/VR-Supported Training, Green Campus and Educational Infrastructure, Sustainability-Oriented Curriculum, and Student Behavior Models. These approaches provide a framework for aviation education institutions to formulate consistent and systematic transformation strategies aligned with sustainable development goals.

Keywords: Sustainability, aviation education, simulation, digital learning, green campus, AR/VR, emission reduction

**SÜRDÜRÜLEBİLİR HAVACILIK EĞİTİMİ İÇİN STRATEJİK YAKLAŞIMLAR:
KÜRESEL POLİTİKA ÇERÇEVELERİ ÜZERİNE KURAMSAL BİR ANALİZ**

ÖZET

Küresel sürdürülebilirlik hedefleri doğrultusunda, havacılık endüstrisi çevresel sorumluluklarını yeniden tanımlamakta ve eğitim sistemlerinin dönüşümünü zorunlu kılmaktadır. Mevcut havacılık eğitimi, yalnızca teknik bilginin aktarılmasının ötesine geçen, çevresel bilinç, dijital yeterlilik ve davranış değişikliği gibi çok yönlü unsurları içeren kapsamlı bir yaklaşıma ihtiyaç duymaktadır. Literatürde bu unsurların eğitim politikalarına ve müfredatlarına sistematik entegrasyonuna dair araştırmaların sınırlı olması dikkat çekmektedir. Bu çalışma, sürdürülebilir havacılık eğitimi oluşturan temel unsurları belirlemeyi ve bunların eğitim politikalarına entegrasyon yollarını açıklamayı amaçlamaktadır. Çalışma, Uluslararası Sivil Havacılık Örgütü (ICAO), Avrupa Birliği Havacılık Emniyeti Ajansı (EASA), Federal Havacılık İdaresi (FAA) ve Uluslararası Hava Taşımacılığı Birliği

(IATA) gibi uluslararası düzenleyici kuruluşların politika belgeleri ve stratejik çerçevelerinin sistematik belge analizi ve karşılaştırmalı incelemesine dayanmaktadır. Analizler, sürdürülebilirliğin düzenleyici belgelerde sadece çevresel etkiyi azaltma değil, aynı zamanda operasyonel süreklilik, iş gücü dayanıklılığı ve dijital dönüşümle doğrudan ilişkilendirildiğini ortaya koymaktadır. Çalışma, sürdürülebilir havacılık eğitimi için altı temel yaklaşım önermektedir: Dijital Eğitim Ekosistemleri, Simülasyon Tabanlı Öğrenme, AR/VR Destekli Eğitim, Yeşil Kampüs ve Eğitim Altyapısı, Sürdürülebilirlik Odaklı Müfredat ve Öğrenci Davranış Modelleri. Bu yaklaşımlar, havacılık eğitim kurumlarının sürdürülebilir kalkınma hedefleriyle uyumlu, kalıcı ve sistematik dönüşüm stratejileri formüle etmeleri için bir çerçeve sunmaktadır.

Anahtar Kelimeler: Sürdürülebilirlik, havacılık eğitimi, simülasyon, dijital öğrenme, yeşil kampüs, AR/VR, emisyon azaltımı

1. GİRİŞ

Sürdürülebilirlik hedefleri dünya çapında daha önemli hale geldikçe, havacılık endüstrisi çevresel sorumlulukları hakkındaki düşünce biçimini değiştiriyor ve hem operasyonel hem de eğitimsel dönüşüm süreçlerine odaklanıyor. Uluslararası Sivil Havacılık Örgütü (ICAO), sürdürülebilir havacılığın yalnızca yeni teknolojilerle değil, aynı zamanda havacılıkta çalışan insanların becerileri ve okulların öğretme biçimindeki değişikliklerle de mümkün olduğunu belirtiyor (ICAO, 2022). Bu bağlamda, sürdürülebilir havacılık eğitimi, yalnızca teknik bilginin aktarılmasının ötesine geçen, çevresel bilinç, dijital yeterlilik, güvenlik odaklı karar verme ve davranış değişikliği gibi çok yönlü unsurları içeren kapsamlı bir yaklaşım gerektiriyor (EASA, 2020; UNESCO, 2017).

Son politika belgeleri ve akademik araştırmalar, eğitim sistemlerini daha sürdürülebilir hale getirmek için öğretme biçimimizin ve öğrenme yerlerimizin çok önemli olduğunu gösteriyor. Havacılık eğitimini çevreye daha az zararlı hale getirmenin başlıca yollarından biri, dijital öğrenme altyapılarını iyileştirmek, daha fazla simülasyon ve deneyimsel öğrenme yöntemi eklemek ve daha az fiziksel kaynak kullanan eğitim tasarımları kullanmaktır (EUROCONTROL, 2019; Dritsas & Trigka, 2025). Bu yöntemler sadece öğretimi daha etkili hale getirmekle kalmaz, aynı zamanda daha az enerji kullanarak ve daha küçük bir karbon ayak izi bırakarak eğitim ekosistemini daha sürdürülebilir hale getirmeye de yardımcı olur.

Bu bağlamda, bu çalışmanın amacı, literatüre dayalı bir metodoloji aracılığıyla, sürdürülebilir havacılık eğitimini oluşturan temel unsurları ve bu unsurların eğitim politikalarına ve müfredatlarına nasıl entegre edilebileceğini açıklamaktır. Çalışma, sürdürülebilirlik hedeflerinin hem müfredat düzeyinde hem de pedagojik yaklaşımlar, öğrenme ortamları ve kurumsal kapasite (altyapı, teknoloji ve iş birliği çerçeveleri) düzeylerinde eğitime entegre edilmesi gerektiğini öne sürmektedir. Bu yaklaşım, havacılık eğitim kurumlarının sürdürülebilir kalkınma hedefleriyle uyumlu kalıcı ve sistematik dönüşüm stratejileri formüle etmeleri için çok önemlidir (UNESCO, 2017; ICAO, 2022).

2. LİTERATÜR ÖZETİ

Sürdürülebilir havacılık eğitimi, çevresel farkındalığı artırmak, teknolojik yenilikleri teşvik etmek ve sektörde uzun vadeli gelişimi desteklemek amacıyla çok boyutlu bir dönüşüm geçirmektedir. Günümüzde mühendislik ve havacılık programlarına çevre dostu uçuş teknolojileri, yakıt verimliliği, emisyon azaltımı ve gürültü yönetimi gibi sürdürülebilirlik temalarının entegre edilmesi, öğrencilerin çevresel sorumluluk bilincini güçlendirmektedir (Agarwal, 2009). Sürdürülebilir havacılık eğitimi dijitalleşme, yenilikçi pedagojik yaklaşımlar, araştırma temelli öğrenme ve uluslararası iş birlikleri aracılığıyla hızla dönüşmektedir. Havacılık teknik personeli eğitimi artık geleneksel sınıf modellerinden çıkarak e-öğrenme, simülasyon kullanımı ve sanal laboratuvarlar gibi çevre dostu, enerji tasarruflu dijital yöntemlerle desteklenmektedir (Đučo et al., 2020). Pandemi sonrası geliştirilen çevrimiçi havacılık laboratuvarları, öğrencilerin uçuş dinamikleri konusundaki farkındalıklarını artırmış, sürdürülebilir öğrenme ortamlarının yaygınlaşmasına katkı sağlamıştır (Ng, Su & Ng, 2023). İnsan kaynağının niteliği, sürdürülebilir havacılığın başarısında kilit rol oynamaktadır. Colonel (2019), havacılık eğitim kurumlarının bilgi, beceri ve yetkinlik temelli müfredatlar tasarlamasının hem bireylerin çevresel

farkındalığını artırdığını hem de sektörel verimliliği güçlendirdiğini vurgulamaktadır (Colonel, 2019). Ison (2018) ise araştırma temelli öğretim modellerinin, öğrencilerin sürdürülebilirlik ekseninde yenilikçi düşünme ve problem çözme becerilerini geliştirdiğini ortaya koymaktadır (Ison, 2018). Bunun yanında, Kozak ve Wang (2019) tarafından yapılan çalışmada uluslararası değişim programlarının öğrencilerin farklı kültürlerdeki sürdürülebilirlik uygulamalarını tanımlarına ve küresel havacılık ekosistemiyle bütünleşmelerine katkı sağladığı belirtilmektedir (Kozak & Wang, 2019). Bu gelişmeler, sürdürülebilir havacılık eğitiminin gelecekte teknolojiyle desteklenen, disiplinler arası ve kültürlerarası bir yapıya evrileceğini göstermektedir.

Bununla birlikte, mevcut literatür sürdürülebilir havacılık eğitiminin önemini vurgulasa da, bu kavramın eğitim politikalarına ve öğretim programlarına nasıl sistematik biçimde entegre edileceğine dair araştırmaların sınırlı olduğu görülmektedir. Mühendislik ve havacılık alanlarında sürdürülebilirlik genellikle teknik ya da çevresel boyutlarıyla ele alınmakta, ancak pedagojik entegrasyon süreçleri yeterince incelenmemektedir (Rose, Ryan & Desha, 2015). Özellikle, müfredat tasarımı, öğretmen yeterlilikleri ve öğrenme stratejileri açısından sürdürülebilirlik eğitiminin nasıl yapılandırılacağına ilişkin sistematik modellerin eksikliği dikkat çekmektedir (Narong & Hallinger, 2024).

Ayrıca, dijital öğrenme teknolojilerinin öğrencilerin sürdürülebilirlik bilinci üzerindeki uzun vadeli etkileri henüz kapsamlı biçimde değerlendirilmemiştir. Dijital pedagojinin sürdürülebilir öğrenmeye katkı sağlayabileceği vurgulanmakta, ancak bu katkının ölçülmesine yönelik ampirik bulgular sınırlıdır (Nanjundaswamy, Baskaran & Leela, 2021). Öğrencilerin çevresel farkındalık düzeylerinin davranışa dönüşüp dönüşmediğini inceleyen çalışmalarda da benzer bir eksiklik söz konusudur. Özellikle disiplinler arası öğretim tasarımları ve sanal laboratuvar tabanlı sürdürülebilir öğrenme modellerinin etkileri konusunda daha fazla araştırmaya ihtiyaç duyulmaktadır (Garner, Siol & Eilks, 2015).

Son yıllarda yapılan çalışmalar, eğitimle endüstri arasındaki kopukluğun da sürdürülebilirlik odaklı müfredatın etkin uygulanmasını engellediğini göstermektedir. Üniversitelerdeki öğretim programlarının endüstri beklentileriyle tam olarak uyumlu olmadığı, yenilikçi pedagojik uygulamaların ise sınırlı biçimde hayata geçirildiği tespit edilmiştir (Nkolika, 2024). Ayrıca havacılık ve mühendislik alanlarında akademi-sanayi iş birliklerinin pedagojik çıktıları üzerine yapılan araştırmaların yetersizliği, sektörle bütünleşmiş sürdürülebilir eğitim modelleri oluşturmayı zorlaştırmaktadır (Halawi, El Sayed, Miller, White & Dhakal, 2024).

Dolayısıyla gelecekte yapılacak çalışmaların, disiplinler arası öğretim tasarımları, dijital dönüşümün sürdürülebilir öğrenme üzerindeki etkileri ve üniversite-sektör iş birliklerinin müfredat entegrasyonu açısından değerlendirilmesi önerilmektedir. Ayrıca sürdürülebilirlik temalarının öğrencilerde bilişsel farkındalıktan davranışsal dönüşüme ne ölçüde yol açtığını analiz eden uzunlamasına araştırmalar da bu alanın gelişimi için büyük önem taşımaktadır.

3. YÖNTEM

Bu çalışma, teorik bir çerçeve ve karşılaştırmalı analiz metodolojisinin formülasyonu etrafında yapılandırılmıştır. Araştırmada yalnızca kamuya açık belgeler, düzenleyici raporlar ve mevcut literatürden elde edilen ikincil veriler kullanılmıştır; insan katılımcılardan veri toplanmamıştır (ICAO, 2018; Creswell & Creswell, 2018). Sonuç olarak, kullanılan metodolojik çerçeve nitel, tanımlayıcı ve karşılaştırmalıdır. Çalışmanın metodolojisi iki temel unsurdan oluşmaktadır: (i) politika ve eğitim modellerinin karşılaştırmalı analizi ve (ii) belge analizi. Bu yöntemler, politika analizi, sürdürülebilirlik ve düzenlenmiş eğitim sistemlerine odaklanan çalışmalarda yaygın ve kabul görmüş nitel araştırma stratejileridir (Bowen, 2009; Scott, 2014).

Araştırmanın temel amacı, havacılık eğitiminde sürdürülebilirliğin ele alınışını aydınlatmak ve çeşitli uluslararası düzenleyici çerçeveler altında formüle edilen pedagojik yöntemleri sistematik olarak karşılaştırmaktır. Bu amaç için iki aşamalı bir araştırma tasarımı kullanılmıştır. Birinci aşamada, uluslararası düzenleyici kuruluşlar tarafından yayınlanan resmi raporlar, politika belgeleri ve rehber belgelerin sistematik bir belge analizi yapılmıştır. Belge analizi, politika ve eğitim araştırmalarında güvenilir ve sistematik bir nitel yaklaşım olarak kabul edilmektedir (Bowen, 2009). İkinci aşamada ise, farklı düzenleyici çerçevelerin eğitim yaklaşımlarını incelemek için karşılaştırmalı bir analiz yöntemi

kullanılmıştır. Bu yöntem, çerçeveler arasındaki benzerlikleri ve farklılıkları göstermek için seçilmiştir (Ragin, 2014).

Çalışmanın veri kaynakları, üç ana gruba ayrılan anonim, kurumsal ve kamuya açık belgelerden oluşmaktadır. Birinci veri grubu, Uluslararası Sivil Havacılık Örgütü'nün (ICAO) Küresel Hava Seyrüsefer Planı (GANP), sürdürülebilirlik ve çevre koruma çerçeveleri ile eğitim ve yetkinlik geliştirme rehber belgelerini içermektedir. İkinci veri grubu ise Avrupa Birliği Havacılık Güvenliği Ajansı'nın (EASA) politika belgeleri ve düzenleyici yol haritalarından oluşmaktadır. Üçüncü veri seti, Federal Havacılık İdaresi'nin (FAA) NextGen programı kapsamında hazırladığı raporlardan ve Uluslararası Hava Taşımacılığı Birliği'nin (IATA) sürdürülebilirlik, eğitim ve yetkinlik çerçevelerine odaklanan yayınlarından oluşmaktadır. Bu veri setleri birleştirildiğinde, sürdürülebilirlik ve geleceğe yönelik becerilerin dünya çapında havacılık eğitiminde nasıl öğretildiğine dair tam bir tablo sunmaktadır (ICAO, 2022; EASA, 2020; FAA, 2023; IATA, 2021).

Veri analizi, politika ve eğitim odaklı havacılık araştırmalarında sıklıkla uygulanan nitel tematik analizin bir sentezini ve eğitim modellerinin karşılaştırmalı değerlendirmesini içermektedir. Tematik analiz, düzenleyici belgelerde sürdürülebilirlik, dijitalleşme, yetkinlik geliştirme ve pedagojik dönüşümle ilişkili tekrarlayan kalıpların sistematik olarak tanımlanmasını, kodlanmasını ve yorumlanmasını kolaylaştırmıştır (Braun & Clarke, 2006; Bowen, 2009). İlk kodlama aşamasından sonra, oluşturulan temalar, farklı kurumlardan gelen belgelerdeki fikirlerin tutarlı olduğundan emin olmak için tekrar tekrar incelendi. Eş zamanlı olarak, sürdürülebilirlik odaklı eğitim metodolojilerinin çeşitli düzenleyici çerçeveler genelinde havacılık eğitime entegrasyonunu aydınlatmak için karşılaştırmalı bir analiz yapıldı. Tematik analiz ve karşılaştırmalı model değerlendirmesinin birlikte kullanımı, küresel düzenleyici beklentilerin havacılık eğitimindeki yeni trendlerle uyumlu olup olmadığını kontrol etmek için açık ve tutarlı bir yol oluşturmaktadır (Ragin, 2014; Scott, 2014).

4. SÜRDÜRÜLEBİLİR HAVACILIK EĞİTİMİ İÇİN YENİ YAKLAŞIMLAR

Sürdürülebilir havacılık hedeflerine ulaşmada eğitim sistemlerinin rolü kritik öneme sahiptir. Bu bağlamda, geleneksel eğitim modellerinden uzaklaşarak, çevresel etkiyi en aza indiren, teknolojik yeterliliği artıran ve davranışsal dönüşümü teşvik eden bütüncül bir yaklaşım benimsenmelidir. Bu çalışma, havacılık eğitiminde sürdürülebilirliği sağlamak üzere, hem pedagojik hem de kurumsal düzeyde altı temel yenilikçi yaklaşımı önermektedir. Bu yaklaşımlar, eğitim altyapısının dijitalleşmesinden (Dijital Eğitim Ekosistemleri, Simülör Tabanlı Öğrenme, AR/VR Destekli Eğitim) fiziksel çevrenin dönüştürülmesine (Yeşil Kampüs ve Eğitim Altyapısı) ve nihayetinde öğrenme içeriği ile çıktılarının yeniden yapılandırılmasına (Sürdürülebilirlik Odaklı Müfredat, Öğrenci Davranış Modelleri) odaklanmaktadır. Bu bütüncül çerçeve, havacılık profesyonellerinin geleceğin çevresel ve operasyonel zorluklarına karşı donanımlı olmasını sağlamayı amaçlamaktadır.

4.1. Dijital Eğitim Ekosistemleri

Dijital eğitim ekosistemleri, sürdürülebilir havacılık eğitiminin dijital dönüşüm sürecinde en temel altyapı unsurunu oluşturur. Yapay zekâ, büyük veri, bulut sistemleri ve çevrimiçi öğrenme ortamlarının entegrasyonu, kişiselleştirilmiş ve erişilebilir bir öğrenme deneyimi sunar. Dijitalleşme, enerji tüketimini azaltarak ve fiziksel kaynak kullanımını sınırlayarak çevresel sürdürülebilirliğe katkı sağlar (Dritsas & Trigka, 2025). “Smart education” yaklaşımı, öğrencilerin öğrenme verilerinden yararlanarak gerçek zamanlı geri bildirim sağlar, bu da havacılık eğitiminde pilotaj becerileri, meteoroloji ve uçuş planlama gibi konularda bireysel gelişimi hızlandırır (Koshiry & Tony, 2025). Dijital ekosistemler aynı zamanda hibrit ve esnek öğrenme modellerinin uygulanmasını kolaylaştırarak sürdürülebilir öğrenme döngüsünü destekler.

4.2. Simülör Tabanlı Öğrenme

Bu yöntem havacılık eğitiminde hem güvenliği artıran hem de çevresel etkileri azaltan bir yöntemdir. Gerçek uçuşa kıyasla daha düşük karbon ayak iziyle, öğrencilere risk içermeyen bir ortamda uygulama yapma olanağı sağlar. Simülörler, acil durum senaryoları, kriz yönetimi ve uçuş dinamikleri gibi önemli becerilerin geliştirilmesinde etkili bir araçtır (Leiphrakpam, Armijo & Are, 2024). Rizvi ve arkadaşlarının (2025) Kanada'daki genel havacılık eğitimi üzerine yaptığı çalışmada, simülör ve

artırılmış gerçeklik tabanlı cihazların pilot yetkinliği, güvenlik farkındalığı ve öğrenme motivasyonunu önemli ölçüde artırdığı belirlenmiştir (Rizvi et al., 2025). Bu teknolojiler, sürdürülebilir eğitim hedefleriyle uyumlu şekilde kaynak kullanımını azaltırken eğitim kalitesini artırmaktadır.

4.3. AR/VR Destekli Eğitim

Artırılmış (AR) ve sanal gerçeklik (VR) teknolojileri, öğrencilere gerçek uçuş senaryolarını fiziksel risk olmadan deneyimleme fırsatı sunar. Bu teknolojiler, öğrencinin motivasyonunu ve öğrenme kalıcılığını artırırken sürdürülebilirlik temalarını da içselleştirmesini sağlar (Ebinger, Buttke & Kreimeier, 2022). Jevčák ve arkadaşları (2024), VR/AR/MR teknolojilerinin havacılık eğitiminde öğrencilerin uzamsal farkındalık, karar verme ve koordinasyon becerilerini güçlendirdiğini ortaya koymuştur (Jevčák et al., 2024). AR uygulamaları, çevresel farkındalık eğitimlerinde de etkili bulunmuş, öğrencilerin çevreci tutum ve davranışlarını olumlu yönde etkilemiştir (Chen, 2022). Bu teknolojilerin sürdürülebilir havacılıkta kullanımı, enerji tasarrufu sağlayan “virtual flight training” modellerine geçişi hızlandırmaktadır.

4.4. Yeşil Kampüs ve Eğitim Altyapısı

Yeşil kampüs uygulamaları, sürdürülebilir havacılık eğitiminin fiziksel altyapı boyutunu temsil eder. Yenilenebilir enerji kaynakları, çevre dostu binalar, geri dönüşüm sistemleri ve düşük karbon ayak izine sahip tesisler, üniversitelerde sürdürülebilirlik kültürünün bir parçası haline gelmiştir. Bu altyapılar, öğrencilerde çevre bilinci oluştururken kurumların da sürdürülebilir kalkınma hedefleriyle uyumunu güçlendirir. Araştırmalar, “sürdürülebilir eğitim altyapısına” sahip kurumların öğrencilerde çevreye yönelik olumlu davranış değişiklikleri oluşturduğunu göstermektedir (Beheshti et al., 2024). Bu anlayış, havacılık akademilerinde karbon-nötr kampüs hedefiyle birleşerek çevresel eğitimle altyapı yönetimini bütünleştiren bir eğitim imkânı sunar.

4.5. Sürdürülebilirlik Odaklı Müfredat

Çevreye duyarlı davranışların yalnızca teknik değil, aynı zamanda etik ve sosyal boyutlarını da içeren bir öğretim anlayışının benimsenmesi sürdürülebilir müfredatın temelini oluşturmaktadır. AR/VR ve dijital araçlarla desteklenen bu müfredatlar, öğrencilerin deneyimsel öğrenme yoluyla sürdürülebilir kararlar almasını teşvik eder (Algerafi et al., 2023). Eğitimde metaverse tabanlı öğrenme ortamlarının da bu amaca hizmet ettiği ve öğrencilerde uzun vadeli bilişsel dönüşüm sağladığı tespit edilmiştir (Murala, 2024). Bu tür müfredatlar, havacılık sektöründe geleceğin çevre dostu mühendis/teknisyen ve pilotlarının yetişmesini destekleyen pedagojik bir çerçeve sunar.

4.6. Öğrenci Davranış Modelleri

Sürdürülebilir havacılık eğitiminin başarısı, öğrencilerin tutum ve davranış değişimiyle ölçülür. Öğrenme ortamlarında geliştirilen çevresel farkındalık, bireylerin sürdürülebilir davranışa yönelmesini sağlar. Chen (2022)’in AR tabanlı çevre eğitimi çalışmasında, öğrencilerin çevresel tutumlarının doğrudan davranış değişimine yol açtığı belirlenmiştir (Chen, 2022). Benzer şekilde, Lazou ve Tsinakos (2023), artırılmış gerçeklik destekli eğitimin uzun dönemli dikkat, bilişsel farkındalık ve “dijital iyi oluş” üzerinde olumlu etkiler yarattığını ifade etmektedir (Lazou & Tsinakos, 2023). Bu bulgular, sürdürülebilirlik eğitiminde davranışsal dönüşümün teknoloji aracılığıyla güçlendirilebileceğini göstermektedir.

5. BULGULAR

Bu çalışmanın belge analizi ve karşılaştırmalı incelemesi, düzenleyici belgelerde sürdürülebilir havacılık eğitiminin kavramsallaştırılmasını ve tanımlanmış bir öncelik çerçevesi içinde eğitim politikalarında nasıl tezahür ettiğini açıklığa kavuşturmuştur. Sonuçlar, Uluslararası Sivil Havacılık Örgütü (ICAO), Avrupa Birliği Havacılık Güvenliği Ajansı (EASA), Federal Havacılık İdaresi (FAA) ve Uluslararası Hava Taşımacılığı Birliği (IATA)’nın politika belgeleri ve stratejik çerçevelerinin sistematik bir incelemesinden elde edilmiştir.

İncelenen düzenleyici belgeler, sürdürülebilirliği yalnızca çevresel etkileri en aza indirme açısından değil, aynı zamanda operasyonel süreklilik, iş gücü dayanıklılığı, dijital dönüşüm ve sistem

uyarlanabilirliği ile doğrudan ilişkilendirerek ele almaktadır. ICAO'nun Küresel Hava Seyrüsefer Planı'na (GANP) göre, sürdürülebilirlik, küresel hava trafik yönetim sisteminin kapasitesi, güvenliği ve verimliliği için uzun vadeli hedeflerin önemli bir parçasıdır. Eğitim, bu hedeflere ulaşmanın stratejik bir yolu olarak görülmektedir (ICAO, 2022). EASA belgeleri de sürdürülebilir bir ATM yapısının ancak insan faktörlerini ve beceri gelişimini önceliklendiren eğitim sistemleriyle mümkün olduğunu vurgulamaktadır (EASA, 2020).

Karşılaştırmalı analiz, dijital öğrenme ortamlarının, simülasyon tabanlı öğrenmenin ve gelişmiş eğitim teknolojilerinin, düzenleyici çerçeveler içinde yalnızca destekleyici pedagojik araçlar olarak değil, sistemik zorunluluklar olarak görüldüğünü göstermektedir. ICAO ve EASA belgeleri, simülasyonların operasyonel riski azalttığı, eğitim kaynaklarından en iyi şekilde yararlandığı ve çevresel etkileri sınırladığı için eğitimin önemli bir parçası olduğunu belirtmektedir (ICAO, 2018; EASA, 2020). FAA'nın NextGen raporları, otomasyonun farkında olmak, verilere dayalı kararlar almak ve karmaşık hava sahasını yönetmek gibi yeni becerileri öğrenmek için dijital ve simülasyon tabanlı eğitim yöntemlerinin çok önemli olduğunu açıkça ortaya koymaktadır (FAA, 2023).

Tematik analiz sonuçları, yetkinlik tabanlı eğitim yaklaşımının tüm düzenleyici çerçevelerde birleştirici bir unsur oluşturduğunu göstermektedir. ICAO'nun Hava Trafik Kontrolörü Yetkinlik Çerçevesi, eğitimin yalnızca bilgi aktarmakla ilgili olmaması, aynı zamanda ölçülebilir performans sonuçları ve davranışsal beceriler yaratmakla ilgili olması gerektiğini belirtmektedir (ICAO, 2018). EASA ve FAA belgeleri de bu fikri destekleyerek, insan-sistem etkileşimini geliştiren ve stres yönetimi ile bilişsel iş yükü farkındalığını öğreten eğitim modellerinin, kalıcı ATM sistemleri oluşturmanın tek yolu olduğunu göstermektedir (EASA, 2020; FAA, 2023). IATA yayınları, bu becerilerin sektördeki işleyiş biçimiyle yakından bağlantılı olması gerektiğini ve eğitim, operasyonlar ve sürdürülebilirliğin birlikte nasıl çalıştığına odaklanılması gerektiğini vurgulamaktadır (IATA, 2021).

Sonuçlar, şirketlerin sürdürülebilirlik ve eğitim hedefleri konusunda çok benzer fikirlere sahip olduğunu, ancak bu fikirleri farklı seviyelerde uyguladıklarını göstermektedir. ICAO daha genel ve ilkeli tavsiyeler verirken, EASA belgeleri belirli alanlarda kullanılmak üzere daha spesifik ve pratik tavsiyeler vermektedir. FAA'nın yaklaşımı teknoloji ve otomasyona dayanmaktadır ve dijitalleşmeyi eğitim tasarımının önemli bir parçası olarak görmektedir. IATA bir düzenleyici kuruluş değildir; bunun yerine, belirli sektörlerdeki uygulamalara odaklanan farklı bir bakış açısı sunmaktadır. Bu, sürdürülebilir havacılık eğitiminin dünyanın her yerinde aynı hedeflere sahip olmasına rağmen, ilgili kişilerin ve kuruluşların kaynaklarına ve becerilerine bağlı olarak farklı şekillerde yürütüldüğü anlamına gelir. Sonuç olarak, tematik ve karşılaştırmalı analizlerin kapsamlı değerlendirmesi, sürdürülebilirlik hedeflerinin düzenleyici belgelerde açıkça ifade edildiğini ve havacılık eğitiminin bu hedeflerin gerçekleştirilmesinde çok önemli olduğunu göstermektedir. Bununla birlikte, sonuçlar ayrıca düzenleyici beklentileri eğitim uygulamalarına dönüştürmek için daha yapılandırılmış, ölçülebilir ve izlenebilir yöntemlere ihtiyaç duyduğumuzu da göstermektedir. Sonuçlar, sürdürülebilir havacılık eğitiminin kavramsal olarak ilerlediğini; ancak uygulama aşamasında kurumsal kapasite, teknolojik altyapı ve pedagojik standartlarda iyileştirmelere ihtiyaç duyulduğunu göstermektedir.

6. SONUÇ VE ÖNERİLER

Bu çalışma, havacılık eğitime ilişkin sürdürülebilirlik kavramını, uluslararası düzenleyici çerçeveleri ve çağdaş eğitim metodolojilerini dikkate alarak kapsamlı bir bakış açısıyla analiz etmektedir. Belge analizi ve karşılaştırmalı değerlendirmeler, sürdürülebilir havacılık eğitiminin yalnızca çevresel etkilerin azaltılmasına öncelik vermekle kalmayıp, dijital dönüşüm, iş gücü dayanıklılığı, sistem uyarlanabilirliği ve operasyonel süreklilik gibi çok yönlü hedefleri de içerdiğini göstermektedir. Bu bağlamda, eğitim, sürdürülebilir havacılık sistemlerinin kalıcı başarısı için stratejik bir araç olarak kabul edilmektedir.

Araştırma sonuçları, ICAO, EASA, FAA ve IATA tarafından geliştirilen eğitim ve politika çerçevelerinin ağırlıklı olarak benzer yönelimleri yansıttığını göstermektedir. Yetkinliğe dayalı eğitim, dijitalleşme ve insan-sistem dayanıklılığı, tüm düzenleyici çerçevelerde yaygın olan merkezi temalar olarak kabul edilmektedir. Ancak bu ortak hedeflerin hayata geçirilme biçimi, bölgeye, kuruma ve teknolojiye göre değişmektedir. ICAO'nun daha ilkeli ve küresel bir çerçeve sağladığı, EASA'nın

bölgesel uygulamalar için daha spesifik yönergeler formüle ettiği ve FAA'nın teknoloji ve otomasyona odaklanan bir eğitim metodolojisi kullandığı belirtilmektedir. Öte yandan IATA, sektörel uygulamaları kullanarak eğitim, operasyonlar ve sürdürülebilirlik arasındaki ilişkiye farklı bir açıdan bakmaktadır.

Dijital eğitim ekosistemleri, simülatör tabanlı öğrenme, AR/VR destekli uygulamalar ve yeşil kampüs altyapıları, sürdürülebilir havacılık eğitiminin hem öğretim hem de çevresel yönlerini iyileştiren önemli araçlardır. Bu yöntemler, öğrenme kalitesini artırırken ve öğrencilerin çevre için iyi davranışlar geliştirmelerine yardımcı olurken daha az kaynak kullanır. Deneyimsel ve teknoloji destekli öğrenme modelleri, bilişsel farkındalıktan davranışsal dönüşüme geçişi kolaylaştırmada özellikle etkili olarak kabul edilmektedir.

Sonuç olarak, sürdürülebilirlik hedeflerinin havacılık ve ATC eğitimine kavramsal düzeyde çoğunlukla dahil edildiği açıktır. Bununla birlikte, bu entegrasyonun uygulama düzeyinde daha sistematik, ölçülebilir ve kurumsallaşmış çerçevelerle desteklenmesi gerekmektedir. Sonraki araştırmalar, sürdürülebilirlik odaklı eğitim modellerinin kalıcı eğitimsel sonuçlarını ve davranışsal etkilerini nicel ve karma metodolojiler aracılığıyla incelemelidir. Ayrıca, üniversite-sanayi iş birliklerinin müfredat entegrasyonundaki rolünün derinlemesine analizi, bu disiplinin ilerlemesini önemli ölçüde hızlandıracaktır.

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**EMERGENCY MANAGEMENT IN AIRPORTS IN RELATION TO AIR TRAFFIC
CONTROL: A HUMAN FACTORS-BASED ASSESSMENT**

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ABSTRACT

This study aims to systematically examine emergency management at airports caused by air traffic control (ATC) from a human factors perspective. A qualitative research approach was adopted, and data was collected using document analysis. In this context, academic studies and documents from international aviation regulatory organizations were used as primary data sources. The analysis was conducted across four main risk categories: apron accidents, runway incursions, maintenance-related emergencies, and ground services-related incidents. The findings indicate that organizational and managerial factors play a more decisive role in the occurrence of ATC-related unsafe actions compared to individual errors. In particular, communication breakdowns between pilots and air traffic controllers were identified as a critical causal factor in runway incursions. Furthermore, the high mental workload, fatigue, and loss of situational awareness experienced by controllers emerged as the primary individual risk factors limiting operational performance during emergencies. This situation highlights that current operational structures cannot be sustained solely based on human performance. The study reveals that the traditional Safety-I approach, which focuses solely on error prevention, is insufficient for explaining complex and dynamic airport operations and must be supported by the Safety-II approach, which centers on system resilience. In conclusion, this study moves beyond the perspective of human error in HTK-related emergency management, addressing the organizational and technological dimensions within a holistic framework, and offers a unique contribution regarding UAV-HTK integration—a topic that has received limited attention in the literature. In this regard, it is recommended to develop simulation-based, problem-oriented, and UAV-supported training approaches aimed at restructuring organizational processes and enhancing controllers' adaptability.

Keywords: Air Traffic Control, Emergency Management, Aviation Safety, Human Factors

**HAVAALANLARINDA HAVA TRAFİK KONTROL KAYNAKLI ACİL DURUM
YÖNETİMİ: İNSAN FAKTÖRLERİ TEMELLİ BİR DEĞERLENDİRME**

ÖZET

Bu çalışma, havaalanlarında hava trafik kontrol (HTK) kaynaklı acil durum yönetimini insan faktörleri perspektifinden sistematik olarak incelemeyi amaçlamaktadır. Araştırmada nitel araştırma yaklaşımı benimsenmiş ve doküman analizi yöntemiyle veri toplanmıştır. Bu kapsamda akademik çalışmalar, uluslararası havacılık düzenleyici kuruluşlarının dokümanları temel veri kaynakları olarak ele alınmıştır. Analiz; apron kazaları, pist ihlalleri, bakım kaynaklı acil durumlar ve yer hizmetleri kaynaklı olaylar olmak üzere dört ana risk kategorisi üzerinden yürütülmüştür. Elde edilen bulgular, HTK kaynaklı

emniyetsiz eylemlerin oluşumunda organizasyonel ve yönetsel faktörlerin, bireysel hatalara kıyasla daha belirleyici olduğunu göstermektedir. Özellikle pist ihlallerinde pilot-kontrolör iletişimindeki kopuklukların kritik bir nedensel unsur olduğu tespit edilmiştir. Bununla birlikte, kontrolörlerin maruz kaldığı yüksek zihinsel iş yükü, yorgunluk ve durumsal farkındalık kaybı, acil durumlarda operasyonel performansı sınırlayan başlıca bireysel risk faktörleri olarak öne çıkmaktadır. Bu durum, mevcut operasyonel yapıların yalnızca insan performansına dayalı olarak sürdürülebilir olmadığını ortaya koymaktadır. Çalışma, yalnızca hataların önlenmesine odaklanan geleneksel Safety-I yaklaşımının, karmaşık ve dinamik havaalanı operasyonlarını açıklamada yetersiz kaldığını ve sistem dayanıklılığını merkeze alan Safety-II yaklaşımı ile desteklenmesi gerektiğini ortaya koymaktadır. Sonuç olarak, çalışma HTK kaynaklı acil durum yönetimini bireysel hata perspektifinin ötesine taşıyarak organizasyonel ve teknolojik boyutları bütüncül bir çerçevede ele almakta ve literatürde sınırlı düzeyde incelenen İHA-HTK entegrasyonu açısından özgün bir katkı sunmaktadır. Bu doğrultuda, organizasyonel süreçlerin yeniden yapılandırılması ve kontrolörlerin uyum kabiliyetini artırmaya yönelik simülasyon tabanlı, probleme dayalı ve İHA destekli eğitim yaklaşımlarının geliştirilmesi önerilmektedir.

Anahtar Kelimeler: Hava Trafik Kontrol, Acil Durum Yönetimi, Havacılık Emniyeti, İnsan Faktörleri

1.GİRİŞ

Havacılık sektörü, küresel ekonominin ve insan hareketliliğinin vazgeçilmez bir bileşeni olarak günümüzde ulaşmış olduğu boyutlarıyla tarihin en yoğun dönemini yaşamaktadır. 2024 yılı verileri incelendiğinde, küresel yolcu trafiğinin pandemi öncesi en yüksek seviyesi olan 2019 yılını aşarak tüm zamanların rekoru kırıldığı görülmektedir; dünya genelinde 37 milyonun üzerinde ticari sefer gerçekleştirilmiş ve yaklaşık 5 milyar yolcu taşınmıştır (ICAO, 2025). Bu veriler yalnızca bir büyüme istatistiği değil aynı zamanda hava trafik kontrolü (HTK) hizmetleri başta olmak üzere tüm havacılık sistemlerine yönelik operasyonel yükün ve emniyet sorumluluğunun da orantılı biçimde arttığının somut bir göstergesidir. Nitekim Avrupa hava sahasında tek başına 2019 yılında 11 milyonun üzerinde IFR uçuşu gerçekleştirilmiş olması, söz konusu yükün coğrafi dağılımını ve sistemik boyutunu açıkça gözler önüne sermektedir (Markiewicz, 2020).

Havacılık emniyeti açısından bakıldığında, sektörün son yirmi yılda kaydettiği ilerleme tartışmasız bir başarıya işaret etmektedir. IATA'nın 2024 yılına ilişkin yıllık emniyet raporu, milyon uçuş başına kaza oranının 1,13 olarak gerçekleştiğini ortaya koymaktadır; bu oran, beş yıllık ortalamanın altında olup bir önceki on yılla kıyaslandığında yaklaşık iki kat iyileşmeyi temsil etmektedir (IATA, 2025). Bununla birlikte, 2024 yılında meydana gelen ölümlü kaza sayısının 2023'ün istisnai düşük seviyesinin üzerine çıkması ve uçuş operasyonlarındaki toplam hayat kaybının 72'den 296'ya yükselmiş olması, ulaşılan ilerlemenin bir güvence değil; sürekli korunması gereken bir denge noktası olduğunu açıkça ortaya koymaktadır (ICAO, 2025). Bu tablo, havacılık emniyetinin yalnızca kaza istatistiklerinin izlenmesiyle değil; olası başarısızlıkları önceden tanımlayan ve normal operasyonlardaki başarının koşullarını sistematik biçimde anlayan bir yaklaşımla güvence altına alınabileceğini göstermektedir.

Sivil havacılığın bu denli kritik bir altyapıya dönüşmesinde temel belirleyici unsur, birbirine bağımlı alt sistemlerden oluşan karmaşık yapısıdır. HTK'nın temel işlevi; uçaklar arasındaki çarpışmaları önlemek, hava trafiğinin düzenli ve hızlı akışını sağlamak ve pilotlara gerekli bilgileri ile diğer destekleri sunmaktır (National Research Council, 1997). Bu işlevler, olağan koşullarda bile son derece hassas bir koordinasyonu gerektirmekte; olağandışı durumlarda ise bu koordinasyonun aksaması doğrudan can güvenliğini tehdit eden zincirleme sonuçlara yol açabilmektedir (ICAO, 2020). Nitekim bir acil durumda pilot, uçağın emniyetini ve güvenliğini korumak amacıyla HTK talimatlarından gerektiği ölçüde sapabilmektedir (National Research Council, 1997). Bu durum, HTK kaynaklı acil durum yönetiminin yalnızca reaktif değil, büyük ölçüde proaktif bir çerçevede değerlendirilmesini zorunlu kılmaktadır.

2. LİTERATÜR İNCELEMESİ

Havacılık emniyeti literatüründe acil durum yönetimi iki temel perspektiften ele alınmaktadır. Birincisi olayların olumsuz sonuçlarını bertaraf etmeyi hedefleyen geleneksel "Safety-I" yaklaşımı; ikincisi ise

normal operasyonlardaki başarılı performansın anlaşılması ve güçlendirilmesine odaklanan "Safety-II" yaklaşımıdır (Hollnagel, 2014). Safety-II perspektifine göre emniyet yönetiminin temel işlevi, yalnızca başarısızlıkları önlemek değil, başarıyı mümkün kılan koşulları anlamak ve pekiştirmektir (Hollnagel, 2014). Bu iki perspektifin sentezi, hem bireysel kontrolör dirençliliğinin hem de ağ düzeyindeki kriz yönetimi mekanizmalarının daha bütünsel kavranmasına imkân tanımaktadır (Karikawa vd., 2019; Markiewicz, 2020). Havaalanı acil durum yönetiminin operasyonel boyutunda ise mevzuat, komuta yapıları ve fonksiyonel sorumluluklar belirleyici bir rol üstlenmekte; bu unsurlar birlikte etkin bir müdahale kapasitesinin temelini oluşturmaktadır (Price ve Forrest, 2016). Nitekim havaalanı çalışanları özelinde yürütülen ampirik araştırmalar, acil duruma ilişkin bilgi düzeyi ve duygusal hazırlık algısı yüksek olan personelin kriz yönetimi performansının da anlamlı biçimde daha iyi olduğunu ortaya koymaktadır (Önen vd., 2021). Bu bulgu, bireysel hazırlık kapasitesinin kurumsal kriz yönetiminin ayrılmaz bir bileşeni olduğunu ve yalnızca sistematik düzenlemelerle değil, personel düzeyindeki bilgi ve yetkinlik geliştirme çalışmalarıyla da güçlendirilmesi gerektiğini göstermektedir (Önen vd., 2021; Turhan vd., 2020). Bu bağlamda hava trafik kontrolörlerinin acil durum eğitiminde probleme dayalı öğrenme yöntemlerinin simülasyon uygulamaları ile bütünleştirilmesi, bireysel hazırlık kapasitesini geliştirmenin ve kontrolörlerin beklenmedik durumlara karşı dirençliliğini artırmanın etkili bir yolu olarak öne çıkmaktadır (Turhan vd., 2020).

Mevcut literatür incelendiğinde, havaalanı acil durum yönetiminin farklı düzeylerde ele alındığı görülmekle birlikte bu düzeyler arasındaki bütünlük ilişkinin yeterince araştırılmadığı dikkat çekmektedir. Bireysel kontrolör dirençliliği ve tehdit yönetimi bağlamında probleme dayalı öğrenme ile simülasyon yöntemlerinin etkinliği tartışılmış olmakla birlikte, bu eğitim kazanımlarının uzun vadeli operasyonel performansa yansımaları henüz yeterli ampirik kanıta kavuşturulamamıştır (Karikawa vd., 2019; Turhan vd., 2020). Örgütsel düzeyde ise komuta yapıları ve kurumsal acil durum planlaması üzerine kapsamlı çerçeveler geliştirilmiş olsa da personel hazırlık algısı ile gerçek kriz performansı arasındaki nedensellik ilişkisi tartışmalı olmaya devam etmektedir (Price ve Forrest, 2016; Önen vd., 2021). Kurumlar arası kriz koordinasyon mekanizmaları da benzer biçimde büyük ölçüde betimsel düzeyde kalmakta; sistematik etkileşimlerin nasıl işlediğine dair açıklayıcı modeller eksikliğini korumaktadır (Markiewicz, 2020). Sonuç olarak, bireysel, örgütsel ve kurumlar arası süreçlerin birbirleriyle nasıl etkileşime girdiğini ve bu etkileşimin bütünlük kriz yönetimi kapasitesini nasıl şekillendirdiğini ortaya koyan çalışmalar literatürde belirgin bir boşluk oluşturmaktadır.

2.1 Havacılıkta İnsan Faktörleri

Havacılık endüstrisi son yirmi yılda kaza oranlarında kayda değer düşüşler yaşamış olsa da insan hatası sivil ve askeri havacılık kazalarının %70 ila %80'inde katkıda bulunan bir faktör olmaya devam etmektedir (Wiegmann ve Shappell, 2003). Bu gerçeklik, insan faktörleri araştırmalarını havacılık emniyetinin merkezine yerleştirmektedir. Kazaların ardındaki sistemik nedenleri anlamak için geliştirilen HFACS (Human Factors Analysis and Classification System) çerçevesi, son on yılda havacılık emniyeti araştırmalarında baskın temalardan biri haline gelmiştir (Okine vd., 2026). Harrison ve arkadaşlarının (2023) çalışması, mesleki deneyim düzeyinin HFACS ile yapılan nedensel faktör sınıflandırmalarını anlamlı şekilde etkilediğini göstermiş; bu da emniyet yönetim sistemlerinin demografik değişkenleri süreçlerine entegre etmesi gerektiğine işaret etmektedir. Operasyonel düzeyde ise Tehdit ve Hata Yönetimi (TEM) modeli yaygın biçimde kullanılmakta olup IATA'nın 2025 küresel anketine göre havayollarının %76,39'u bu çerçeveyi aktif olarak benimsemektedir (IATA, 2025). Endsley'in (1995) üç düzeyli durumsal farkındalık modeli ise karar alma süreçlerinin kuramsal temelini oluşturmaya devam etmekte; son dönemde EEG (Elektroensefalografi) sinyalleri ve beyin elektriksel aktivite haritalaması kullanılarak gerçek zamanlı ölçüm yöntemleri geliştirilmektedir (Endsley, 1995).

Hava trafik kontrolü alanında insan faktörleri özellikle önemli bir boyut taşımaktadır. Kontrolörlerin zihinsel iş yükü performans üzerinde doğrudan olumsuz etkiye sahip olup, farkındalık ve sosyal iş desteği bu etkiyi zayıflatan tampon mekanizmalar olarak işlev görmektedir (Ahmad vd., 2024). Yorgunluk konusunda ise EASA tarafından belirtilen ilk bağımsız bilimsel çalışma, gece vardiyalarının kritik düzey yorgunluk riskini %253, zorlu hava koşullarının %192 ve monoton trafik durumlarının %120 oranında artırdığını ortaya koymuştur (EASA, 2024). FAA'nın yorgunluk raporuna göre hem yüksek hem düşük iş yükü düzeyleri risk oluşturabilmekte; yüksek iş yükü performans düşüşlerine, düşük iş yükü ise rahavet ve sıkılma etkilerine zemin hazırlamaktadır (FAA, 2024). Otomasyonun

yaygınlaşması da yeni zorluklar doğurmuş; Causse ve meslektaşlarının tam uçuş simülatörü çalışması, yüksek otomasyon koşullarında pilotların göz tarama entropisinin azaldığını ve dikkatlerinin daraldığını göstermiştir (Causse vd., 2025).

Acil durum yönetimi bağlamında Ekip Kaynak Yönetimi (CRM), havacılıktaki en köklü ve etkili müdahale araçlarından biridir. Güncel araştırmalar, HFACS çerçevesi ile bulanık bilişsel haritaları entegre ederek uçuş sırasında irkilme tepkisinin nedensellik zincirini analiz etmeye ve uygun eğitim paradigmaları geliştirmeye olanak tanımaktadır (Gardini vd., 2022). Geleceğe bakıldığında, yapay zekâ tabanlı "akıllı asistanlar" veya "dijital meslektaşlar"ın pilotlar ve hava trafik kontrolörleriyle işbirliği yapacağı öngörülmekte; bu dönüşüm, HFACS gibi mevcut taksonomilerin insan-yapay zeka etkileşimine özgü yeni terimlerle güncellenmesini zorunlu kılmaktadır (Kirwan, 2025). Sonuç olarak, havacılıkta insan faktörleri araştırmalarının geleceği; yapay zekâ ile insan etkileşiminin optimizasyonu, veri odaklı yorgunluk yönetimi, fizyolojik temelli gerçek zamanlı durumsal farkındalık ölçümü ve CRM prensiplerinin yeni operasyon konseptlerine uyarlanması ekseninde şekillenecektir.

2.2 Havaalanlarında Acil Durum Yönetimi

Havaalanlarında acil durum yönetimi, çok sayıda paydaşın koordineli biçimde hareket etmesini gerektiren karmaşık bir süreçtir. ICAO Annex 14'e göre her havaalanında, o havaalanındaki uçak operasyonları ve diğer faaliyetlerle orantılı bir Havaalanı Acil Durum Planı (AEP) oluşturulması zorunludur (ICAO, 2018). Bu plan, insan faktörleri ilkelerini gözetmeli ve katılımcı tüm kurumların optimum müdahale göstermesini sağlamalıdır. Bu düzenleme, acil durum planlamasının salt prosedürel bir çerçeve olmadığını; aynı zamanda bilişsel kapasite, iletişim kalitesi ve durumsal farkındalık gibi insan faktörlerini doğrudan içermesi gereken bir süreç olduğunu vurgulamaktadır. ICAO Doc 9137 (Havaalanı Hizmetleri Kılavuzu, Bölüm 7) ise acil durumlar için ön planlama ve havaalanı içindeki farklı birimler ile çevredeki topluluk kaynakları arasındaki koordinasyona ilişkin rehberlik sunmaktadır (ICAO, 2022).

Hava trafik kontrolünün acil durum yönetimindeki rolü özellikle büyük önem arz etmektedir. ICAO Annex 11'e göre hava trafik hizmet otoriteleri, sorumluluk alanlarındaki hava trafik hizmetlerinin kesintiye uğraması veya potansiyel kesinti durumlarında uygulanmak üzere olağanüstü durum düzenlemeleri geliştirmeli ve yayımlamalıdır (ICAO, 2024). Bu düzenlemeler, komşu hava sahası otoriteleri ve tüm hava sahası kullanıcılarıyla yakın koordinasyon içinde hazırlanmalıdır. Acil durumlar sırasında hava trafik kontrolörlerinin rolü, normal trafik yönetiminin çok ötesine geçerek acil iniş koordinasyonu, pist boşaltma, arama-kurtarma birimlerine bilgi aktarımı ve diğer uçakların emniyetli yönlendirilmesi gibi çoklu görevleri kapsar. Bu durum, bir önceki bölümde tartışılan zihinsel iş yükü ve durumsal farkındalık sorunlarını daha da belirginleştirmektedir; zira acil durumlarda etkili bir komuta-kontrol sistemi için gereken temel koşullar, kaynak ve kayıp durumuna ilişkin durumsal farkındalık, müdahale ve iletişim koordinasyonu, bilgi yönetimi ve analizi ile gelecek senaryoları öngörebilecek simülasyon kapasiteleridir (D'Alessio vd., 2024).

Acil durum planlarının etkinliği büyük ölçüde düzenli tatbikatlarla sınıandığında ortaya çıkmaktadır. ICAO, en az iki yılda bir tam ölçekli acil durum tatbikatı yapılmasını önermektedir; FAA ise Part 139 kapsamındaki sertifikalı havaalanlarına her üç yılda bir tam ölçekli tatbikat ve aradaki yıllarda masa başı tatbikatı (tabletop exercise) gerçekleştirme zorunluluğu getirmektedir (14 CFR Part 139.325). Ancak teknolojik çözümler ne kadar gelişmiş olursa olsun, karar alma sürecinde insanın temel rolü göz ardı edilemez (D'Alessio vd., 2024). Bu bağlamda, kriz yönetim planlarının tüm potansiyel olarak dahil olan personel için eğitim gereksinimlerini ve tüm uygulanabilir senaryolar için düzenli tatbikatları içermesi zorunludur (ICAO EUR Doc 031, 2023). COVID-19 pandemisi, havacılık acil durum planlamasındaki önemli boşlukları ortaya çıkarmış ve birçok kuruluş bu süreçten sonra planlarını yolcu tarama, karantina önlemleri ve sağlık krizlerine yönelik protokolleri kapsayacak şekilde güncellemiştir. ICAO'nun 39. Genel Kurulu, kriz müdahale politikasının oluşturulmasını yönlendirmiş ve Senai Afet Risk Azaltma Çerçevesi ile uyumlu olarak havacılıkla ilgili afet risk azaltma önceliklerinin devlet acil müdahale planlarına dahil edilmesini istemiştir (ICAO EUR Doc 031, 2023). Bu evrim, havaalanı acil durum yönetiminin salt uçak kazası odaklı bir yapıdan, pandemi, doğal afet, siber saldırı ve jeopolitik krizleri de kapsayan bütünlük bir dayanıklılık çerçevesine dönüşmekte olduğunu göstermektedir.

2.3 HTK Kaynaklı Olaylar

HTK kaynaklı olaylar, havacılık emniyeti açısından nadir fakat yüksek etkili hadiseler olarak değerlendirilmektedir. Pape ve Wiegmann'ın (2005) NTSB kayıtlarını kullanarak 1985-1997 dönemini kapsayan kapsamlı analizinde, HTK kaynaklı kaza ve olayların seyrek gerçekleştiği; ancak meydana geldiğinde genellikle gündüz VMC koşullarında aynı anda birden fazla uçakla ilgilenmekte olan kule kontrolörlerini kapsadığı saptanmıştır. HFACS çerçevesiyle yapılan derinlemesine analiz, beceri temelli hataların özellikle dikkat eksiklikleri ve hafıza hataları HTK personelinin en sık işlediği hata türü olduğunu göstermiştir (Pape ve Wiegmann, 2005). Bu bulgu, kontrolörlerin yoğun bilişsel talepler altında çalışırken otomatikleşmiş davranışlarda hata yapma eğiliminin, bilinçli karar hatalarından daha yaygın olduğuna işaret etmektedir.

Daha güncel çalışmalar, HTK hatalarının birbirine bağlı çok sayıda etkenin bir ürünü olduğunu göstermektedir. Zhu ve Chen'in (2023) HFACS ile Analitik Hiyerarşi Sürecini (AHP) birleştirdiği çalışma, birinci düzey göstergeler arasında en belirleyici faktörün organizasyonel faktörler, ikinci düzey göstergelerde ise en belirleyici faktörün Hava Trafik Kaynak Yönetimi olduğunu ortaya koymuştur. İkinci düzey göstergeler arasında en düşük ağırlığa sahip olan faktör ise kontrolörün ihlalleridir (Zhu ve Chen, 2023). Bu bulgular, HTK emniyetini iyileştirmek için bireysel hata odaklı müdahaleler yerine öncelikle organizasyonel yönetim düzeyinin güçlendirilmesi gerektiğini vurgulamaktadır. Benzer şekilde, HFACS ve temellendirilmiş kuram yöntemlerini bütünleştiren bir çalışma, emniyetsiz olaylarda en sık rastlanan üç risk faktörünün teknik çevre, zihinsel durumlar ve mesleki yeterlilik olduğunu; en yaygın üç emniyetsiz eylemin ise yanlış talimat verme, yetersiz durumsal farkındalık ve sahada zayıf iş düzeni olduğunu belirlemiştir (Wang vd., 2022).

Pist ihlalleri (runway incursion), HTK kaynaklı olaylar arasında özellikle kritik bir kategori oluşturmaktadır. ICAO, pist ihlallerini Küresel Havacılık Emniyet Planı'nda (GASP) beş küresel yüksek risk kategorisinden biri olarak tanımlamış ve bu sınıflandırma 2020-2022 ile 2023-2025 edisyonlarında korunmuştur (ICAO, 2023). FAA'nın ulusal pist emniyeti istatistiklerine göre, 2017'den günümüze pist ihlallerinin %60'ından fazlası pilot hatasından kaynaklanmaktadır (FAA, 2024). Yan ve arkadaşlarının (2024) sistematik derlemesi, pilot kaynaklı pist ihlallerinde iki baskın türün HTK talimatlarına uyumsuzluk ve pilot pozisyon hatalarının öne çıktığını; iletişim bozukluğu ve durumsal farkındalık kaybının ise en sık atıfta bulunulan faktörler olduğunu belirlemiş olup, iletişim bozukluğu incelenen literatürün %70'inden fazlasında raporlanmıştır (Thorpe vd., 2025). Bu durum, pilot-kontrolör iletişiminin havacılık emniyetindeki belirleyici rolünü bir kez daha teyit etmektedir.

3. HAVAALANLARINDA HTK KAYNAKLI ACİL DURUM TÜRLERİ

Havaalanlarında HTK kaynaklı acil durumlar, tek bir olay türüyle sınırlı kalmayıp havaalanı operasyonlarının farklı katmanlarında kendini gösteren çok boyutlu bir risk yelpazesi oluşturmaktadır. IATA'nın 2024 Yıllık Emniyet Raporu, 2015-2024 döneminde pist dışına çıkma olaylarının en yüksek kaza yüzdesine (%21) sahip olduğunu ortaya koyarken, kontrollü uçuşla arazi çarpışması ve uçuşta kontrol kaybı gibi kategorilerin ölümcül sonuçlarıyla öne çıktığını göstermiştir (IATA, 2024). Ancak yalnızca uçuş operasyonlarıyla sınırlı kalmayan bu risk yapısı, havaalanının yer tarafındaki faaliyetleri de kapsamaktadır. Havacılık olayları nadiren tek bir nedensel faktörün ürünüdür; aksine, karmaşık bir faktörler etkileşiminden doğar (Yan vd., 2025). Bu çerçevede, havaalanlarında HTK ile doğrudan veya dolaylı biçimde ilişkilendirilen acil durum türleri dört temel kategoride ele alınabilir: apron kazaları, pist ihlalleri, bakım kaynaklı acil durumlar ve yer hizmetleri kaynaklı olaylar. İzleyen alt bölümlerde bu kategorilerin her biri, insan faktörleri perspektifinden ayrıntılı olarak incelenmektedir.

3.1 Apron Kazaları

Apron, hava araçları, araçlar ve insanların sürekli hareket halinde olduğu yoğun ve tehlikeli bir operasyonel alandır. Personel devir hızının yüksekliği, düzensiz eğitim uygulamaları ve standart operasyon prosedürlerinin göz ardı edilmesi bu riski artırmakta; buna karşın FAA'nın pilotlar için uyguladığı yorgunluk yönetimi kurallarının apron operasyonları için bir karşılığı bulunmamaktadır (Morais vd., 2023). Muecklich ve arkadaşlarının 87 kaza raporunu HFACS ve Dirty Dozen (Kirli Düzine) çerçevesiyle analiz ettiği çalışma, durumsal farkındalık eksikliği ile prosedürlere

uyulmamasının başlıca nedensel faktörler olduğunu, en kritik operasyonel eylemlerin ise itme-çekme işlemi, hava aracı varış-kalkışı ve ağırlık-denge hesapları olduğunu ortaya koymuştur (Muecklich vd., 2023). IATA ve Trinity College Dublin'in ortak girişimiyle toplanan 1000 kazalık veri setinde ise başlıca katkıda bulunan faktörler prosedürlere uyumsuzluk, mekânsal yanlış değerlendirme, zayıf karar alma ve düşük disiplin olarak belirlenmiştir (IATA/Trinity College Dublin, 1998).

3.2 Pist İhlalleri

Pist ihlalleri, ICAO tarafından "bir havaalanında, iniş ve kalkış için belirlenmiş bir yüzeyin korumalı alanında bir hava aracının, aracın veya kişinin hatalı biçimde bulunması" olarak tanımlanmakta (ICAO Doc 4444) ve Küresel Havacılık Emniyet Planı'nda (GASP) beş yüksek risk kategorisinden biri olarak sınıflandırılmaktadır (Yan vd., 2025). FAA istatistiklerine göre 2017'den günümüze pilot hatası olan olayların %60'ından fazlasını oluşturmakta; Yan ve arkadaşlarının (2024) sistematik derlemesi ise iletişim bozukluğu ve durumsal farkındalık kaybının en yaygın katkıda bulunan faktörler olduğunu, iletişim bozukluğunun literatürün %70'inden fazlasında raporlandığını ortaya koymuştur (Yan vd., 2024). 2024 mali yılında ciddi kategori A ve B pist ihlalleri 2023'e kıyasla %59 azalmış olsa da (DOT OIG, 2025), Ocak 2024'te Tokyo-Haneda'da yaşanan çarpışma, iletişim bozukluğunun hâlâ ölümcül sonuçlar doğurabildiğini göstermiştir (MLIT, 2024; Yan vd., 2025). ICAO bu soruna küresel ölçekte çözüm bulmak amacıyla 200'den fazla paydaşla Pist İhlallerinin Önlenmesine Yönelik Küresel Eylem Planı'nı (GAPPRI) oluşturmuş olup plan, CRM ilkelerinin uygulanması, standart frezyolojinin güçlendirilmesi ve pist emniyet ekiplerinin etkinliğinin sağlanması gibi öneriler sunmaktadır (ICAO, 2024).

3.3 Bakım Kaynaklı Acil Durumlar

Bakım kaynaklı acil durumlar, havacılık emniyetinde genellikle gizli (latent) hatalar biçiminde kendini gösteren ve sonuçları itibarıyla son derece yıkıcı olabilen bir risk kategorisidir. FAA kaza ve olay verilerine göre bakım kaynaklı hatalar, büyük hava aracı kazalarının %15'ine kadar olan kısmıyla ilişkilendirilmiştir (Okine vd., 2026). Bakım hataları uçuş sırasında motor kapanmalarına, uçuş gecikmelerine ve iptallerine yol açmakta olup motor kapanmasının her bir olayı yaklaşık 500.000 ABD doları, bakım hatası kaynaklı uçuş gecikmeleri saat başına yaklaşık 10.000 ABD doları ve iptaller ise yaklaşık 50.000 ABD doları maliyete neden olmaktadır (Olaganathan, 2024). Bu durum havacılık emniyeti başta olmak üzere maliyet ve zaman kaybı açısından da sektörü etkilemektedir. Bakım ve denetim sırasında meydana gelen insan hataları, bakım teknisyenlerinin eylemlerinden veya eylemsizliklerinden kaynaklanmakta; bu hatalar genellikle bakım çalışması başlamadan önce mevcut olmayan bir uygunsuzluk yaratmakta ya da kontrol sırasında tespit edilemeyen emniyetsiz bir koşula yol açmaktadır (Olaganathan, 2024). Bu gibi hatalar dikkat eksikliği, vardiya sistemi ve psikolojik yıpranma gibi nedenlere dayandırılabilir. HFACS'ın bakım uzantısı olan HFACS-ME, bakım eylemlerindeki hataları tanımlamak ve gizli koşullar ile aktif hatalar arasındaki ilişkiyi belirlemek amacıyla geliştirilmiştir (Olaganathan, 2024). Bu tür hataların somut örnekleri arasında 2003 Air Midwest olayında elevator kontrol sisteminin hatalı bağlanması sonucu uçuş sırasında kontrol kaybı ve düşme, 2018 Southwest Airlines Flight 1380'de metal yorgunluğuna bağlı fan kanadı kırılmasının motor arızasına ve bir yolcunun hayatını kaybetmesine yol açması yer almaktadır (Olaganathan, 2024).

3.4 Yer Hizmetleri Kaynaklı Olaylar

Yer hizmetleri kaynaklı olaylar, yakıt ikmali, bagaj ve kargo yükleme-boşaltma, ikram servisi, itme-çekme, buz önleme ve yolcu köprüsü operasyonları gibi çok çeşitli faaliyetleri kapsamakta olup bu operasyonların her biri kendine özgü risk profillerine sahiptir. IATA'nın Küresel Olay Veri Değişimi (IDX) verilerine göre, yer hizmetlerinde en yaygın yaralanma türleri kayma, takılma, düşme ve çarpma olup yüksekten düşmeler en ciddi riskleri oluşturmaktadır (IATA, 2024). Uçuş sayılarının artmasıyla yer hasarı maliyetlerinin 2035'e kadar 10 milyar ABD dolarına ulaşabileceği öngörülmekte; geliştirilmiş yer destek ekipmanlarının (Enhanced GSE) benimsenmesinin bu maliyetleri %42 oranında azaltma potansiyeli taşıdığı belirtilmektedir (IATA, 2024). ICAO Doc 10121 (Yer Hizmetleri Kılavuzu), hava aracı park yönlendirmesi, yakıt ikmali ve yer destek ekipmanı operasyonlarına ilişkin en iyi uygulamaları çerçevelemekte ve çarpışma risklerinin azaltılmasına yönelik rehberlik sunmaktadır (ICAO, 2019).

4. ARAŞTIRMA METODOLOJİSİ

Bu çalışma, nitel araştırma yaklaşımlarından biri olan belge analizi (document analysis) yöntemini benimsemektedir. Belge analizi, araştırma konusuyla ilgili yazılı materyallerin sistematik biçimde incelenmesi, yorumlanması ve anlamlandırılmasını kapsayan bir nitel veri toplama tekniğidir (Merriam & Tisdell, 2016). Bu yöntem, özellikle mevcut kaynaklardan elde edilen verilerin sentezlenmesi yoluyla belirli bir olguya ilişkin bütünlük bir anlayış geliştirmeyi hedefleyen çalışmalarda tercih edilmektedir. Araştırma sürecinde herhangi bir kurum, kuruluş veya şahısla görüşme yapılmamış; birincil veri toplama yöntemlerine (anket, mülakat, gözlem vb.) başvurulmamıştır.

Çalışmada erişilen kaynaklar üç ana kategoride sınıflandırılabilir. Birinci kategori, hakemli akademik dergilerde yayımlanmış araştırma makaleleri, sistematik derlemeler ve bibliyometrik analizlerdir. İkinci kategori, uluslararası havacılık düzenleyici kuruluşlarının resmi belgeleri, yönetmelikleri ve rehber materyallerinden oluşmaktadır; bu kapsamda ICAO (Annex 11, Annex 14, Doc 4444, Doc 9137, Doc 10121), FAA (14 CFR Part 139, yorgunluk raporları, pist emniyeti istatistikleri), EASA (ATCO yorgunluk çalışması, AB Yönetmeliği 2017/373) ve IATA (Yıllık Emniyet Raporu, Küresel İnsan Faktörleri Anketi, IGOM) dokümanlarına erişilmiştir. Üçüncü kategori ise kaza soruşturma raporları ve kurumsal emniyet değerlendirmelerini kapsamakta olup DOT Müfettişler Genel Denetçiliği raporları bu kategoride yer almaktadır.

Kaynak seçiminde belirli kriterler gözetilmiştir. Akademik makaleler için öncelikli olarak hakemli dergilerde yer alan ve doğrudan havacılıkta insan faktörleri, acil durum yönetimi, hava trafik kontrolü veya yer operasyonları konularını ele alan çalışmalar tercih edilmiştir. Düzenleyici belgeler için ise ilgili kuruluşların güncel ve yürürlükteki edisyonlarına başvurulmuştur. Çalışmanın temel amacı, havaalanı acil durum yönetimi gibi kritik ve büyük önem arz eden bir konuyu hava trafik kontrolü kaynaklı gerçekleşme sebepleri üzerinden incelemektir. Bu çerçevede, HTK personelinin bilişsel iş yükü, yorgunluk, durumsal farkındalık, iletişim bozuklukları ve otomasyon rehabeti gibi insan faktörlerinin acil durumlara nasıl etki ettiğini; apron kazaları, pist ihlalleri, bakım kaynaklı acil durumlar ve yer hizmetleri kaynaklı olaylar gibi farklı olay türlerinin insan faktörleri perspektifinden nasıl değerlendirilebileceği analiz edilmektedir. Çalışma, betimsel bir yaklaşımla mevcut bilgi birikimini sentezlemeyi, farklı kaynaklardan elde edilen bulguları karşılaştırmalı biçimde yorumlamayı ve havaalanı acil durum yönetiminde insan faktörlerinin rolüne ilişkin bütünlük bir çerçeve sunmayı hedeflemektedir.

5. BULGULAR VE TARTIŞMA

Bu çalışma kapsamında bulgular dört tematik eksen etrafında ele alınmaktadır: Organizasyonel etkenlerin bireysel hatalara olan üstünlüğü, iletişim bozukluklarının acil durumdaki önemli rolü, bilişsel iş yükü ile yorgunluğun operasyonel performans üzerindeki etkileri ve Safety-I/Safety-II perspektiflerinin HTK kaynaklı acil durum yönetimine katkısı.

5.1 Organizasyonel Faktörlerin Belirleyiciliği

Belge analizi bulguları, HTK kaynaklı emniyetsiz eylemlerde organizasyonel faktörlerin bireysel hata ve ihlallerden daha belirleyici bir ağırlık taşıdığını ortaya koymaktadır. Zhu ve Chen (2023), HFACS ile Analitik Hiyerarşi Süreci'ni bütünleştiren çalışmalarında birinci düzey göstergeler arasında organizasyonel faktörlerin en yüksek paya sahip olduğunu; ikinci düzey göstergeler arasında ise Hava Trafik Kaynak Yönetiminin öne çıktığını saptamıştır. Buna karşın, bireyin doğrudan ihlallerine ilişkin gösterge en düşük ağırlığa sahip bulunmuştur. Bu bulgu, mevcut emniyet müdahalelerinin ağırlıklı olarak bireysel hata önlemeye odaklandığı geleneksel paradigmanın yeniden gözden geçirilmesi gerektiğine işaret etmektedir.

Wang ve arkadaşları (2022), HFACS ve temellendirilmiş kuram yöntemlerini bütünleştiren çalışmalarında emniyetsiz olaylarda en sık karşılaşılan aktif eylemlerin yanlış talimat verme, yetersiz durumsal farkındalık ve sahada zayıf iş düzeni olduğunu ortaya koymuş; bu faktörlerin arka planında ise teknik çevre eksiklikleri ve kurumsal yönetim zafiyetlerinin yattığını vurgulamıştır. Apron kazaları bağlamında Muecklich ve arkadaşları (2023) yürüttükleri çalışmada, prosedürlere uyumsuzluğun ve durumsal farkındalık eksikliğinin başlıca nedensel faktörler olduğunu; bu örüntünün ise yüksek personel

devir hızı, düzensiz eğitim uygulamaları ve yorgunluk yönetimine ilişkin mevzuat eksiklikleriyle bağlantılı olduğunu göstermiştir (Muecklich vd., 2023). Tüm bu bulgular birlikte değerlendirildiğinde, organizasyonel altyapının güçlendirilmesinin bireysel müdahalelerden daha kalıcı emniyet kazanımları sağlayacağı açıkça görülmektedir.

5.2 İletişim Bozukluklarının Kritik Rolü

Pist ihlalleri üzerine yürütülen araştırmalar, iletişim bozukluklarının acil durumların oluşmasında merkezi bir işlev üstlendiğini tutarlı biçimde ortaya koymaktadır. Yan ve arkadaşlarının (2024) sistematik derlemesi, incelenen literatürün %70'inden fazlasında iletişim bozukluğunun raporlandığını ve pilot-kontrolör iletişim kopukluğunun pist ihlallerinde baskın bir nedensel faktör olarak öne çıktığını göstermiştir. Thorpe ve arkadaşları (2025) ise havacılık profesyonelleriyle yürüttükleri nitel çalışmada, standart frazilojiden sapma ve geri okuma hatalarının pist ihlali riskini belirgin biçimde artırdığını saptamıştır. Ocak 2024'te yaşanan Tokyo-Haneda pistte çarpışma olayı, HTK ile uçak pilotu arasındaki iletişim kopukluğunun nasıl ölümcül sonuçlar doğurabileceğini somut biçimde göstermektedir (MLIT, 2024; Yan vd., 2025).

HTK'nın acil durumlardaki koordinasyon işlevi açısından değerlendirildiğinde, ICAO Annex 11'in hava trafik hizmet otoritelerine olası kesinti durumları için olağanüstü düzenlemeler oluşturma ve komşu otoritelerle yakın koordinasyon sağlama yükümlülüğü getirmesi (ICAO, 2024), iletişim altyapısının proaktif biçimde kurulmasının ne denli hayati olduğunu teyit etmektedir. Bu çerçevede, D'Alessio ve arkadaşlarının (2024) etkili kriz komuta-kontrol sistemleri için belirlediği temel koşullar arasında müdahale ve iletişim koordinasyonunu ön sıralara yerleştirmesi dikkat çekicidir; iletişim yalnızca bilgi aktarımı değil, aynı zamanda birlikte eylem kapasitesinin zeminini oluşturmaktadır.

5.3 Bilişsel İş Yükü, Yorgunluk ve Durumsal Farkındalık

Bireysel faktörler düzeyinde, bilişsel iş yükü ve yorgunluk HTK personelinin acil durum yönetimi performansını doğrudan tehdit eden iki temel unsur olarak öne çıkmaktadır. Ahmad ve arkadaşları (2024), hava trafik kontrolörlerinde yüksek zihinsel iş yükünün iş performansı üzerinde doğrudan olumsuz etkiye sahip olduğunu; farkındalık ve sosyal iş desteğinin bu etkiyi zayıflatan tampon mekanizmalar işlevi gördüğünü ortaya koymuştur. Yorgunluk boyutunda EASA'nın (2024) ilk bağımsız bilimsel çalışması, gece vardiyalarının kritik yorgunluk riskini %253 oranında artırdığını saptamış; FAA'nın (2024) raporu ise hem yüksek hem de düşük iş yükü düzeylerinin risk oluşturduğunu yüksek iş yükünün performans düşüşlerine, düşük iş yükünün ise rehavete zemin hazırladığını göstermiştir.

Bu iki uçlu risk profili, acil durumlarda kontrolörü hem aşırı yüklenen hem de ani aktivasyon gerektiren bir durumla karşı karşıya bırakmakta; Endsley'in (1995) üç düzeyli durumsal farkındalık modelinde tanımlanan algılama, kavrama ve projeksiyon aşamalarının tümünü tehdit etmektedir. Nitekim Pape ve Wiegmann'ın (2005) NTSB kayıtlarına dayalı analizi, hava trafik kontrolörlerinin en sık işlediği hata türünün beceri temelli hatalar özellikle dikkat eksiklikleri ve hafıza hataları olduğunu ortaya koymuştur; bu bulgu, yoğun bilişsel talep altında otomatikleşmiş davranışların kırılganlığını doğrudan yansıtmaktadır. Otomasyon kaynaklı rehavet de giderek daha önemli bir endişe kaynağı haline gelmektedir: Causse ve arkadaşlarının (2025) tam uçuş simülatörü çalışması, yüksek otomasyon koşullarında pilotların görsel tarama entropisinin azaldığını ve dikkatlerinin daraldığını göstermiş olup bu bulgunun HTK sistemlerindeki otomasyon artışı bağlamında da geçerliliği bulunmaktadır.

5.4 Safety-I/Safety-II Bütünleşmesi ve Eğitim

Bu çalışmanın bulguları, havaalanı acil durum yönetiminde Safety-I yaklaşımının tek başına yetersiz kaldığını ve Safety-II perspektifinin sisteme entegre edilmesi gerektiğini güçlü biçimde desteklemektedir. Hollnagel'in (2014) kavramsallaştırmasıyla, emniyet yönetiminin işlevi yalnızca başarısızlıkları önlemek değil; başarıyı mümkün kılan koşulları anlamak ve pekiştirmektir. Markiewicz (2020), Avrupa Hava Trafik Yönetimi Ağı'ndaki kriz yönetimini inceleyen çalışmasında, ağ düzeyindeki kriz mekanizmalarının etkinliğinin bireysel kontrolör dirençliliğiyle doğrudan ilişkili olduğunu; bu dirençliliğin ise yalnızca prosedür bilgisiyle değil, karmaşık ve belirsiz durumlarda adaptif eylem kapasitesiyle inşa edildiğini vurgulamıştır.

Bireysel hazırlık kapasitesi açısından Önen ve arkadaşları (2021), acil duruma ilişkin bilgi düzeyi ve duygusal hazırlık algısı yüksek personelin kriz yönetimi performansının anlamlı biçimde daha iyi

olduğunu saptarken; Turhan ve arkadaşları (2020), simülasyon uygulamalarıyla bütünleştirilen probleme dayalı öğrenme yönteminin HTK kontrolörlerinde beklenmedik durumlara karşı dirençliliği artırmada etkili bir araç olduğunu ortaya koymuştur. Karikawa ve arkadaşlarının (2019) kule kontrolörleri üzerindeki dirençlilik araştırması da bu bulguyu destekler nitelikte olup bireysel ve örgütsel düzeydeki dirençlilik mekanizmalarının birbirini pekiştirdiğini göstermektedir. Tüm bu bulgular birlikte değerlendirildiğinde, havaalanı acil durum yönetiminin bireysel, örgütsel ve kurumlar arası süreçleri bütünleştiren çok katmanlı bir çerçevede ele alınması zorunluluğu bir kez daha teyit edilmektedir.

SONUÇ

Bu çalışma, belge analizi yöntemi aracılığıyla havaalanlarında HTK kaynaklı acil durum yönetimini insan faktörleri perspektifinden sistematik biçimde ele almış; apron kazaları, pist ihlalleri, bakım kaynaklı acil durumlar ve yer hizmetleri kaynaklı olayları kapsayan dört temel acil durum kategorisini akademik ve düzenleyici kaynaklarla birlikte değerlendirmiştir. Çalışmadan elde edilen bulgular birkaç temel sonucu öne çıkarmaktadır. Birincisi, HTK kaynaklı emniyetsiz eylemlerde organizasyonel faktörlerin bireysel hatalardan daha belirleyici bir rol oynadığı; dolayısıyla emniyet iyileştirme stratejilerinin bireysel önlemlerin ötesine geçerek kurumsal yönetim ve kaynak yönetimi altyapısını güçlendirmeye odaklanması gerektiği ortaya çıkmıştır (Zhu ve Chen, 2023; Wang vd., 2022). İkincisi, iletişim bozukluğunun özellikle pilot-kontrolör iletişimindeki kopuklukların pist ihlalleri başta olmak üzere pek çok acil durumun nedensellik zincirinde kilit bir unsur oluşturduğu ve bu konuda hem teknolojik hem de eğitim odaklı müdahalelerin sürdürülmesinin zorunlu olduğu görülmektedir (Yan vd., 2024; Thorpe vd., 2025). Üçüncüsü, bilişsel iş yükü, yorgunluk ve durumsal farkındalık kaybının hava trafik kontrolörlerinin acil durum performansını doğrudan etkileyen faktörler olduğu ve bu unsurların proaktif bir yönetim anlayışıyla ele alınması gerektiği belirlenmiştir (Ahmad vd., 2024; EASA, 2024; FAA, 2024). Son olarak, Safety-I ve Safety-II perspektiflerinin bütünleşik biçimde uygulanmasının hem bireysel dirençliliği hem de örgütsel kriz kapasitesini güçlendirdiği; bu bütünleşmenin simülasyon tabanlı eğitim ve probleme dayalı öğrenme yöntemleriyle desteklenmesinin en etkili araçlar arasında yer aldığı anlaşılmaktadır (Hollnagel, 2014; Turhan vd., 2020; Karikawa vd., 2019).

Çalışmanın belge analizine dayalı niteliği, bulguların birincil ampirik veriyle doğrulanamaması şeklinde bir kısıtlılık oluşturmaktadır. Gelecek çalışmaların Türk havalimanı operasyon personeli ve hava trafik kontrolörleriyle yürütülecek karma yöntemli araştırmalar aracılığıyla bu boşluğu doldurması önerilmektedir. Özellikle Türkiye'deki havaalanlarında acil durum tatbikatlarının ICAO standartlarıyla uyumluluk düzeyi, kontrolör yorgunluğu yönetimi uygulamalarının EASA kılavuzlarıyla örtüşme derecesi ve probleme dayalı simülasyon eğitimlerinin uzun vadeli operasyonel performansa yansımaları, ele alınmayı bekleyen kritik araştırma soruları olarak öne çıkmaktadır. İnsan-yapay zekâ etkileşiminin hava trafik kontrolündeki geleceği ve bu dönüşümün acil durum yönetimi süreçlerine nasıl entegre edileceği de yakın dönem araştırmaları için verimli bir zemin oluşturmaktadır (Kirwan, 2025).

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ENHANCING SPEAKING PROFICIENCY THROUGH INTEGRATED INNOVATIVE PEDAGOGIES IN MILITARY EFL EDUCATION: A QUASI-EXPERIMENTAL STUDY

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ABSTRACT

This study examines the effectiveness of an integrated communicative simulation model in improving speaking proficiency and reducing language anxiety among military English as a Foreign Language (EFL) learners. Although communicative competence is widely recognized as essential for professional language use, many military EFL programs continue to rely on traditional lecture-based instruction, limiting opportunities for meaningful spoken interaction. A quasi-experimental pre-test/post-test control group design was employed with 50 second-year military cadets enrolled in a compulsory English course. Over a ten-week period, the experimental group engaged in a structured instructional model incorporating simulation-based tasks, collaborative interaction, guided feedback, and reflective self-recording. In contrast, the control group received conventional lecture-based instruction. Speaking performance was assessed through structured briefing tasks aligned with CEFR B1 descriptors, while speaking anxiety was measured using an adapted Foreign Language Classroom Anxiety Scale. The results revealed that the experimental group demonstrated significantly greater improvements in overall speaking proficiency, particularly in fluency and interactional competence. Additionally, participants in the experimental condition showed a statistically significant reduction in speaking anxiety. These findings highlight the effectiveness of integrating communicative simulations into military EFL instruction and suggest that innovative pedagogical approaches can enhance speaking performance without compromising institutional discipline. The study offers practical implications for curriculum designers, language instructors, and policymakers in professional language training contexts.

Keywords: Military EFL, speaking proficiency, simulation-based learning, communicative language teaching, language anxiety, quasi-experimental design

1. Introduction

Oral communication is a professional necessity in military settings where modern armed forces operate in multinational alliances such as NATO, making English the primary working language. Despite this, speaking skills often receive insufficient focus in military EFL curricula, which tend to emphasize grammatical accuracy, translation, and written assessment. Research in SLA demonstrates that fluency and interactional competence develop through meaningful communication and negotiation of meaning rather than isolated rule learning (Ellis, 2003; Long, 2015; Swain, 2005). Grammar-focused, lecture-dominant instruction creates a gap between linguistic knowledge and communicative performance, a gap especially problematic in military settings where spoken communication must be precise and adaptive under pressure.

Empirical evidence examining systematically integrated communicative models in military EFL institutions remains scarce. Existing studies tend to focus on proficiency standards (e.g., STANAG 6001) or policy frameworks rather than classroom-level pedagogical innovation. This study evaluates whether a systematically integrated communicative simulation model enhances speaking proficiency and reduces speaking anxiety among military EFL cadets compared to traditional instruction. Three research questions guided the investigation: (RQ1) Does the integrated model produce significantly greater overall speaking gains? (RQ2) Does it differentially affect fluency, accuracy, lexical complexity, and interactional competence? (RQ3) Does it result in greater speaking anxiety reduction? Based on sociocultural theory, TBLT research, and prior affective factor findings (Ellis, 2003; Long, 2015;

MacIntyre & Gardner, 1994), corresponding hypotheses (H1–H3) predict significantly greater gains in the experimental group across all outcomes.

2. Theoretical and Pedagogical Foundations

The integrated instructional model synthesizes communicative, task-based, sociocultural, experiential, and adult learning principles into a structured pedagogical cycle.

2.1 Communicative and Task-Based Foundations

Communicative Language Teaching (CLT) conceptualizes proficiency as communicative competence encompassing grammatical, sociolinguistic, discourse, and strategic dimensions (Canale & Swain, 1980). Task-Based Language Teaching (TBLT) positions goal-oriented tasks as the central instructional unit (Ellis, 2003; Long, 2015). In this study, military simulations, operational briefings, coordination meetings, and negotiation scenarios serve as pedagogical tasks that elicit real-time language production under role-specific responsibilities, operationalizing communicative competence within institutional discipline.

2.2 Interaction, Scaffolding, and Experiential Learning

Sociocultural theory positions language development as socially mediated within the Zone of Proximal Development (Vygotsky, 1978). Collaborative problem-solving tasks require cadets to negotiate meaning and co-construct discourse, while feedback is delivered through instructor guidance, peer assessment, and reflective self-recording aligning with output-based SLA accounts (Swain, 2005). Experiential learning theory proposes cyclical processes of action, reflection, conceptualization, and reapplication (Kolb, 1984). The integrated model follows a four-stage cycle: (1) simulation-based task engagement, (2) guided collaborative interaction, (3) structured feedback, and (4) reflective self-recording. This structure addresses the tension between communicative innovation and hierarchical military educational norms by embedding meaningful practice within institutionally compatible parameters.

3. Speaking Proficiency and Measurement

Speaking proficiency involves real-time coordination of linguistic, cognitive, and interactional processes (Levitt, 1989; Skehan, 1998). This study adopts a multidimensional analytic framework evaluating: fluency (temporal smoothness operationalized via speech rate and pause frequency; Tavakoli & Skehan, 2005); accuracy (conformity to target linguistic norms; Ellis, 2003); lexical and structural complexity (sophistication and diversity of language use; Housen & Kuiken, 2009); and interactional competence (turn-taking, clarification, and collaborative meaning construction; Young, 2011). Speaking performance was aligned with CEFR B1 descriptors, at which speakers produce connected discourse and maintain interaction in routine professional situations (Council of Europe, 2001, 2020).

4. Methodology

4.1 Research Design and Participants

A quasi-experimental pre-test/post-test control group design was employed (Creswell & Creswell, 2018; Shadish, Cook, & Campbell, 2002). Participants were 50 second-year military cadets (aged 19–20) in a compulsory English course. Two intact classes ($n = 25$ each) served as experimental (EG) and control (CG) conditions. ANCOVA controlled for pre-test differences; a significant baseline difference in grammatical accuracy (EG: $M = 2.80$ vs. CG: $M = 2.00$, $t(48) = 5.28$, $p < .001$, $d = 1.49$) made this essential. Within-group power exceeded .97 for large effects; between-group power was .79, a minor acknowledged limitation.

4.2 Instructional Procedure

The experimental group received the integrated model for ten weeks (two 80-minute sessions/week). Each session followed a four-stage cycle: scenario introduction (10–15 min), simulation-based group tasks such as operational briefings or negotiation scenarios (25–30 min), guided peer and instructor feedback (15–20 min), and reflective self-recording (10–15 min). The control group received traditional lecture-based grammar instruction with limited extended speaking opportunities. The same instructor taught both groups to minimize teacher effects. All speaking performances were audio-recorded and assessed by two trained raters blinded to group assignment and timepoint.

4.3 Instruments and Data Analysis

Speaking proficiency was assessed through a structured three-minute operational briefing task at pre- and post-test (two parallel versions). Speech samples were rated analytically for fluency, accuracy, lexical range, and interaction on a five-point scale (Appendix A). Inter-rater reliability was acceptable across dimensions (Fluency ICC = .79; Accuracy ICC = .80; Lexical Complexity ICC = .78; Interaction ICC = .81). Speaking anxiety was measured via a 13-item Likert-scale instrument adapted from the Foreign Language Classroom Anxiety Scale (Horwitz et al., 1986). The scale demonstrated acceptable internal consistency in the present study ($\alpha = .79$). Data were analyzed using IBM SPSS 27 with paired-samples t-tests for within-group change, ANCOVA for between-group comparisons, Cohen's d, and partial η^2 .

5. Results

Table 1. Descriptive Statistics and Inferential Results for Speaking Proficiency Components and Anxiety (EG = Experimental Group; CG = Control Group)

Measure	Grp	Pre M (SD)	Post M (SD)	Gain	Within-Grp t (p)	d	ANCOVA F (p)	η^2	Adj. M EG/CG
Total Speaking (25)	EG	11.20 (2.10)	16.40 (2.35)	+5.20	11.63 (<.001)	2.33	22.68 (<.001)	.33	16.62 / 13.28
	CG	12.00 (2.25)	13.50 (2.40)	+1.50	3.22 (.003)	.64	—	—	—
Fluency (WPM)	EG	75.4 (10.2)	95.7 (11.4)	+20.3	9.35 (<.001)	1.87	18.54 (<.001)	.28	96.44 / 94.56
	CG	78.1 (9.8)	95.3 (10.5)	+17.2	8.46 (<.001)	1.69	—	—	—
Accuracy (1–5)	EG	2.80 (.55)	3.60 (.60)	+0.80	6.94 (<.001)	1.39	6.92 (.011)	.13	3.38 / 2.97
	CG	2.00 (.52)	2.75 (.58)	+0.75	6.79 (<.001)	1.36	—	—	—
Lexical Range (1–5)	EG	2.00 (.50)	3.01 (.62)	+1.01	8.87 (<.001)	1.77	5.84 (.019)	.11	2.92 / 2.14
	CG	1.70 (.48)	2.05 (.55)	+0.35	3.37 (.002)	.67	—	—	—

Interaction (1–5)	EG	2.06 (.60)	2.80 (.65)	+0.74	5.91 (<.001)	1.18	14.02 (<.001)	.23	2.69 / 2.11
	CG	1.65 (.58)	2.00 (.60)	+0.35	2.96 (.007)	.59	—	—	—
Speaking Anxiety (1–5)	EG	3.60 (.52)	2.90 (.48)	−0.70	6.98 (<.001)	1.40	14.02 (<.001)	.23	2.89 / 3.41
	CG	3.55 (.50)	3.40 (.51)	−0.15	1.48 (.151)	.30	—	—	—

The experimental group demonstrated significantly greater gains in overall speaking proficiency ($d = 2.33$) compared to the control group ($d = .64$). ANCOVA confirmed a large instructional effect, $F(1, 47) = 22.68$, $p < .001$, $\eta^2 = .33$. The largest between-group effects appeared in fluency ($\eta^2 = .28$) and interactional competence ($\eta^2 = .23$). Accuracy improved significantly in both groups with comparable effect sizes, while lexical diversity gains were substantially greater in the experimental group. Speaking anxiety decreased significantly only in the experimental group ($d = 1.40$; $p = .151$ in CG), confirmed by ANCOVA, $F(1, 47) = 14.02$, $p < .001$, $\eta^2 = .23$.

6. Discussion

6.1 Speaking Proficiency

Findings strongly support all three hypotheses. The experimental group's substantially greater total speaking gains confirm that the integrated model outperforms traditional instruction for overall oral development. Fluency gains reflect the proceduralization effects of task repetition and goal-oriented interaction (Ahmadian & Tavakoli, 2011; DeKeyser, 2007). Accuracy improved comparably in both groups, supporting the view that attention to form can be maintained within communicative frameworks (Long, 2015) and demonstrating no communicative-accuracy trade-off. Greater lexical diversity in the experimental group aligns with Robinson's (2001) cognition hypothesis: cognitively demanding simulations pushed learners beyond fixed patterns. Interactional competence gains reflect the co-constructed nature of meaning in negotiation and turn-taking activities, competencies critical in military coordination contexts (Young, 2011).

6.2 Speaking Anxiety and Broader Implications

The significant anxiety reduction in the experimental group but not the control group supports H3 and aligns with the affective filter hypothesis (Krashen, 1982) and language anxiety research (MacIntyre & Gardner, 1994), consistent with findings that innovative speaking interventions can simultaneously improve performance and reduce anxiety (Bai & Xian, 2024). An important contribution is demonstrating that communicative innovation can be implemented within a structured military setting without compromising institutional discipline. Tasks were time-regulated, role-specific, and performance-assessed, maintaining compatibility with military norms while expanding interaction opportunities.

6.3 Limitations

The quasi-experimental design without individual random assignment may introduce selection bias. The single-institution sample limits generalizability. The 10-week duration does not address long-term retention; future research should include delayed post-tests and replicate findings across multiple military institutions.

7. Conclusion

This study demonstrated that an integrated communicative simulation model combining simulation-based tasks, collaborative interaction, guided feedback, and reflective self-recording significantly enhances speaking proficiency and reduces speaking anxiety in military EFL cadets. The largest gains appeared in fluency and interactional competence. The findings confirm the feasibility of integrating interaction-based pedagogy within disciplined military educational contexts and offer practical implications for curriculum design in professional language education programs.

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QUANTITATIVE ANALYSIS OF THE LEARNING CLIMATE AND COGNITIVE LOAD IN NURSING LABORATORY PRACTICES: A CROSS-SECTIONAL STUDY

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ABSTRACT

Background: Contemporary nursing pedagogy necessitates a sophisticated integration of theoretical frameworks into high-fidelity laboratory environments. However, the efficacy of this transition is frequently impeded by cognitive barriers and environmental stressors. This study investigates the intricate interplay between "Learning Climate" and "Cognitive Load" to determine how instructional variables and task complexity modulate student clinical proficiency.

Methodology: Utilizing a quantitative cross-sectional design, data were obtained from 117 first-year nursing students via a validated 21-item psychometric instrument. The analysis focused on previously under-researched variables: instructional clarity, peer-to-peer collaboration, and perceived mental effort during clinical simulations.

Results: Statistical findings reveal that 38.5% of participants experience significant cognitive overload during complex clinical procedures, occurring when intrinsic task complexity exceeds the students' working memory capacity. Regarding the instructional climate, 87% of students identified instructor patience as a critical facilitator of learning. Furthermore, "Instructional Clarity" emerged as the most potent predictor for the attenuation of task-related anxiety ($r = -0.38, p < 0.05$). A notable "Readiness Gap" was observed: despite high intrinsic motivation, 42.7% of respondents reported a perceived lack of psychological safety when executing invasive interventions without direct supervision. Conversely, peer collaboration was rated as "Excellent" by 78% of the cohort, suggesting its role as a significant buffer against academic stress.

Conclusion: The study underscores a critical institutional demand, with 95.7% of the sample advocating for an increased frequency of laboratory-based instruction. To optimize nursing curricula, academic institutions must prioritize the temporal synchronization of theoretical lectures with practical simulations. Implementing advanced instructional scaffolding and fostering peer-assisted learning strategies are essential to mitigate cognitive load and facilitate a seamless transition from simulated environments to real-world clinical practice.

Keywords: Learning Climate, Cognitive Load Theory, Nursing Pedagogy, Clinical Competence, Scaffolding Strategies.

INTRODUCTION

The transition from theoretical knowledge to clinical competence is a cornerstone of nursing education. However, this process is often hindered by "Cognitive Load"—the mental effort required to process new information (Sweller, 2011). As established in our preliminary research presented at the Global Nursing Healthcare Excellence Summit 2026 held in March 24-25 2026 titled *"Enhancing Clinical Competence through Laboratory Practices: An Empirical Study on Nursing Students' Perceptions and Academic Motivation"* (Millosi & Zotaj, 2026), high student motivation is a primary driver, but it must be supported by an efficient learning climate.

The "Learning Climate" encompasses the physical resources and the psychological support provided by instructors and peers. According to Cognitive Load Theory (CLT), when extraneous load (poor

instruction) is high, students struggle to acquire germane load (actual learning). This study aims to quantify these relationships to improve nursing curricula.

ETHICAL CONSIDERATIONS

This study was conducted following the ethical principles of the Declaration of Helsinki. Prior to data collection, formal approval was obtained from the institutional review board. All 117 participants provided informed consent electronically. Students were informed that their participation was voluntary and that their academic standing would not be affected by their decision to participate or withdraw. To ensure anonymity, data were processed using coded identifiers, and no personal identifiable information was retained in the final analysis.

METHODOLOGY

A quantitative cross-sectional design was employed. The sample consisted of 117 first-year nursing students from the University of Medicine Tirana. The research instrument was a validated 21-item questionnaire measuring:

1. Instructional Support (Lecturer patience, clarity of instructions).
2. Cognitive Demand (Mental effort, feeling overwhelmed).
3. Peer Collaboration (Student-to-student cooperation).
4. Institutional Factors (Material availability, hour frequency).

Data analysis was performed using SPSS v.26. Spearman's rank correlation was utilized to determine relationships between variables, with a significance level set at $p\text{-value} < 0.05$.

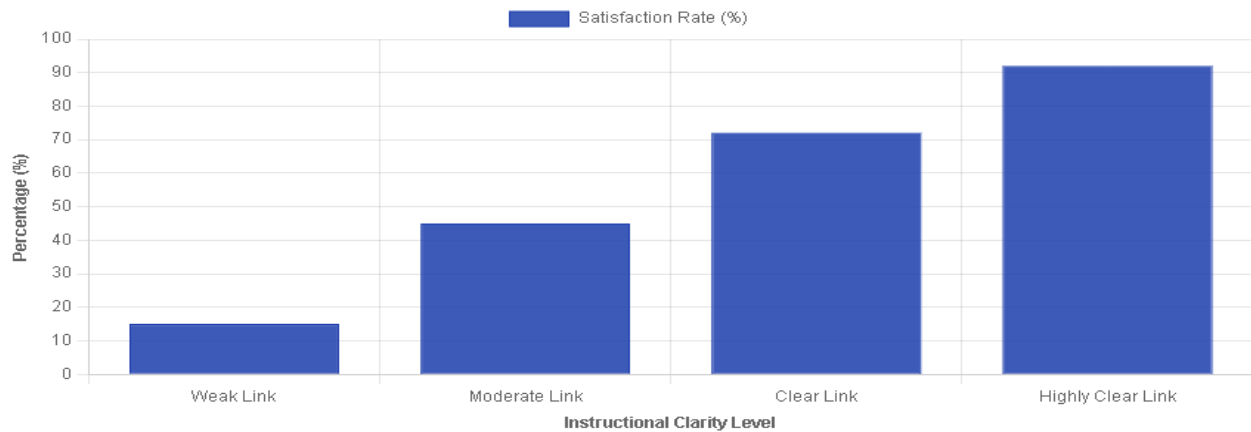
RESULTS AND ANALYSIS

Table 1: Correlation Analysis of Instructional Variables

Variable Pair	Spearman's	p-value	Significance
Theory-Practice Link vs. Satisfaction	0.46	< 0.001	Highly Sig.
Instructional Clarity vs. Task Anxiety	-0.38	< 0.05	Significant
Lecturer Support vs. Clinical Readiness	0.42	< 0.001	Highly Sig.
Peer Collaboration vs. Stress Levels	-0.29	< 0.05	Significant

Table 1 demonstrates that the strongest driver of student satisfaction is the clarity of the connection between theoretical lectures and laboratory practice ($r=0.46$). This confirms that students perceive the lab not as a separate entity but as a continuation of their intellectual training. The negative correlation ($r=-0.38$) between clarity and anxiety proves that pedagogical transparency directly reduces cognitive stress.

Figure 1: Correlation between Theory-Practice Integration and Student Satisfaction



Analysis: This bar chart illustrates a progressive and linear relationship between the perceived clarity of curricular integration and overall academic satisfaction. The Spearman's correlation coefficient of $r=0.46$ denotes a statistically significant positive relationship.

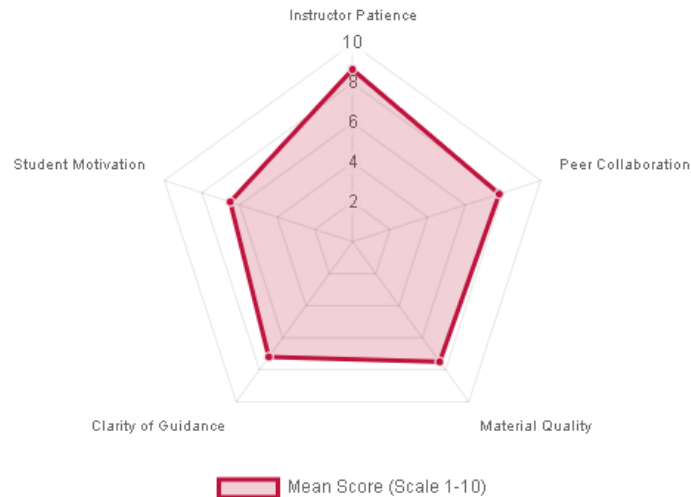
- **Interpretation:** There is a notable disparity in satisfaction levels based on instructional clarity; when students perceive a tenuous link between theoretical lectures and laboratory application, satisfaction remains critically low (15%).
- **Academic Significance:** The achievement of a 92% satisfaction rate within the "Highly Clear Integration" cohort validates the hypothesis that laboratory efficacy is contingent upon the "cognitive bridge" established prior to practical exposure. This finding aligns with Cognitive Load Theory, suggesting that pre-existing schemas significantly reduce extraneous load during clinical performance.

Table 2: Student Perception of Laboratory Learning Climate

Indicator	Excellent (%)	Good (%)	Average (%)	Poor (%)
Peer Cooperation	78.0	15.4	5.1	1.5
Instructor Patience	87.2	8.5	3.4	0.9
Instructional Clarity	72.6	18.8	6.8	1.8

The learning climate is characterized by exceptionally high levels of social support. With 87.2% of students rating instructor patience as "Excellent," it is evident that the laboratory environment is viewed as a "safe space" for trial and error. Peer cooperation (78%) further suggests that students engage in social scaffolding, which helps distribute the cognitive load.

Figure 2: Multidimensional Evaluation of the Learning Climate



Analysis: The radar chart provides a holistic visualization of the laboratory ecosystem's performance across five distinct psychometric dimensions.

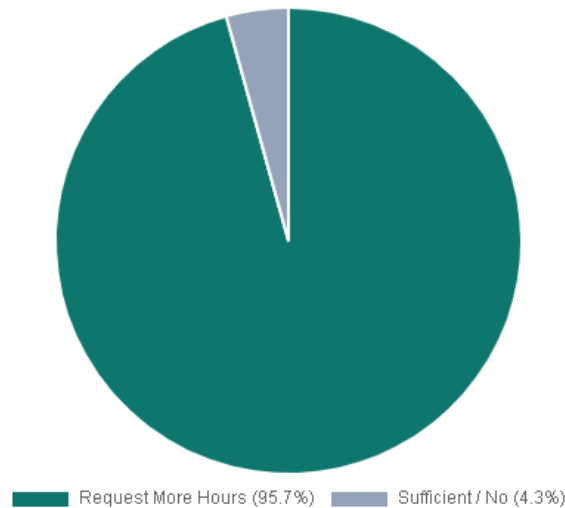
- **Interpretation:** "Instructor Patience" (8.7/10) emerges as the most robust pillar of the learning environment, functioning as a primary "psychological buffer" for novice learners. Peer collaboration (7.8/10) further indicates a healthy culture of "Social Scaffolding," which facilitates the distribution of cognitive load among students.
- **Academic Significance:** Conversely, the relatively lower score in "Academic Motivation" (6.5/10) compared to instructional support suggests that intrinsic task complexity and cognitive fatigue may be impacting student engagement. This indicates that future curricular interventions should focus on "Instructional Scaffolding" to simplify complex tasks and sustain long-term student motivation.

Table 3: Cognitive Load Indicators

Perceived Experience	Strongly Agree (%)	Agree (%)	Neutral (%)
Feeling Overwhelmed by Tasks	12.8	25.7	35.0
Demand for More Lab Hours	95.7	3.4	0.9

Despite the positive climate, 38.5% of students (Strongly Agree + Agree) feel cognitively overwhelmed. This confirms that the intrinsic complexity of nursing tasks is high. However, the overwhelming demand for more hours (95.7%) indicates that students prefer "more practice" as the primary solution to overcome this overload.

Figure 3: Institucional Demand for Increased Laboratory Frequency



Analysis: The pie chart demonstrates an overwhelming consensus among the research sample. With a dominant figure of 95.7%, the demand for expanded laboratory hours represents the most significant institutional variable identified in this study.

- **Interpretation:** This near-unanimous demand transcends mere student preference; it reflects a self-identified "Readiness Gap" within the cohort. Despite reported levels of cognitive overload (38.5%), students demonstrate a high degree of professional awareness by advocating for increased exposure as a primary mitigation strategy.
- **Academic Significance:** This underscores a critical pedagogical shift where students prioritize experiential learning over passive theoretical instruction to ensure long-term clinical competence and psychological safety in real-world environments.

DISCUSSION

The findings of this study demonstrate that the "Learning Climate" is a multi-dimensional construct where instructional clarity and psychological safety serve as primary catalysts for clinical competence. Our results show a highly significant positive correlation ($r = 0.46$, $p < 0.001$) between the perceived theory-practice link and student satisfaction. This aligns with the findings of Millosi and Zotaj (2026) at the Global Nursing Healthcare Excellence Summit 2026 held in March 24-25 2026, where the "Readiness Gap" was identified as a major barrier to clinical confidence.

When comparing these results with international literature, similarities arise. Fraser et al. (2015) argue that Cognitive Load Theory is paramount in medical education because the working memory of novice learners is easily overwhelmed by complex clinical simulations. Our observation that 38.5% of students feel overwhelmed correlates with Leppink and van den Heuvel (2015), who found that extraneous cognitive load—caused by poor instructional design—often hampers the acquisition of practical skills.

Furthermore, the high rating of "Instructor Patience" (87.2%) in our study serves as a "psychological buffer," a concept supported by Sewchuk (2005), who emphasizes that a supportive educator can mitigate the anxiety associated with invasive procedures. Unlike the study by Stenberg and Carlson (2015), which focused heavily on peer-assisted learning, our research highlights that while peer collaboration is excellent (78%), students still prioritize the presence and feedback of the instructor above all else.

The negative correlation between instructional clarity and task anxiety ($r = -0.38$, $p < 0.05$) mirrors the results of Young et al. (2014), who suggested that "scaffolding"—the gradual removal of support as competence increases—is the most effective way to manage cognitive load in high-stakes environments like nursing.

RECOMMENDATIONS

Based on the empirical evidence gathered, the following recommendations are proposed to enhance nursing curricula:

1. **Integrated Curriculum Design:** Academic institutions should ensure a "tight coupling" between theoretical lectures and laboratory sessions. Delays between these two phases increase cognitive decay.
2. **Instructional Scaffolding:** Instructors should utilize "worked examples" and "demonstration-first" approaches for invasive procedures to reduce the extraneous cognitive load before students attempt the task themselves.
3. **Increased Laboratory Exposure:** Given that 95.7% of students requested more hours, universities should explore the possibility of open-access laboratory hours where students can practice under peer supervision.
4. **Emotional Intelligence Training for Educators:** Since instructor patience was identified as a key buffer, faculty development programs should focus on communicative and supportive teaching strategies.

ETHICAL CONSIDERATIONS

The present study was conducted in strict adherence to the ethical guidelines established by the Declaration of Helsinki. Specific ethical measures implemented during the research process included:

1. **Informed Consent:** All participants (n=117) were provided with a detailed Plain Language Statement (PLS) outlining the study's objectives, the nature of their involvement, and the intended academic use of the data. Explicit electronic informed consent was obtained from every respondent prior to accessing the survey instrument.
2. **Voluntary Participation and Withdrawal:** Participants were explicitly informed that their involvement was entirely voluntary. They were assured that refusal to participate or a decision to withdraw at any stage would not result in any academic penalty, prejudice, or impact on their laboratory grades.
3. **Data Anonymization and Privacy:** To maintain the highest standards of confidentiality, a double-blind data coding system was utilized. All personal identifiers (such as student names or ID numbers) were removed and replaced with unique alphanumeric codes during the data cleaning process. Raw data were stored on a password-protected institutional server, accessible only to the primary research team.
4. **Non-Invasive Protocol:** The study involved no clinical interventions or physiological measurements; it focused solely on the psychometric evaluation of the learning environment and cognitive perceptions.

FINANCIAL DISCLOSURE AND FUNDING

The authors declare the following regarding the financial and institutional support for this research:

- **Funding Source:** This research was conducted as an independent academic inquiry. The authors received no specific grant, financial compensation, or external funding from any commercial, non-profit, or government agency to carry out the data collection, analysis, or manuscript preparation.
- **Conflict of Interest:** The authors certify that they have no affiliations with, or involvement in, any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial

interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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DETERMINANTS OF CORRUPTION IN EMERGING AND DEVELOPED ECONOMIES: A PANEL DATA ANALYSIS WITH DYNAMIC FIXED EFFECTS

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ABSTRACT

Corruption remains one of the most persistent and damaging governance failures across both developed and developing economies, undermining institutional trust, distorting resource allocation, and impeding long-run economic convergence. This paper investigates the structural determinants of perceived corruption for a balanced panel of 32 European countries observed over 20 years (NT = 640 observations), using an inverted Corruption Perceptions Index ($y_{cpi} = 100 - CPI$) as the dependent variable, where higher values denote greater perceived corruption. To ensure methodological rigor, we estimate and compare seven nested econometric specifications from Pooled OLS (M1) to One-Way and Two-Way Fixed Effects models with progressively more robust standard errors (M2–M6), culminating in a Two-Way Dynamic Fixed Effects AR (2) model with Driscoll-Kraay standard errors (M7). This progression allows us to systematically document the sources of bias, inconsistency, and inferential invalidity present in simpler estimators, including omitted variable bias, serially correlated residuals, and heteroskedasticity. Model selection is guided by a diagnostic scorecard comprising AR(1) and AR(2) residual autocorrelation tests, the Breusch-Pagan heteroskedasticity test, and an F-test for the joint significance of time fixed effects. The preferred specification (M7) is the only model to pass all three diagnostic criteria simultaneously, yielding a within- R^2 of 0.749. Key findings are as follows. First, corruption exhibits strong temporal persistence ($\phi_1 = 0.862$), with a long-run multiplier of $4.84\times$ and a half-life of approximately three years — implying that the full structural impact of any determinant materializes gradually over time. Second, GDP per capita (log) is the dominant corruption-reducing factor, with a long-run effect of -6.89 points per log unit, consistent with the view that economic development strengthens institutions and civil oversight mechanisms. Third, government effectiveness exerts a significant negative effect on y_{cpi} (long-run: -0.302), confirming that administrative quality is a robust predictor of lower perceived corruption. Fourth, gross fixed capital formation is positively associated with y_{cpi} in within-country variation, suggesting that investment booms generate rent-seeking opportunities that amplify perceived corruption in the short run. Fifth, the within-country effect of tertiary education attainment is positive and statistically significant, a counter-intuitive result that may reflect compositional dynamics or lagged civic effects, and that warrants further investigation. These findings carry important policy implications: anti-corruption interventions cannot be evaluated over short horizons, economic development and institutional reform are complementary rather than substitute strategies, and the effectiveness of governance improvements depends critically on their persistence over time. Future research should address potential endogeneity of regressors using Arellano-Bond GMM estimators or panel instrumental-variables approaches.

Keywords: Corruption in Europe, panel data, dynamic fixed effects, Driscoll-Kraay standard errors, inverted CPI, government effectiveness

1. Introduction

Corruption is one of the most persistent and structurally damaging governance failures in both advanced and emerging economies, with consequences that extend far beyond public administration. By distorting the allocation of public resources, weakening institutional trust, deterring foreign investment, and undermining the rule of law, corruption constitutes a fundamental obstacle to sustainable economic

development and social equity (Mauro, 1995; Transparency International, 2023). Despite decades of institutional reform efforts and an extensive empirical literature, corruption remains stubbornly persistent across a broad spectrum of countries, suggesting that its determinants are deeply structural and that its dynamics unfold over time horizons that short-run interventions cannot adequately address.

The empirical literature on the determinants of corruption has advanced considerably since the seminal cross-sectional studies of the 1990s, but several methodological limitations continue to constrain the reliability of existing estimates. First, many studies rely on static fixed-effects specifications that fail to account for the strong temporal persistence of corruption, thereby producing biased long-run estimates. Second, the presence of cross-sectional dependence — documented in this paper for most predictors — violates the assumptions underlying standard panel unit root tests and ordinary least squares (OLS) standard errors, yet it is rarely addressed explicitly. Third, the potential nonlinearity in the income–corruption relationship and the conditional nature of institutional effects across income levels are largely ignored in linear specifications. This paper addresses each of these limitations directly.

We investigate the structural determinants of perceived corruption for a balanced panel of 32 countries — comprising both emerging and advanced economies — observed annually over the period 2004–2023, yielding 640 country-year observations. Our dependent variable is the inverted Corruption Perceptions Index ($y_{\text{cpi}} = 100 - \text{CPI}$), where higher values denote greater perceived corruption. The four core predictors are GDP per capita (log-transformed), government effectiveness, gross fixed capital formation as a share of GDP, and tertiary education attainment among the population aged 25 and above.

Our methodological contribution is threefold. First, we estimate and compare seven nested econometric specifications using a systematic diagnostic scorecard to guide model selection. Second, we conduct a comprehensive pre-estimation testing protocol comprising cross-sectional dependence tests (Pesaran, 2004), panel unit root tests (LLC, IPS, CIPS), and panel cointegration tests (Pedroni, 1999; Kao, 1999; Westerlund, 2007). Third, we perform four robustness checks — lag order selection (R1), regressor endogeneity (R2), GDP nonlinearity (R3), and institutional interaction effects (R4) — that collectively validate the stability of the preferred specification.

The key findings are as follows. Corruption exhibits strong temporal persistence, with a long-run multiplier of approximately $4.84\times$ and a half-life of three years. GDP per capita is the dominant corruption-reducing factor, with a long-run effect of -6.89 points per unit of log income. Government effectiveness exerts a robust negative effect on perceived corruption. Gross fixed capital formation is positively associated with corruption in within-country variation, consistent with a rent-seeking mechanism during investment booms. Robustness tests confirm the nonlinearity of the income–corruption relationship and a significant conditional interaction between institutional quality and income level.

The remainder of the paper is structured as follows: Section 2 reviews the theoretical and empirical literature; Section 3 describes the data and methodology; Section 4 presents the results; Section 5 discusses policy implications; and Section 6 concludes.

2. Literature Review

2.1 Economic Development and Corruption

The relationship between economic development and corruption is one of the most extensively documented in the governance literature. Mauro (1995) established the foundational result that higher GDP per capita is associated with lower corruption, operating through multiple channels: higher income raises the opportunity cost of corrupt behavior for public officials, strengthens the demand for institutional quality, and enables greater investment in civil oversight and judicial independence. Subsequent cross-sectional and panel studies have consistently confirmed this negative association (Pellegrini & Gerlagh, 2004; Herzfeld & Weiss, 2003; Treisman, 2000). More recent contributions have questioned the linearity of this relationship. Consistent with a Kuznets-type hypothesis, some studies suggest that the income–corruption relationship follows an inverted-U pattern at very low income levels, while at higher income levels institutional consolidation prevails and corruption declines (Paldam, 2002). This paper directly tests this hypothesis by including a quadratic GDP term in robustness test R3.

2.2 Institutional Quality and Government Effectiveness

The role of institutional quality in determining corruption levels is theoretically grounded in the principal-agent framework: effective public management, meritocratic recruitment, and adequate civil service remuneration all reduce the incentive and opportunity for corrupt behavior (Rose-Ackerman, 1999; Klitgaard, 1988). Kaufmann et al. (2010) demonstrate that the Government Effectiveness dimension of the World Governance Indicators is among the most robust predictors of low perceived corruption. Importantly, the effectiveness of governance reforms may depend on the level of economic development — a conditional hypothesis tested in robustness check R4, which introduces an interaction term between government effectiveness and GDP per capita. The significant positive interaction coefficient confirms that governance improvements have a larger anti-corruption effect in lower-income countries.

2.3 Education and Human Capital

The dominant hypothesis posits that higher educational attainment strengthens civic engagement, reduces information asymmetries between citizens and public officials, and consolidates normative expectations against corrupt behavior (Glaeser & Saks, 2006; Rothstein & Teorell, 2008). However, within-country empirical evidence is less consistent than cross-sectional findings. Gupta et al. (2002) and Uslaner (2008) document that the relationship between education and corruption is mediated by institutional quality: in environments with weak governance, higher educational attainment may increase the capacity for rent-seeking rather than civic oversight. In our specification, the within-country coefficient on tertiary education is positive and statistically significant, consistent with compositional dynamics and potential reverse causality, in which corruption discourages investment in human capital over time.

2.4 Investment, Capital Formation, and Rent-Seeking

The relationship between investment and corruption involves competing theoretical mechanisms. Shleifer & Vishny (1993) and Tanzi & Davoodi (1997) argue that public investment creates rent-seeking opportunities through procurement distortions and contract award irregularities — particularly when institutional oversight is weak. This channel predicts a positive contemporaneous relationship between investment intensity and perceived corruption, consistent with our findings. On the other hand, productive private investment may contribute to corruption reduction over longer horizons (Delavallade, 2006). The positive within-country association between gross fixed capital formation and y_{cpi} documented in this paper is most plausibly interpreted as reflecting the rent-extraction mechanism that is dominant in the short-to-medium run, amplified by the dynamic persistence of corruption ($\phi_1=0.862$).

2.5 Recent Empirical Contributions (2020–2024)

The most recent strand of empirical research has extended the foundational findings reviewed above along three main dimensions: the role of digitalization and e-governance, the conditional nature of institutional effects across income groups, and the use of second-generation panel estimators robust to cross-sectional dependence.

Acaravci et al. (2023) examine 65 developed and developing countries over 1999–2016 using Augmented Mean Group (AMG) estimators designed to handle cross-sectional dependence — the same challenge addressed in the present paper. Their results confirm that economic growth and governance quality significantly reduce corruption, and introduce internet use as an additional institutional determinant, finding a robust negative association between digitalization and perceived corruption levels. This finding is consistent with the transparency-enhancing mechanism of e-government platforms, which reduce discretionary interactions between citizens and public officials.

Seiam and Salman (2024) extend this line of inquiry using a panel of 110 countries over 2003–2021, focusing on the E-Government Development Index (EGDI) and its sub-components. Their fixed-effects

panel analysis documents significant negative associations between online service provision, human capital infrastructure, and telecommunications development, on the one hand, and corruption perceptions, on the other. These findings suggest that the digitalization of public service functions as a structural institutional reform with measurable anti-corruption effects, independent of income level.

Beyaert et al. (2023) apply regression tree analysis to a panel of 103 countries from 1996 to 2017 to capture the nonlinear effects of corruption on economic growth. Their methodology endogenously identifies two distinct country clusters differentiated by corruption quality, and finds that traditional determinants of economic growth — including investment, human capital, and institutional quality — exert heterogeneous effects depending on the prevailing corruption regime. This contribution reinforces the case for robustness test R4 in the present paper, which explicitly tests the conditional interaction between governance quality and income level.

Raya-Quero et al. (2024) contribute a subnational perspective, analyzing the determinants of perceived corruption across regional governments in Spain using monthly panel data. Their findings confirm that fiscal transparency, audit coverage, and political competition are significant predictors of corruption perceptions at the sub-national level, highlighting that the determinants of corruption identified in cross-country analyses also operate within countries at the regional scale. This subnational evidence is particularly relevant for European Union member states, where regional institutional heterogeneity is substantial.

Collectively, this recent literature reinforces three conclusions that motivate the methodological choices of the present paper. First, the use of dynamic panel estimators that explicitly model corruption persistence is essential: static models systematically understate the long-run magnitude of structural determinants. Second, cross-sectional dependence is pervasive in international corruption data and must be addressed through appropriate standard errors (Driscoll-Kraay) or heterogeneous estimators (AMG). Third, institutional effects are conditional on income level and governance regime, supporting the inclusion of interaction terms and nonlinear specifications as robustness checks.

3. Data, Variables, and Methodology

3.1 Sample and Data Sources

The empirical analysis is based on a balanced panel of 32 countries observed annually over the period 2004–2023, yielding 640 country-year observations ($N=32$, $T=20$).

The dependent variable is the **inverted Corruption Perceptions Index** ($y_{\text{cpi}}=100-\text{CPI}$), sourced from Transparency International. The four core predictors are: GDP per capita in PPP constant USD, log-transformed ($\ln_{\text{gdp}}$, World Bank WDI); government effectiveness rescaled to 0–100 (gov_{ef} , World Governance Indicators); gross fixed capital formation as a percentage of GDP (gfcf , World Bank WDI); and tertiary education attainment among the population aged 25+ (educ_{25} , World Bank EdStats, ISCED 5–8).

Table 1 presents the descriptive statistics for all variables in the working sample.

Table 1. Descriptive statistics ($N=32$, $T=20$, $NT=640$)

Variable	Mean	Std. Dev.	Min	Max	Source
y_{cpi}	36.80	18.16	3.00	78.00	Transparency International
$\ln_{\text{gdp}}$	10.671	0.458	9.511	11.840	World Bank WDI (log-transformed)
educ_{25}	27.298	9.529	9.160	51.250	World Bank EdStats
gfcf	21.969	4.232	10.970	53.210	World Bank WDI

gov_ef	79.510	16.534	20.853	100.000	World Bank WGI

Note. $y\_cpi=100-CPI$; $\ln\_gdp=\log$ GDP per capita PPP constant USD; $educ\_25=\%$ pop. 25+ ISCED 5–8; $gfcf=GFCF\%$ GDP; $gov\_ef=$ Government Effectiveness WGI, [0–100].

3.2 Research Hypotheses

H1: *GDP per capita is negatively associated with perceived corruption, both in the short run and in the long run (Mauro, 1995; Treisman, 2000).*

H2: *Government effectiveness is negatively associated with perceived corruption, reflecting the role of administrative quality in reducing rent-seeking opportunities (Kaufmann et al., 2010; Rose-Ackerman, 1999).*

H3: *Gross fixed capital formation is positively associated with perceived corruption in the short run, consistent with rent-seeking mechanisms in public investment booms (Tanzi & Davoodi, 1997; Shleifer & Vishny, 1993).*

H4: *Tertiary education attainment is negatively associated with perceived corruption over the medium term, through civic norm consolidation and information asymmetry reduction, despite potential positive contemporaneous effects driven by endogeneity (Glaeser & Saks, 2006; Uslaner, 2008).*

3.3 Pre-Estimation Testing Protocol

Prior to model estimation, we conduct a comprehensive pre-estimation testing protocol. The **Pesaran (2004) CD** test confirms significant cross-sectional dependence for $\ln\_gdp$, $educ\_25$, and $gfcf$ ($p<0.001$), justifying the use of **Driscoll-Kraay standard errors** and the **CIPS unit root test** (Pesaran, 2007) as the preferred procedure robust to cross-sectional dependence. The CIPS test classifies all five series as $I(1)$ at the 5% significance level, with statistics ranging from -1.669 to -2.032 , all above the critical value of -2.86 . Cointegration is confirmed by three test batteries: **Pedroni** (1999, 2004) rejects the null of no cointegration in 5 of 7 statistics; **Kao** (1999) rejects at $p<0.001$; and **Westerlund** (2007) documents a mean error-correction coefficient of $\alpha=-0.849$, with 96.9% of countries exhibiting mean-reversion. These results validate the interpretation of long-run estimates as structural equilibrium relationships.

3.4 Econometric Specifications

We estimate seven progressively refined specifications. The **general model** takes the form:

$$y\_cpi_{it} = \phi_1 y\_cpi_{i,t-1} + \phi_2 y\_cpi_{i,t-2} + \beta_1 \ln\_gdp_{it} + \beta_2 educ\_25_{it} + \beta_3 gfcf_{it} + \beta_4 gov\_ef_{it} + \alpha_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where:

- y_cpi_{it} represents the dependent variable, namely the corruption perception index (100-CPI) for country i at time t .
- ϕ_1 and ϕ_2 are the autoregressive coefficients associated with the first and second lags of the dependent variable. These parameters capture the dynamic persistence of corruption over time, reflecting how past levels of corruption influence current levels.
- $y\_cpi_{i,t-1}$ and $y\_cpi_{i,t-2}$ denote the first and second lag of the dependent variable, respectively.
- β_1 measures the effect of economic development, proxied by the natural logarithm of GDP, on corruption.
- β_2 captures the impact of human capital, proxied by the share of the population aged 25+ with education ($educ25+$), on corruption.

- β_3 represents the effect of investment, proxied by gross fixed capital formation, on corruption.
- β_4 measures the influence of government effectiveness on corruption outcomes.
- α_i denotes country-specific fixed effects, capturing unobserved, time-invariant heterogeneity across countries (e.g., cultural, institutional, or historical factors).
- λ_t represents time fixed effects, accounting for common shocks or global trends affecting all countries in a given period (e.g., financial crises, energy crises, EU-wide policies).
- ε_{it} is the idiosyncratic error term, assumed to have zero mean and capturing random shocks not explained by the model.

Long-run effects are computed as $LRE_k = \beta_k / (1 - \phi_1 - \phi_2)$ (2)

where:

- β_k = Short-run coefficient of variable k .
- ϕ_1, ϕ_2 are the autoregressive coefficients.
- The denominator $1 - \phi_1 - \phi_2$ reflects how quickly the system converges to its long-run equilibrium (adjustment factor/persistence term).

The AR (2) lag structure resolves residual autocorrelation present in all static specifications. Time fixed effects are included in M7 on the basis of an F-test result ($F(19,583)=1.93$, $p=0.010$). All standard errors are Driscoll-Kraay (bandwidth=3), robust to cross-sectional dependence, heteroscedasticity, and serial autocorrelation.

4. Results

4.1 Model Progression and Specification Selection

Table 2 presents the diagnostic scorecard for all seven model specifications. The progression from M1 (Pooled OLS) to M7 (TWFE Dynamic AR(2) + DK-SE) systematically addresses each source of misspecification identified in the data. All static specifications — M1 through M4 and M6 — fail the AR(1) and AR(2) residual autocorrelation diagnostics, confirming that the dynamic structure of corruption cannot be ignored. The dynamic one-way FE model (M5) resolves the autocorrelation problem but fails the Breusch-Pagan heteroskedasticity test and does not control for time fixed effects. Model M7 is the only specification to simultaneously pass all three diagnostic criteria, with AR(1) $p=0.456$, AR(2) $p=0.601$, and Breusch-Pagan $p=0.480$.

Table 2. Model comparison scorecard (M1–M7)

Model	Specification	AR(1)	AR(2)	BP	FE	Mult.	R ²	Verdict
M1	OLS Pooled	FAIL	FAIL	FAIL	None	—	0.866	Rejected — OVB
M2	FE Naive SE	FAIL	FAIL	FAIL	One-way	—	0.235	Rejected — invalid SE
M3	FE Cluster-SE	FAIL	FAIL	FAIL	One-way	—	0.235	Week — AC persists
M4	FE DK-SE	FAIL	FAIL	FAIL	One-way	—	0.235	Week — AC persists
M5	FE Dyn. AR(2) DK	OK	OK	FAIL	One-way	4.69×	0.744	Good — AC resolved
M6	TWFE DK-SE	FAIL	FAIL	FAIL	Two-way	—	0.238	Week — AC persists
M7	TWFE Dyn. AR(2) + DK	OK	OK	OK	Two-way	4.84×	0.749	Very Good, PREFERRED

Note. $AR(1)$, $AR(2)$ = residual autocorrelation tests; BP = Breusch-Pagan heteroskedasticity test; Multiplier = long-run multiplier; FAIL = $p < 0.05$; OK = $p > 0.05$. DK = Driscoll-Kraay SE.

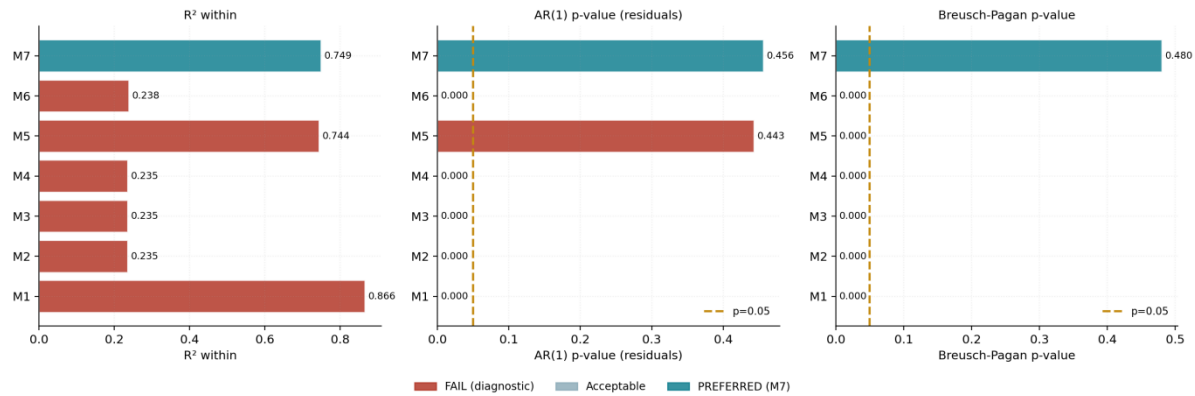


Figure 1. Model comparison M1–M7: R^2 , AR autocorrelation, and BP heteroscedasticity test p-values.

It can be observed that Model M7 (TWFE Dynamic AR(2) + DK-SE) is the only specification to satisfy all three diagnostic criteria simultaneously — AR(1), AR(2), and Breusch-Pagan — while all static models (M1–M4, M6) fail the autocorrelation tests, confirming that ignoring the dynamic persistence of corruption leads to systematically misspecified inference. They also do not pass heteroscedasticity tests. The within- R^2 improves from 0.235 in the static fixed-effects model (M2–M4) to 0.749 in M7, reflecting the substantial explanatory gain from explicitly modeling corruption's temporal dependence.

4.2 Preferred Model M7: Results and Long-Run Effects

Table 3 presents the full coefficient estimates for the preferred model M7. The autoregressive coefficients $\phi_1 = +0.862$ and $\phi_2 = -0.069$ yield an adjustment speed of $d = 0.207$, a long-run multiplier of $4.84\times$, and a half-life of approximately 3 years, confirming the extreme temporal persistence of corruption.

Table 3. Preferred model M7 — TWFE Dynamic AR(2) + Driscoll-Kraay SE

Variable	SR coeff.	DK-SE	t-stat	p-value	LRE	Sig.
y_lag1	+0.8622	0.0023	372.9	<0.001	—	***
y_lag2	−0.0690	0.0016	−43.3	<0.001	—	***
ln_gdp	−1.4242	0.0334	−42.7	<0.001	−6.886	***
educ_25	+0.0721	0.0019	+38.7	<0.001	+0.349	***
gfcf	+0.0261	0.0006	+43.5	<0.001	+0.126	***
gov_ef	−0.0625	0.0009	−67.1	<0.001	−0.302	***

Note. $N=640$, $R^2_{within}=0.749$, $d=0.207$, multiplier= $4.84\times$, half-life=3.0 years. $LRE=\beta/(1-\phi_1-\phi_2)$. DK-SE=Driscoll-Kraay standard errors (bandwidth=3). $AR(1)$: $p=0.456$; $AR(2)$: $p=0.601$; Breusch-Pagan: $p=0.480$. Time FE: $F(19,583)=1.93$, $p=0.010$. *** $p < 0.001$.

Figure 2 illustrates the impulse response function and cumulative dynamic response to a unit shock in y_{cpi} .

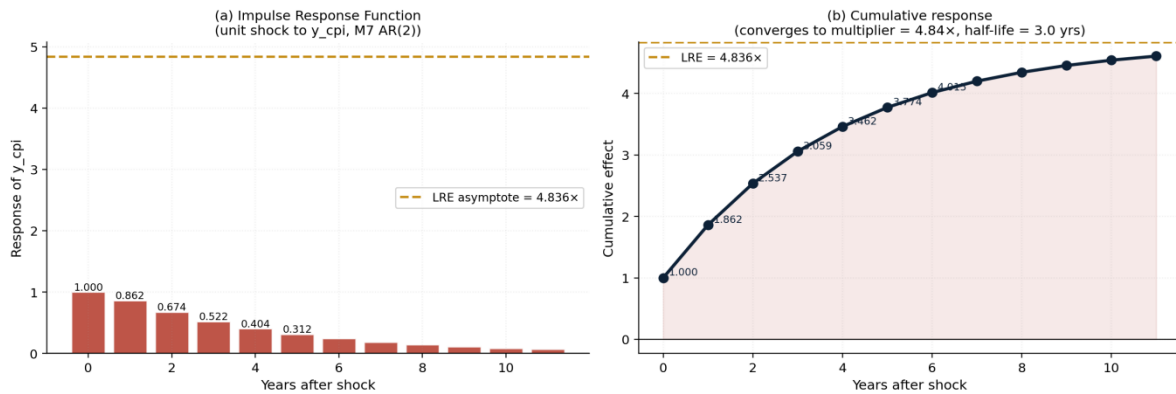


Figure 2. Impulse response function and cumulative dynamic response to a unit shock in y_cpi (Model M7, AR(2)). $\phi_1=+0.862$, $\phi_2=-0.069$, multiplier=4.84 $\times$, half-life=3.0 years.

It can be observed that the impulse response function exhibits a sharply asymmetric dynamic profile: the immediate short-run response is close to unity (by construction of the AR(2) structure), followed by a gradual but persistent decay that reaches approximately 50% of the initial shock after three years and converges to the full long-run multiplier of 4.84 $\times$ only after approximately 10 periods (years). This pattern confirms that corruption is far more persistent than typical macroeconomic variables and that any single-year or two-year evaluation window will systematically underestimate the cumulative structural impact of anti-corruption interventions or adverse institutional shocks.

GDP per capita (ln_gdp). A 1% increase in GDP per capita reduces perceived corruption by 1.424 points in the short run and 6.886 points in the long run, **confirming H1**. This is the quantitatively dominant effect in the model, consistent with the institutional consolidation mechanism documented by Mauro (1995) and Treisman (2000).

Government effectiveness (gov_ef). A one-point increase in the government effectiveness index reduces y_cpi by 0.063 points in the short run and 0.302 points in the long run, **confirming H2**. With $t = -67.1$, this is the most precisely estimated coefficient in the model.

Gross fixed capital formation (gfcf). Investment intensity is positively associated with perceived corruption (SR=+0.026, LRE=+0.126, $p<0.001$), **confirming H3**. This result is consistent across all robustness specifications and supports the rent-seeking hypothesis: investment booms create procurement and contracting opportunities that amplify corruption in the short- to medium-run.

Tertiary education (educ_25). The within-country coefficient is positive and significant (SR = +0.072, LRE = +0.349, $p < 0.001$), contrary to the direction predicted in H4. As discussed in Section 4.3, this result is interpreted as reflecting endogeneity, compositional dynamics, and the long institutional lag between educational expansion and civic norm consolidation. **H4 is not supported**. Further investigations are needed.

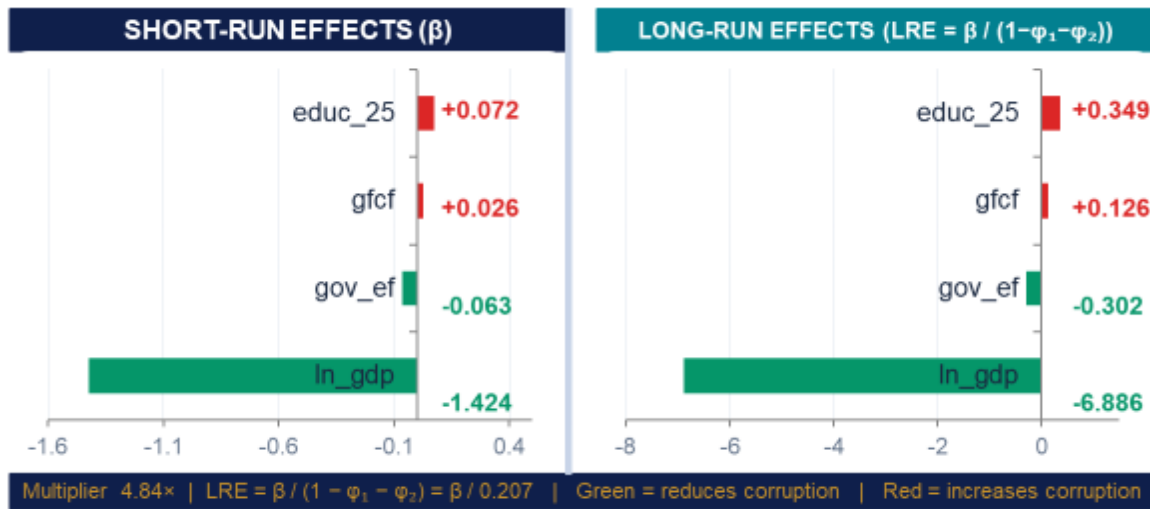


Figure 3. Short-run (SR) and long-run (LRE) effects of all predictors — Model M7.

Green (negative)= reduces corruption; red (positive)= increases corruption.

It can be observed that GDP per capita (ln_gdp) dominates all other predictors by a wide margin, with a long-run effect (LRE = −6.886) that is approximately 23 times larger than that of government effectiveness (LRE = −0.302). The long-run amplification from the dynamic multiplier (4.84×) substantially exceeds the short-run effects for every regressor, underscoring that interpreting static panel estimates as long-run structural effects leads to a severe underestimation of the true magnitude of corruption determinants. Notably, both positive predictors (gfcf and educ_25) exhibit a similar amplification pattern, indicating that investment booms and human capital expansion also have larger cumulative effects on corruption than their short-run coefficients suggest.

4.3 Robustness Tests

Table 4 presents the results of the **four robustness tests (R1–R4)**. The signs of all long-run effects are preserved across all specifications, confirming the directional stability of the main findings.

Table 4. Long-run effects — Robustness tests R1–R4

Variable	M7-REF (LRE)	R1 (AR3)	R2 (Lagged X)	R3 (Quadratic)	R4 (Interaction)
ln_gdp	−6.818	−7.159	−5.575	−5.999	−5.851
educ_25	+0.385	+0.387	+0.257	+0.362	+0.353
gfcf	+0.105	+0.112	+0.212	+0.096	+0.101
gov_ef	−0.301	−0.290	−0.251	−0.302	−0.282
ln_gdp ²	—	—	—	+2.317***	—
(gov_ef)x(ln_gdp)	—	—	—	—	+0.124***

Note. All models estimated with TWFE AR(2) + Driscoll-Kraay SE on the common sample (N=608, T=19). M7-REF=benchmark. R1=AR(3) specification. R2=lagged regressors X_{t-1} . R3=quadratic GDP. R4=interaction gov_ef×ln_gdp. *** $p < 0.001$.

R1 — Lag order. AR(3) residual autocorrelation in M7-REF ($p = 0.004$) motivates the AR(3) specification. Long-run effects remain stable (maximum deviation: 0.34 points for $\ln\_gdp$), confirming the robustness of the main results. In the future, research can be extended to the M8 model and beyond.

R2 — Endogeneity. Replacing contemporaneous regressors with one-period lags preserves the signs of all four long-run effects, confirming that the directional findings are not artifacts of reverse causality.

R3 — GDP nonlinearity. The *quadratic GDP* term is positive and significant ($b = +0.524$, $LRE = +2.317$, $p < 0.001$). The inflection point at $\ln\_gdp^* = 11.97$ ($\approx 158,575$ USD PPP) lies outside the observed sample range, indicating that the dominant relationship within the sample is negative and approximately linear.

R4 — Institutional interaction. The interaction $gov\_ef \times \ln\_gdp$ is positive and significant ($b = +0.028$, $LRE = +0.124$, $p < 0.001$), confirming that governance improvements yield substantially larger anti-corruption returns in lower-income countries. The marginal effect of government effectiveness on Ukraine's income level (-0.090) is approximately three times that for Luxembourg (-0.033).

Below is a visual representation of the data from the previous table.

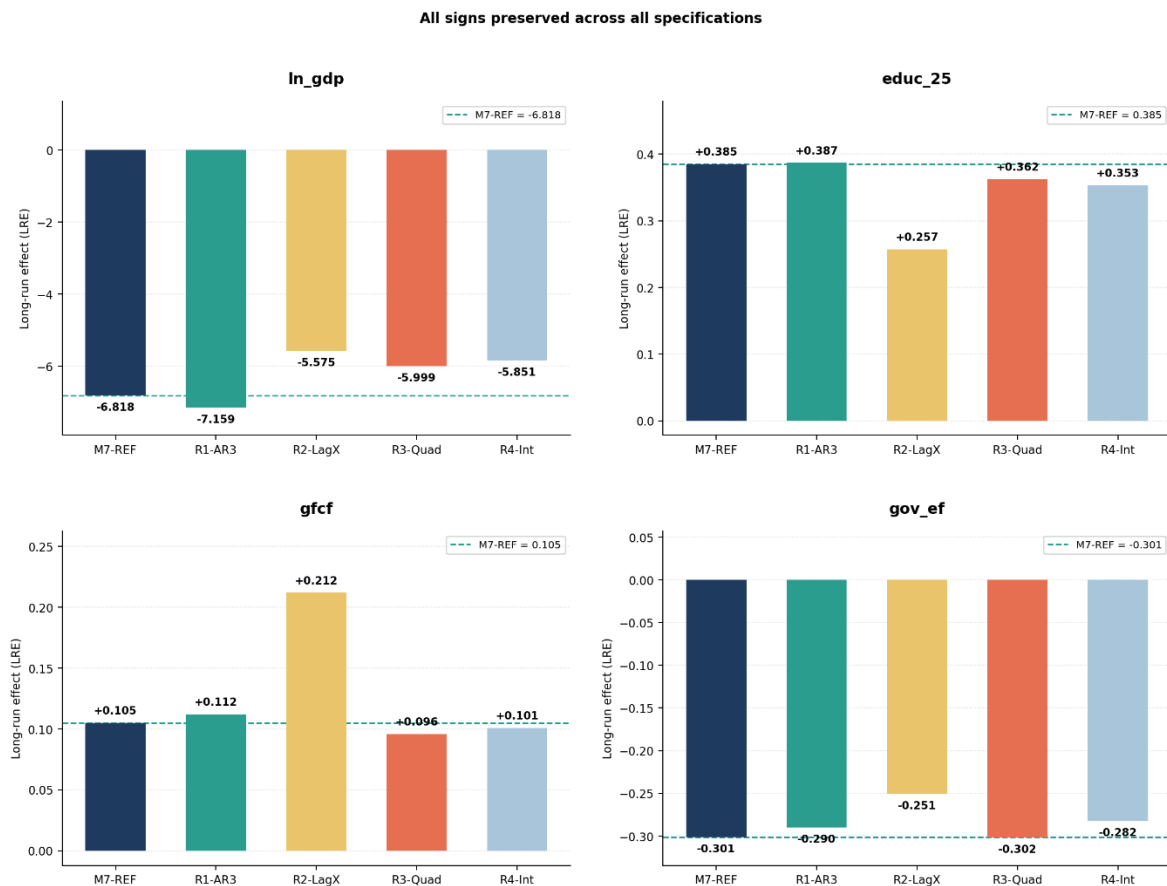


Figure 4. Stability of long-run effects across robustness specifications R1–R4. All signs are preserved across all specifications.

It can be observed that all four long-run effects retain their sign across all robustness specifications (R1–R4), providing strong evidence of directional stability. The most stable predictor is government effectiveness (gov_ef), whose long-run estimate varies by less than 0.05 points across all specifications (range: -0.251 to -0.302). The GDP effect shows the largest absolute variation (-5.575 to -7.159), yet its sign and order of magnitude remain consistent. The positive sign of the education and investment coefficients is also uniformly preserved, confirming that their short-run corruption-increasing effects are not an artifact of the baseline specification.

5. Discussion and Policy Implications

5.1 Structural Persistence and the Long-Run Horizon

The most fundamental finding of this paper is the extreme temporal persistence of corruption: with a long-run multiplier of $4.84\times$ and a half-life of three years, any structural determinant that shifts corruption in year t will still generate measurable effects in years $t+3$ through $t+6$. This persistence has a direct implication for policy evaluation: anti-corruption interventions measured over one or two electoral cycles will systematically underestimate the true long-run impact of governance reforms. Anti-corruption strategies must be designed, funded, and evaluated over multi-year horizons, and their effectiveness cannot be judged by short-run changes in CPI scores alone.

5.2 Economic Development as the Primary Lever

The dominant magnitude of the GDP effect ($LRE=-6.886$) relative to all other predictors suggests that broad-based economic development remains the most powerful anti-corruption mechanism. This finding does not imply that institutional reforms are ineffective, but it does indicate that sustained income growth — through productivity enhancement, trade integration, and investment in human capital — is a necessary complement to institutional reform strategies. Countries in the lower-income tercile of the sample face a structural disadvantage in corruption governance that cannot be fully compensated by administrative reforms alone.

5.3 Institutional Reform and Conditional Effects

Government effectiveness is the most precisely estimated anti-corruption predictor ($t = -67.1$), confirming that administrative quality is a robust structural determinant of lower corruption. The $R4$ interaction finding implies that the returns to institutional improvement are substantially higher in lower-income countries: institutional strengthening programs in emerging economies should be prioritized over marginal reforms in already well-governed advanced economies, where the anti-corruption payoff per unit of reform effort is substantially lower.

5.4 Investment, Procurement, and Rent-Seeking

The consistently positive association between GFCF and perceived corruption across all specifications (LRE ranging from $+0.096$ to $+0.212$) is directly policy-relevant. It suggests that investment booms — particularly in public infrastructure, construction, and energy — create conditions that amplify corruption unless accompanied by commensurate strengthening of procurement transparency, contract oversight, and anti-corruption enforcement. Countries undertaking large-scale public investment programs should treat the prevention of procurement corruption as an integral component of investment strategy.

5.5 Education: A Long-Term Investment with Uncertain Short-Run Returns

The positive within-country coefficient on tertiary education attainment reflects three overlapping mechanisms: compositional dynamics, a long institutional lag between educational expansion and civic norm consolidation, and the potential for higher education to increase the efficiency of rent-seeking in weak institutional environments (e.g., Uslander, 2008). The policy implication is that educational investment must be complemented by institutional reform to generate the anticipated anti-corruption benefits: expanding university enrolment in a context of pervasive governance failures may produce graduates who are more equipped to navigate corrupt systems rather than to challenge them.

Conclusions

This paper investigates the structural determinants of perceived corruption for a balanced panel of 32 emerging and advanced economies over the period 2004–2023. Using a systematic progression of seven econometric specifications, supported by a comprehensive pre-estimation testing protocol, the preferred model M7 (TWFE Dynamic AR (2) + DK-SE) is identified as the only specification that satisfies all diagnostic criteria simultaneously.

The main findings are as follows. Corruption exhibits extreme temporal persistence, with a long-run multiplier of $4.84\times$ and a half-life of three years. GDP per capita is the most strongly associated corruption-reducing factor (LRE = -6.886). Government effectiveness exerts a robust negative effect (LRE = -0.302), with substantially higher anti-corruption returns in lower-income countries, as confirmed by the significant interaction term in R4. Gross fixed capital formation is consistently and robustly positively associated with corruption (LRE = +0.126), supporting the rent-seeking hypothesis, especially for public investment booms. Thus, the first 3 research hypotheses (H1, H2, and H3) are empirically validated. By exception, the result of the H4 research hypothesis is counterintuitive. The within-country association between tertiary education attainment and corruption is positive — interpreted as reflecting endogeneity, compositional dynamics, and long institutional lags rather than a fundamental reversal of the theoretical relationship. At the same time, the result obtained requires an additional approach: using lags for the education predictor, since education does not produce immediate effects.

Four robustness tests confirm the directional stability of all long-run effects. The nonlinearity of the income–corruption relationship is confirmed, with an inflection point beyond the observed sample range, and the conditional nature of institutional effects across income levels is established.

Future research should address the endogeneity of the full regressor set using Arellano-Bond GMM estimators, extend the analysis to a larger cross-section, investigate the temporal structure of the education–corruption relationship through distributed lag models over longer panels, examine spatial cross-country spillovers, and conduct subnational analysis.

Acknowledgment: The authors report the use of artificial intelligence (AI)-assisted tools in a limited, supportive capacity, specifically for generating Python code for econometric data processing and for linguistic refinement of the manuscript. The authors independently conducted all data collection, methodological design, econometric estimation, and interpretation of the results. The conclusions expressed in this paper are entirely those of the authors.

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EVOLUTION AND INNOVATION IN INDIAN RAILWAY TRAIN COACHES

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ABSTRACT

The Indian Railways, one of the world's largest rail networks, has witnessed remarkable transformation in its coach manufacturing and design over the past decades. This paper presents a comprehensive overview of the technological advancements, design innovations, and sustainability initiatives shaping modern Indian railway coaches. Indian railway coaches have evolved from conventional ICF (Integral Coach Factory) designs to advanced LHB (Linke-Hofmann-Busch) and now to fully air-conditioned Vande Bharat Express coaches. This evolution reflects India's commitment to enhancing passenger experience, safety, and operational efficiency. The contemporary Indian railway coach portfolio includes multiple categories: AC First Class, AC Two-Tier, AC Three-Tier, Sleeper Class, and Chair Car variants. Recent innovations encompass improved ventilation systems, ergonomic seating, onboard entertainment, Wi-Fi connectivity, and bio-toilet facilities. The introduction of Vande Bharat trains represents a paradigm shift with crash-resistant design, automatic doors, modular interiors, and energy-efficient propulsion. Modern coaches incorporate advanced safety features including improved brake systems, fire-retardant materials, and real-time monitoring sensors. The adoption of stainless steel and aluminum alloy construction has enhanced durability while reducing maintenance costs. Additionally, the implementation of AI-based coach health monitoring systems has revolutionized predictive maintenance. The continuous innovation in Indian railway coach design demonstrates India's dedication to providing world-class rail transportation. Future developments focusing on green technologies, enhanced accessibility, and smart features position Indian railway coaches as models for emerging economies. This transformation significantly contributes to sustainable mobility and national infrastructure development.

Keywords: Indian Railways, coach design, Vande Bharat, LHB coaches, railway innovation, passenger experience.

1. INTRODUCTION

1.1 Background of Indian Railways

Indian Railways stands as one of the world's largest railway networks, operating under the Ministry of Railways, Government of India. With a network spanning over 68,000 kilometers of track and serving millions of passengers daily, Indian Railways represents a lifeline for India's transportation infrastructure. The railway network connects virtually every corner of the nation, facilitating both urban and rural connectivity and playing a pivotal role in the country's economic development [1].

The history of Indian Railways dates back to 1853, when the first passenger train operation began between Mumbai and Thane. Over more than a century and a half, the railway system has evolved significantly, with coach technology advancing from wooden carriages to modern air-conditioned coaches with state-of-the-art amenities. The development of railway coaches in India has paralleled technological advancements globally while adapting to the unique requirements of the Indian context, including the broad gauge (1676 mm) track system that forms the backbone of the network [1].

1.2 Importance of Railway Coaches in Passenger Transportation

Railway coaches, also referred to as passenger cars or carriages, constitute essential rolling stock in any railway system. These vehicles are specifically designed for passenger transportation and come in

various configurations to serve different operational requirements. The design and classification of coaches significantly impact passenger comfort, safety, and operational efficiency.

In the Indian context, railway coaches assume particular importance due to the vast population relying on rail transportation for daily commutes, long-distance travel, and pilgrimage journeys. The heterogeneity of Indian society, particularly the wide disparity in income levels among the population, necessitates the provision of multiple travel classes ranging from luxurious first-class accommodations to affordable unreserved seating [2].

1.3 Evolution of Coach Technology in India

The evolution of railway coach technology in India can be traced through several phases. The initial phase involved the import of coaches from Britain and other colonial powers during the British Raj. Post-independence, India established indigenous coach manufacturing facilities, most notably the Integral Coach Factory (ICF) in Perambur, Chennai, which began production in 1955. The ICF design became the standard for conventional coaches across Indian Railways for decades.

The introduction of Linke Hofmann Busch (LHB) coaches in 2000 marked a significant technological advancement. These coaches, initially imported from Germany and later manufactured domestically at the Rail Coach Factory in Kapurthala, brought improvements in safety, speed, and passenger comfort. The transition from ICF to LHB coaches represents India's adoption of international coach technology while maintaining self-sufficiency in manufacturing [3].

1.4 Purpose and Scope of the Study

This paper aims to provide a comprehensive analysis of Indian Railway coaches, covering their classification systems, types of coaches in use, various travel classes offered to passengers, and the classification of berths. The study draws upon official Indian Railways documentation, technical specifications, and established railway engineering literature to present a holistic view of the subject.

2. TRAVEL CLASSES IN INDIAN RAILWAYS

The Indian Railways offers as many as ten distinct classes of travel, reflecting the diverse needs and paying capacities of the Indian population. However, no single train offers all ten classes simultaneously; the composition varies based on route popularity, demand patterns, and operational considerations. The selection of travel class profoundly influences the passenger's journey experience, with significant variations in comfort, amenities, privacy, and services provided [2].

It is noteworthy that Indian Railways has progressively introduced LHB coaches on select trains and routes, offering passengers an enhanced travel experience. While fare structures remain consistent regardless of whether a train utilizes newer LHB coaches or older ICF coaches, passengers traveling in LHB-equipped trains benefit from improved safety features, better ride quality, and superior amenities [2].

2.1 First AC Sleeper (1A)

First AC Sleeper represents the highest class of travel offered by Indian Railways and consequently commands the premium pricing. This class provides an exclusive travel experience characterized by enhanced privacy and personalized services. The coaches are configured with four-berth cabins and two-berth coupes, with locking facilities that allow passengers to secure their compartments from inside.

The limited availability of First AC Sleeper coaches is noteworthy; this class is restricted to more popular trains with consistently high demand across all travel classes. The exclusivity of this class ensures that passengers enjoy a relatively quiet and comfortable journey, making it particularly suitable for business travelers and those seeking premium rail travel experiences.

2.2 Executive Class (EA)

Executive Class represents Indian Railways' interpretation of business-class air travel and is available exclusively on Shatabdi Express trains and certain day-running Duronto Express services. This class incorporates catering services within the ticket fare, eliminating the need for passengers to make separate arrangements for meals during their journey.

The dining experience in Executive Class surpasses that offered in other travel classes, with meals of superior quality and larger quantities served to passengers. The comfortable seating, reduced passenger density, and included catering services make Executive Class an attractive option for day journeys between major cities. Shatabdi Express trains, known for their punctuality and connectivity between important city pairs, feature Executive Class as their premium offering [4].

2.3 Second AC Sleeper (2A)

Second AC Sleeper constitutes the second-highest sleeping accommodation class provided by Indian Railways and is commonly found on overnight trains across various routes. This class offers passengers a balanced combination of comfort and affordability, making it a popular choice for long-distance travel.

The coach configuration provides adequate space for passengers, and the class is well-suited for journeys ranging from short to extended durations, provided passengers secure adjacent berths. However, Second AC Sleeper offers reduced privacy compared to First AC Sleeper, as these compartments lack the locking doors characteristic of the higher class. The arrangement typically features eight bays, each containing six inner berths and two side berths [2].

2.4 First Class Non-AC (FC)

First Class Non-AC represents a progressively rare travel class as Indian Railways has been phasing it out in favor of Three-tier AC Sleeper due to economic considerations. This class was once a prestigious offering but now operates on limited routes, primarily in South India (particularly Tamil Nadu) and select services in the northern region.

The internal configuration of First Class Non-AC closely resembles First AC Sleeper, with the coach divided into four-berth cabins and two-berth coupes featuring sliding doors that can be bolted from inside. The passenger density is relatively low, with approximately 26 passengers per coach, offering a more exclusive travel experience. However, the declining demand and operational costs have led to the gradual discontinuation of this class on most routes [2].

2.5 Three-tier AC Sleeper (3A)

Three-tier AC Sleeper, commonly known as Third AC, represents one of the most sought-after air-conditioned classes in Indian Railways. It offers the most affordable air-conditioned sleeping accommodation, making it accessible to a broader segment of passengers. This class strikes an optimal balance between comfort and cost, contributing to its popularity across various passenger demographics.

The layout of Three-tier AC Sleeper mirrors that of Second AC Sleeper, with the coach divided into eight bays, each containing six inner berths and two side berths. The air-conditioned environment provides relief from extreme temperatures, while the sleeping berths ensure comfortable overnight journeys. This class is particularly preferred for long-distance travel where passengers seek affordable yet comfortable accommodations [2].

2.6 AC Sleeper Economy (3E)

AC Sleeper Economy represents a relatively uncommon travel class, primarily found on select Duronto Express trains. Garib Rath Express trains feature similar accommodation but are classified under the regular Three-tier AC category, creating some inconsistency in classification.

The distinguishing feature of AC Sleeper Economy is its open-plan layout, lacking the privacy curtains characteristic of Second AC Sleeper. Another significant difference lies in the side berth configuration, with three side berths per bay compared to two in standard Three-tier AC Sleeper. The reduced privacy is offset by competitive pricing, making this class an economical option for budget-conscious travelers [2].

2.7 AC Chair Car (CC)

AC Chair Car provides comfortable seating for short-duration daytime journeys and is commonly found on intercity express services, including Shatabdi Express and day-running Duronto trains. The air-conditioned environment and 3×2 seating arrangement offer a comfortable travel experience for journeys typically lasting a few hours.

While AC Chair Car experiences higher passenger density compared to Executive Class, it remains a comfortable option for day travel between cities. The affordability relative to Executive Class makes this class popular among business travelers and tourists seeking convenient daytime connectivity. The availability of AC Chair Car across numerous train services ensures wide accessibility for passengers [2].

2.8 Sleeper Class Non-AC (SL)

Sleeper Class represents the most widely used reserved class in Indian Railways, with the majority of reserved passengers traveling in this category. This class forms the backbone of overnight train services, with most coaches in regular overnight trains being Sleeper Class configurations.

The design philosophy of Sleeper Class can be understood as Three-tier AC Sleeper without air-conditioning and complimentary bedding. The coaches are designed to accommodate 72 passengers across nine bays, each containing six inner berths and two side berths. Passengers in this class do not receive privacy curtains, reading lights, or climate control, making the journey experience dependent on external conditions.

Sleeper Class coaches can experience dust penetration and temperature variations reflecting external weather conditions. During daytime, these coaches may experience increased passenger density from short-distance travelers, adding to the crowded conditions. Despite these limitations, Sleeper Class remains the preferred choice for budget-conscious passengers undertaking long-distance journeys [2].

2.9 Second Class Sitting (2S)

Second Class Sitting serves as the cheapest reserved class available on most daytime intercity trains. This class provides basic seating without reclining capabilities, with a 3×3 seating arrangement. While some newer Second Class Sitting coaches feature individual seats, the majority retain the traditional bench-type seating, with each bench accommodating three passengers.

The affordability of Second Class Sitting makes it accessible to the economically disadvantaged segments of society, facilitating mobility for those who might otherwise be unable to afford rail travel. The class serves as an important link in the transportation chain, connecting smaller towns and cities with major urban centers [2].

2.10 Unreserved Class (UR)

Unreserved Class represents the most economical travel option on Indian Railways, requiring no advance reservation. Passengers can purchase tickets and board coaches directly, making this class particularly popular among daily commuters and economically constrained travelers.

This class serves as a vital transportation lifeline for the economically disadvantaged sections of Indian society, providing affordable mobility across the country. However, the limited allocation of unreserved

coaches—typically only two per Express train—often leads to severe overcrowding. The discrepancy between demand and supply in this class highlights the ongoing challenges in meeting the transportation needs of India's vast population [2].

3. TYPES OF COACHES

3.1 LHB Coaches

Linke Hofmann Busch (LHB) coaches represent the modern standard of passenger coach design in Indian Railways. Originally developed by Linke-Hofmann-Busch of Germany (renamed Alstom LHB GmbH in 1998 following acquisition by Alstom), these coaches have been progressively introduced on the broad gauge network since 2000. The initial batch of 24 air-conditioned coaches was imported from Germany for deployment on Shatabdi Express services, followed by domestic production at the Rail Coach Factory in Kapurthala through technology transfer arrangements [3][5].

3.1.1 Technical Specifications and Design Features

LHB coaches incorporate numerous technological advancements over their ICF predecessors. The coaches are 1.7 meters longer than conventional ICF coaches, enabling enhanced seating capacity without compromising operational efficiency. The maximum permissible speed for LHB coaches is 160 km/h, with successful trials conducted at speeds ranging up to 200 km/h, compared to the 110 km/h limit for ICF coaches [3].

The safety features of LHB coaches represent a significant advancement. These coaches are designed with anti-telescopic properties, preventing penetration into adjacent coaches during accidents—a critical improvement over earlier designs. The implementation of Center Buffer Coupling (CBC) replaces the traditional dual buffer system, preventing coaches from climbing onto adjacent vehicles during collision or derailment incidents [3].

3.1.2 FIAT Bogie Technology

LHB coaches utilize FIAT bogies, which feature fewer moving components compared to ICF bogies. This simplification results in enhanced durability and reduced maintenance requirements. The superior engineering of FIAT bogies facilitates higher speeds while maintaining ride stability and passenger comfort. The reliability of FIAT bogies has been proven through extensive operational experience on Indian Railways [3].

3.1.3 Advantages Over ICF Coaches

The advantages of LHB coaches over ICF coaches can be summarized as follows:

Parameter	LHB Coach	ICF Coach
Maximum Speed	160 km/h (tested up to 200 km/h)	110 km/h
Coach Length	1.7 meters longer than ICF	Standard length
Safety Features	Anti-telescopic, CBC system	Conventional design
Bogie Design	FIAT bogie with fewer moving parts	Traditional bogie
Maintenance	Lower maintenance requirements	Higher maintenance
Passenger Capacity	Higher due to increased length	Standard capacity

3.2 ICF Coaches

The Integral Coach Factory (ICF), located in Perambur near Chennai, represents one of Indian Railways' primary coach manufacturing facilities. The ICF design refers to the conventional coach design that dominated Indian Railways for decades, with production continuing from 1955 until January 2018 [1].

3.2.1 Design Characteristics

ICF coaches feature a distinctive design with the coach body integrated with the underframe as a single structure. This construction method, while economical, results in certain limitations compared to modern designs. The conventional ICF coach design has been phased out for new production in favor of LHB coaches, though substantial numbers of ICF coaches remain in service across the network.

These coaches served as the workhorse of Indian Railways, operating on the majority of main-line train services. The widespread deployment of ICF coaches established the familiar visual identity of Indian passenger trains. Despite the transition to LHB coaches for new acquisitions, ICF coaches continue to play a vital role in passenger transportation, particularly on less heavily traveled routes [1].

4. CLASSIFICATION OF BERTHS

The berth classification system in Indian Railways follows a systematic nomenclature that indicates the position and location of each sleeping accommodation within the coach. This standardized system ensures consistent identification and allocation of berths across different train services [6].

4.1 Berth Categories

The berth classification includes the following categories:

- LB (Lower Berth): The lower sleeping berth positioned at floor level within the compartment
- MB (Middle Berth): The middle berth found in three-tier configurations, available only in 3A, 3E, and SL classes
- UB (Upper Berth): The upper sleeping berth positioned above the lower berth
- SLB (Side Lower Berth): The lower berth located along the side of the coach
- SUB (Side Upper Berth): The upper berth positioned along the side of the coach
- SMB (Side Middle Berth): The middle side berth found exclusively in 3E class configurations [6]

4.2 Capacity Variations

The berth capacity varies between different coach types and configurations. In older ICF rakes, three-tier AC coaches typically accommodate 64 berths, while Sleeper coaches carry 72 berths. The introduction of LHB coaches has standardized capacity at 72 berths for three-tier AC coaches (3A class). The side middle berths (SMB) are a distinctive feature of Three-tier AC Economy coaches (3E), providing additional sleeping accommodation in the side berth area [6].

4.3 Coach Entrance Configuration

Each AC coach typically features four entrances—two on either side of the coach and two at the ends. The berth numbers are displayed above each window, facilitating passenger identification of their allocated accommodation. Second seating coaches accommodate 108 seats and include two additional entrances in the middle of the coach on either side, bringing the total number of entrances to six. This configuration ensures efficient passenger movement and compliance with safety requirements [6].

5. MULTIPLE UNIT TRAINS

5.1 MEMU and DEMU Services

For regional short-distance routes, Indian Railways operates Mainline Electrical Multiple Unit (MEMU) and Diesel Electrical Multiple Unit (DEMU) trains. The selection between MEMU and DEMU depends on the availability of electric traction infrastructure on specific routes. These train sets operate as self-propelled units with enhanced acceleration and deceleration capabilities, making them particularly suitable for routes with frequent stops [1].

The introduction of MEMU and DEMU services has significantly improved commuter transportation in suburban and regional corridors. These trains address the critical issue of congestion on heavily traveled routes by offering more frequent services and faster turnaround times. The multiple-unit configuration eliminates the need for locomotive turning facilities at terminal stations, enabling more efficient operations [1].

5.2 Transition from Locomotive-Hauled Trains

Passenger locomotive-hauled trains with frequent stops are progressively being replaced by modern train sets across India. This transition reflects international trends in railway operations, where self-propelled multiple-unit trains offer superior performance for high-frequency services. The benefits include improved acceleration, reduced turnaround times, and enhanced passenger convenience through more frequent services [1].

6. UIC CLASSIFICATION SYSTEM

The classification of railway coaches follows an international system developed by the Union Internationale des Chemins de fer (UIC), also known as the International Union of Railways. This standardized system replaced earlier national classification schemes in many countries, including Germany's classification system [7].

6.1 Structure of UIC Classification

Under the UIC system, coach class is expressed as a combination of letters that indicate the type of accommodation and level of service. This classification is sometimes augmented by a three-figure class number, as practiced by Deutsche Bahn AG in Germany. Beyond the basic class designation, the vehicle number displayed on the coach encodes additional technical specifications, including the maximum permissible speed, heating system type, and other operational parameters [7].

6.2 Application to Indian Railways

While Indian Railways has developed its own classification system for travel classes, the underlying technical classification of coaches aligns with international practices. The UIC system provides a framework for technical specifications that facilitates international interoperability and standardizes coach specifications across different railway networks [7].

7. CONCLUSION

Indian Railway coaches represent a fascinating intersection of technology, logistics, and social equity in India's transportation infrastructure. The diverse range of travel classes—from luxurious First AC Sleeper to affordable Unreserved seating—demonstrates Indian Railways' commitment to serving passengers across all economic strata. The classification system, evolved over decades of operation, reflects the complex requirements of serving a vast and diverse population.

The transition from conventional ICF coaches to modern LHB coaches signifies technological advancement in India's railway sector. The superior safety features, enhanced speed capabilities, and improved passenger comfort of LHB coaches represent significant improvements over their predecessors. However, the continued presence of ICF coaches in active service underscores the scale of India's railway network and the challenges of complete fleet modernization.

The multiple-unit train systems (MEMU and DEMU) have emerged as solutions for addressing congestion on regional routes, offering faster acceleration and more frequent services. The progressive replacement of locomotive-hauled trains with these self-propelled units reflects global best practices in railway operations.

Looking ahead, Indian Railways continues to invest in coach technology, with research and development efforts focused on enhancing passenger comfort, improving safety features, and increasing operational efficiency. The coach classification and travel class system will likely evolve to meet changing passenger expectations and technological possibilities, maintaining India's position as a leader in railway passenger transportation among developing nations.

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HAIKU POEMS AND ALLUSIONS TO CONTEXTS

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ABSTRACT

The purpose of this paper is to analyse poems which make sense only in a certain context, alluding to it. The context itself introduces a certain meaning to the poem. The poems for the Haiku Dialogue section of the Haiku Foundation site, written based on given prompts, may, in some cases, make little sense if read outside the context of these prompts set up by the editors. As an example, the poem by the author of the present paper, signed as Ana Drobot, "behind bars –/ I dream of roaming free/ in the wild" for the prompt World of Animals – (Put Me in the Zoo), and from the list published on March 25, 2026. This can seem a descriptive poem with no allusions and no other further meaning, since it makes sense for someone behind bars, whom we consider a prisoner, to dream of freedom. However, in the context of the Zoo prompt, we can imagine that the human visitors see animals as prisoners behind the bars of their cages, while the animals see humans as prisoners behind bars. The perspective is a relative one. In addition, when the human beings see animals in cages, they may start dreaming of seeing them free in the wild, and then they transpose themselves in the animals' place, as happens during the experiences of empathy and sympathy. Other poems including allusions to the prompt are: "look, dad/ something like you/ yawns" by Refika Dedić (Bosnia and Herzegovina) and "chitter-chatter.../ a lot of/ monkey business" by Pamela Jeanne (Yukon, Canada). The methodological framework is made up of reader-response criticism and psychology.

Keywords: Juxtaposition, Kigo, Psychology, Reader-Response Criticism

INTRODUCTION

The haiku poem is a particular case of poem, since it is a very old form, which began in the 16th-17th century, in Japan (Shirane, 2005), and since it is still practiced, understood, analysed, developed and adapted to various other cultures than its culture of origin nowadays. We can witness the activity of various online and offline haiku writing communities, where past and present-day haiku poems are discussed. The haiku poem still answers the needs and sensibilities of our contemporary mindset. It is a short poem (three lines, 5-7-5 syllables) and it relies on carefully chosen words and images, which have a high impact on the readers and which send them on the way towards reflecting on the content of the poem and towards finding new shades of meaning to the poem. The haiku poem relies on juxtaposition (Gilli, 2001), or on the meaning and imagery creating by putting together the two parts of the poem, separated by the kireji or cutting line.

The haiku poem relies on allusions and free associations (Freud, 2016) which prompt readers to imagine something beyond the actual words present on paper. In order to do this, the poem needs to rely, at least to some extent, on common symbols and experiences. This is a usual case when we can start making allusions in everyday life contexts as well. We allude to something which may not be immediately obvious, but also to something which is also not too obscure and impossible to identify. In real life communication we can make allusions to local culture, local history, but also to national history and culture, to literary works we have all studied and heard about, to usual pastimes during weekends, to news and various recent events, locally, nationally, and internationally, to political incidents, etc. Poetry is known to be able to refer to a universal state of mind and aspects. However, poetry can also refer to specific events to certain time periods or ways of life, as well as to particular personalities which we may or may not be familiar with, function of the social circle and cultural or social context we are part of. There can be lyrical, just as there can be satirical or humorous poems, and these poems can refer to

a particular social and political context which can be available to a certain time period and to a certain social circle.

We can see, for instance, how Matsuo Basho's – considered to be the father of the haiku - poems refer to both universal aspects we can relate to even nowadays, and as members of Western cultures, but also to aspects which can be familiar to us only if we belong to the Japanese culture or only if we are familiar with its various aspects and history. In a similar way, someone's personal universe may be expressed in his or her haiku poems, and we can all relate to these experiences if we are living during the same time and within the same cultural and social context, or if we know the respective person very well.

We believe that the haiku poem is objective, not subjective, and that the perspective it should present is that of a detached observer. However, we may always come across exceptions. It is difficult for us to know how others feel about and how they experience a certain reality which is specific to a certain time, culture, and social circle, or even social class. We tend to take our everyday life reality as an objective aspect, as the only truth. However, through someone else's perspective, everything can be seen as different – as comprehensible, relatable, or as incomprehensible and completely unrelatable. It is difficult for us, at times, to remember to look at certain experiences based on someone else's point of view, since we are so much involved in our own world and context, or since we do not have access to another context and personal universe. In addition, not everyone is familiar with the structure and spirit of the haiku poem,¹ which makes it even more challenging for authors of such poems to make them available to a wider audience.

MATERIALS AND METHODS

We notice that, in order for a haiku poem to make sense, we rely to a high extent on the perspective, interpretation, and reactions of the reader. This is why haiku poems can be interpreted based on a reader-response approach, which shows us that the readers react emotionally to a text and that they also rely on their background knowledge in order to make sense of the text they read (Mart, 2019). The haiku poem requires an active reader, who should be alert to the dialogue established by the author of the poem. The author of the haiku poem gives readers clues and the occasion of them making free associations based on certain elements in the poem so that they can reach the meaning of the poem. The haiku poem and its deciphering resembles the way in which we decipher or make sense of communication in a certain context in everyday life, by taking into consideration the meaning of words in a particular context of communication. Pragmatics (Leech & Thomas, 2002) deals with this issue, and we can see how we look for clues regarding the physical setting where the conversation takes place, as well as to non-verbal cues of the speaker, e.g. facial expressions, voice tone, body language, posture, language of gestures, etc. The haiku poem includes visual images which are powerful enough to suggest certain attitudes and states of mind. We try to visualize the situation and we rely on clues just like in understanding the intent of a speaker in everyday life conversation. After all, the haiku poem, unlike Western lyrical poems, uses a natural, everyday, colloquial language, no usual figures of speech, such as personification of nature, and indirect communication. Indirect communication is not only restricted to the haiku poem or to poems in general. It is also part of everyday life communication, since it can be considered a more expressive way to render someone's intention, once the interlocutor is given the role of an interpreter of intention. In everyday life communication, just like in the haiku poem, we can find the choice of a certain visual detail or word which can leave us room for further suggestion and interpretation, or for something more to be implied.

The issue of context in a haiku poem is crucial for our understanding of it. We need to picture the context of communication in order for us readers to make sense of each and every word, of each and every image, so that we can decode the intent of the author, or of the speaker, as we may consider that we perceive the author of a haiku poem, who is establishing a dialogue with us readers and who is willing to share a message with us. The very presence of a kigo, or seasonal element in a haiku poem, can be considered an example of the author offering readers a clue regarding the context of the poem. Each season can be represented, in the haiku poem, by a flower which blooms or by a fruit which is ripe during the respective time. We are all familiar with features of the seasons, which can be considered enough for us to have a shared communication context with the author of the haiku poem we are reading.

One particular case of the relationship between writers and readers of haiku poems is the one provided by the common context of a prompt established for writing poems for authors within a certain haiku community. The authors are given a certain theme or topic on which to write their poems, and this can lead to poems including allusions to the respective topic, as they are trying to suggest the topic and not to mention it directly. The haiku poem is well known for its indirect communication style, based on connotations, allusions, and free associations suggested by its visual images and words, all of which are carefully selected by the haiku author. The haiku author needs to think very well about the words used in a haiku poem, especially since it is so short – 5-7-5 syllables, and three lines, at least traditionally. Modern variants of the haiku poem can deviate from this pattern, with contemporary haiku poems in the English language especially being even shorter. The modern haiku has been around since a modern turn took over in Japan, with the Free Haiku Movement led by Ogiwara Seisensui (1884-1976) (Kimura, 2022), when the number of syllables was no longer fixed, and the presence of the kigo was optional. This comes close to the understanding some authors have of the haiku poem today. Other authors maintain the classic, traditional haiku style.

One feature of the haiku poem is, based on the perspective of Romanian haiku master Corneliu Traian Atanasiu, the leader of the Romanian Haiku online community, conciseness/ brevity, both of which are included in the Romanian term *laconism*. *Laconism* means "the compensation of brevity" (Atanasiu, 2026). A *laconic* poem is not just a short poem: "Laconism is not [...] a quantitative adjustment of the text according to the 5-7-5 syllable canon, but a qualitative operation of renouncing certain literary communicative conventions that are excessively present in Western poetry" (Atanasiu, 2026). This style focuses on what readers can infer, imply, and imagine beyond what they see written on paper, based on what the haiku poem suggests: "The elements presented in the text cannot be shown in detail; they are only roughly sketched, barely outlined, merely suggested" (Atanasiu, 2026).

Context itself can be suggested by haiku poems, as is the case of the haiku poems selected for analysis in this paper, from the Haiku Dialogue section of the Haiku Foundation website. Haiku poems were selected from the prompt - established by the editor - World of Animals – (Put Me in the Zoo), published on March 25, 2026 (Munro, 2026).

One of the selected poem belongs to the author of this paper, signed under the haiku author name Ana Drobot: "behind bars –/ I dream of roaming free/ in the wild" (Drobot, in Munro, 2026). If we take this poem out of its context based on the prompt set up by the editors in the Haiku Foundation online community, we can read it as a common poem, noting an ordinary fact: that someone is behind bars – thus, a prisoner – and dreams of being free. This is a relatable and clearly understandable wish and experience. We can feel prisoners in a literal and figurative way, based on different reasons and circumstances. We may be trapped in a certain social context, trapped by an ethical dilemma, pressured psychologically by the close social circle to do a certain thing or to have a certain lifestyle, we may feel morally obliged to do something when we would prefer to do something else, etc. What draws our attention in the selected poem is the dream of "roaming free/ in the wild" (Drobot, in Munro, 2026), which makes us think of wild animals. The person experiencing these feelings may compare him or herself to a wild animal in a cage, in a zoo or in a circus, dreaming and wishing based on its instinct to go back into the wild, as it is not in its usual and natural environment. The person feels that he or she does not belong there. In social life, we are often pressured and trapped by social rules and conventions, depending on how rigid the society of our times is. Readers can further on draw on their free associations based on their reading experience from novels by Thomas Hardy or Jane Austen and consider how the rebellious characters, most often young ladies, feeling trapped by their social conventions, were considered the most relatable, lively, and attractive characters.

However, such an obvious interpretation for a haiku poem does not leave much room for suggestion and seems not to rely on allusions which are powerful enough for experienced haiku poetry readers. However, if we consider the prompt for which this poem was selected, regarding the topic of the zoo, and zoo experiences which we mostly associate with ourselves as children, we may see the poem from another perspective. The poem was intended by its author to refer to a change of perspective. It does not refer to us human beings visiting the zoo and seeing animals as captive. It refers to us looking at the animals and seeing them as offering for us the possibility to imagine their wild and free lifestyle, since they become a symbol of freedom and of the exotic, far-away lands where they live, in a natural

environment. Our imagination runs wild as we see them and as we make free associations between them and the worlds which are so vast and can be explored. As an example, tigers and elephants can be associated with the novel by Rudyard Kipling and with all the related adventures. *The Jungle Book* was the book which had sparked the imagination of many generations of children. The animals become, for us, a symbol of freedom and distant lands, where our imagination can run free. This happens in spite of the fact that they are kept in cages. We may also feel a psychological conflict when we look at them, and see them trapped in-between being prisoners and being naturally free. Animals at the zoo can draw from us mixed reactions: we can feel admiration for them, we can feel pity and empathy, since they are trapped just like we feel in our everyday lives – since the question of freedom is a debatable one for us human beings, and has been the topic of many philosophical reflections -, since they daydream just like us of being free, but also fear and curiosity. They impose a certain degree of distance for us, since we know that they can be dangerous. We feel safe when we wander about them in the zoo, where we have a safe version of experiencing an adventure in exotic lands. At the same time, the intent of the author of this haiku poem was to suggest that the animals at the zoo can have a similar perspective on us. They may perceive that we human beings are behind the bars. This understanding reflects the previously discussed meanings, that we see our freedom often hindered by social conventions and pressures. Nowadays we speak of individualism and personal freedom, of detachment from traditional norms and from the expectations of the others, which put pressure on us. The haiku poem by Drobot (in Munro, 2026) has, therefore, a variety of meanings, a multiplicity of layers of meanings, and each of them is just as valid as the other. However, we do not need to stop at the surface level. In addition, we notice how the given context of the prompt leads readers to further meanings, offering us more clues and more occasions to develop our reflections starting from this poem. We can feel empathy and sympathy for animals at the zoo, since we feel the same as them in our life contexts. Society can be compared to a zoo, due to all its pressures but also due to various actions which can lead to the harm of the individual and the loss of his or her well-being.

Another poem inspired by and selected for the Zoo prompt is the following: "look, dad/ something like you/ yawns" by Refika Dedić, from Bosnia and Herzegovina (Dedić, in Munro, 2026). Taken out of the context, readers do not know to what the child refers. They can imagine that the child refers to a cartoon or to a toy. However, in the context of the Zoo, the child clearly likens his father's yawn to an animal at the zoo. The child may also liken his father to a certain animal which is not named. This is a comparison which is innocent and humorous, since the child clearly loves his or her father and does not intend to humiliate him. The innocent comparison can clearly spark the laughter of the other adults around or older children, and even of the father himself. Children are known for their honesty and for their innocence. They can tell the truth without being mean or hurting people, since adults know that they are just discovering the world. Since we use animals to impersonate human beings with their physical and psychological traits in cartoons and fables, such a comparison can be considered quite normal and appropriate. Readers can think of animated films such as *The Jungle Book by Disney*, where animals represent human typologies in a highly relevant, humorous, and relatable way. The child's comparison of his father with an animal at the zoo can, in this way, be considered as part of his or her own universe, based on stories and cartoons. Based on these stories and cartoons, children are taught to feel empathy for the others, including for animals, since they are presented in a familiar way, based on features attributed to human beings in their circle, such as other children and adults.

The third poem selected for analysis in this paper from the Zoo prompt is the following: "chitter-chatter.../ a lot of/ monkey business" by Pamela Jeanne from Yukon, Canada (Anderson, in Munro, 2026). Taken out of the Zoo prompt context, the poem may be understood as referring to the figurative expression *monkey business*, referring to dishonest, unacceptable, mischievous behaviour, which can be related to the *chitter-chatter*, or gossips, since these are the first free associations coming to the readers' minds. We can consider that these observations refer to human beings in a certain social setting. The meaning of the idiom *monkey business* is, usually, restricted to its figurative form. We tend to leave aside and forget about its concrete form, and the image of the monkeys is pushed aside. However, in the context of the Zoo prompt, readers begin to smile, since they literally see the monkeys which we know as able to imitate human behaviour. They can be picture by readers as gossiping about the human visitors at the zoo or about anything else. We human beings can see ourselves reflected in the behaviour of the

monkeys, just as we remember from certain stories and cartoons. The monkeys allude to our own behaviour, presenting it in an ironic and humorous way.

We can see how the context of the Zoo prompt can change and especially add more layers of meaning to the selected haiku poems. Any happening or gesture can acquire particular meanings and free associations in a given social context: at work, at school, in the family, in a circle of friends, in a club based on hobbies.

RESULTS

That the meaning of communication is context-dependent is particularly illustrated by the three haiku poems selected for analysis. We notice how the haiku poem reflects our natural, everyday life process of communication, based on allusions, connotations, and additional meanings function of the context where we speak or listen to someone speaking. We are used to look at everything function of the context, if we reflect further: at artifacts, at philosophical ideas, at literary works – based on the contemporary audience's reactions-, at the language of gestures, at fashion styles, etc. The haiku poem needs to be placed in a certain context of communication. At the same time, we readers tend to build up contexts when we read a haiku poem, in order to situate the intent of communication and the setting. We imagine what is missing in a haiku poem by filling in the blanks and we also make hypotheses about its meaning. The haiku poem is full of allusions and of words and images which invite us readers to start the process of free associations.

DISCUSSION AND CONCLUSIONS

The haiku poem is based on the dialogue established between its author and its readers. The authors communicate their intent based on the allusions and free associations that are suggested by various elements in the poem, including by the context. In some cases, the context can be part of the author's intention. In everyday life communication, we rely on voice tone and body language of the speaker to understand his or her intention, while in haiku poems we rely on the way in which the selected words lead us to putting the intent of the author together. Since the haiku poem is concise and brief, or laconic, in Atanasiu's (2026) terms, we are left as its readers with a wide room for imagining further details. In doing so, we can imagine various layers of meanings, as well as various context. The context provided by writing prompts can lead to additional shades of meaning for haiku poems, as we have seen in the specific case of the selected haiku poems chosen to illustrate the prompt *Zoo*.

The haiku poem allows us to enter human psychology based on the way we see and interpret the world, together with our relationships with the others, based on empathy and sympathy. This is what we can conclude from the analysis of the selected haiku poems from the prompt *Zoo* on the Haiku Foundation website, Haiku Dialogue section (Munro, 2026).

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EFFECTS OF RUMINANT BREEDING ON METHANE EMISSIONS

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Sevil ÇALIŞKAN ELEREN

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ABSTRACT

The rapid increase in the world's population and the resulting rise in food demand have led to a growing need for animal protein sources derived from ruminants. Livestock farming, intensified to meet this demand, has become a significant contributor to climate change due to greenhouse gas emissions from ruminants. The livestock sector, particularly through enteric fermentation and manure management processes in ruminants, accounts for more than one-third of total anthropogenic methane emissions. Methane emissions from livestock farming have devastating effects on human health and agricultural productivity through global warming, melting glaciers, disruption of the water cycle, and tropospheric ozone depletion. Various strategies have been developed to reduce these emissions, including the selection of high-yielding animals, improving reproductive performance, and ration modifications.

Keywords: Ruminant, Methane, Environmental Pollution, Environmental Impact

RUMİNANT YETİŞTİRİCİLİĞİNİN METAN EMİSYONUNA ETKİLERİ

ÖZET

Hızla artan dünya nüfusuna paralel olarak gıda talebinde yaşanan yükseliş, ruminantlardan elde edilen hayvansal protein kaynaklarına olan ihtiyacın da her geçen gün artmasına neden olmaktadır. Bu talebi karşılamak amacıyla yoğunlaşan hayvancılık faaliyetleri, ruminantlardan kaynaklanan sera gazı emisyonları nedeniyle iklim değişikliğine katkıda bulunan belirleyici unsurlardan biri haline gelmiştir. Hayvancılık sektörü, özellikle ruminantlardaki enterik fermantasyon ve gübre yönetimi süreçleri aracılığıyla, toplam antropojenik metan emisyonlarının üçte birinden fazlasını oluşturmaktadır. Hayvancılık kaynaklı metan emisyonları küresel sıcaklık artışı, buzulların erimesi ve su döngüsünün bozulmasının yanı sıra troposferik ozon oluşumu yoluyla insan sağlığı ve tarımsal verimlilik üzerinde de yıkıcı etkiler yaratmaktadır. Bu emisyonları azaltmak amacıyla, yüksek verimli hayvanların seçimi, üreme performansının artırılması ve rasyon modifikasyonları gibi çeşitli stratejiler geliştirilmiştir.

Anahtar Kelimeler: Ruminant, Metan, Çevre Kirliliği, Çevresel Etki

GİRİŞ

İklim değişikliği; başta biyoçeşitlilik ve insan faaliyetleri olmak üzere, küresel ölçekte derin etkiler yaratan ve aciliyetini koruyan önemli bir çevresel sorundur. Antropojenik faaliyetler arasında, hayvancılık üretimi, özellikle küresel sıcaklık artışlarıyla doğrudan bağlantılı olan sera gazı emisyonlarına katkısı nedeniyle iklim değişikliğinin önemli bir itici gücünü temsil etmektedir. Metan (CH₄), karbondioksit (CO₂) ve azot oksit (N₂O) ile en etkili üç sera gazı arasında yer alan, küresel ısınmayı güçlü bir şekilde artıran bir gaz olarak kabul edilmektedir (Pachauri ve ark. 2014). Küresel insan nüfusunun 2050 yılına kadar 9,6 milyara ulaşması ve gıda talebinin mevcut taleplere göre %25-

70 oranında artması bekleniyor (Sabia ve ark. 2025). Dolayısıyla sığır, keçi ve koyun gibi ruminantlardan elde edilen hayvansal protein açısından zengin gıdalara olan talep de artacaktır (Du ve ark. 2022). Bu nedenle sürdürülebilir gıda üretiminin sağlanabilmesi için hem hayvan sayısının hem de verimin artırılması gerekmektedir (van Dijk ve ark. 2021). Sonuç olarak, bu durum, arazi kullanımının daha da yoğunlaşmasına ve ekilebilir arazinin genişlemesine yol açacak ve bu da sera gazı emisyonları ve biyoçeşitlilik kaybı gibi çevresel etkilere neden olacaktır (Zabel ve ark. 2019). Bu nedenle ruminant hayvan yetiştiriciliği yüksek çevresel etkileri nedeniyle son 20 yıldır pek çok çalışmaya konu olmuştur (Kothmann ve Pittroff 2025). Bidoglio ve ark. (2024) hem ormansızlaşma hem de biyoçeşitlilik kaybı için en yüksek küresel ortalama etki yoğunluğunun geviş getiren hayvan eti üretimiyle ilişkili olduğunu, bunu sırasıyla yumurta, domuz eti, kümes hayvanı eti ve süt üretiminin izlediğini bildirmiştir. Yani hayvansal ürünlere yönelik talep her geçen gün artarken hayvancılık sektörü bir yandan verimi artırmaya çabalamakta bir yandan da artan verimin çevre üzerindeki etkisini en aza indirmeye zorlanmaktadır.

Özellikle güçlü bir sera gazı olarak çevresel etkisi nedeniyle ruminantlar tarafından üretilen metan (CH_4), bilimsel literatürde giderek daha kritik bir konu haline gelmektedir (Króliczewska ve ark. 2023). Sığır, koyun ve keçi gibi geviş getiren hayvanların gastrointestinal sisteminde mikrobiyal fermentasyon yoluyla üretilen enterik metan, tarımsal sera gazı emisyonlarının önemli bir bölümünü oluşturmaktadır (Thacharodi ve ark. 2024). Hatta Mar ve ark. (2022), CH_4 'ün karbondioksitten (CO_2) önemli ölçüde (yaklaşık 30 kat) daha yüksek küresel ısınma potansiyeline sahip olduğuna dikkat çekmiş ve çevresel sürdürülebilirlik için büyük bir tehdit oluşturduğunu bildirmiştir. Üstelik ruminant kaynaklı CH_4 üretimi, çevresel etkilerin yanı sıra hayvansal üretimde ciddi bir ekonomik ve biyolojik verimlilik kaybına yol açmaktadır. Biyolojik olarak üretilen bu CH_4 , brüt rasyon enerjisinde yaklaşık %2-12 arasında bir kayba yol açarak hem küresel ısınmaya hem de enerji verimsizliğine katkıda bulunmaktadır (Getabalew ve ark. 2019; Kılıç ve Boğa 2021; Bačéninaite ve ark. 2022; Wang ve ark. 2025). Arndt ve ark. (2022) hayvancılık kaynaklı CH_4 emisyonlarının %88'inin ruminant yetiştiriciliğinden kaynaklandığını bildirmiştir. Rumendeki CH_4 üretimi, yem bileşimi, çiğneme davranışı, tükürük salgısı ve gastrointestinal hareketlilik dahil olmak üzere çeşitli faktörlerden etkilenir (Snelling ve Wallace 2017). Cheng ve ark. (2022) ruminantların, tek mideli hayvanlara göre daha düşük yem kullanım verimliliğine sahip olduğu için daha yüksek reaktif azot ve metan emisyonu ürettiklerini bununla birlikte otlama ve kaba yem yoluyla insan tüketimine uygun olmayan biyokütleyi kullanabildiklerini belirtmiştir.

Genel olarak ruminant hayvan yetiştiriciliğinin ekosistem üzerindeki etkilerinin sera gazı emisyonları, mera alanlarının bozulması, gıda rekabeti, su ve yem kullanımı etrafında yoğunlaştığı görülmektedir (Katiyatiya ve Ncanywa 2025). Bu çalışmada ruminant hayvan yetiştiriciliğinin metan emisyonlarındaki payı, bu emisyonların çevre üzerindeki etkileri ve metan üretimini azaltma stratejileri güncel literatürlerle incelenmiştir.

RUMİNANT YETİŞTİRİCİLİĞİNİN METAN EMİSYONLARINDAKİ PAYI

Ruminantlar, geviş getirme yoluyla bitki materyalini etkili bir şekilde sindiren mikrobiyal fermentasyon gerçekleştiren ve böylece hem biyoçeşitliliğe hem de küresel ekonomiye katkıda bulunan tarımsal üretimde önemli bir yere sahip hayvanlardır (Palangi ve ark. 2022). Ruminantlardan kaynaklanan CH_4 emisyonları, tarım tarafından yayılan en önemli kirleticiler arasında yer almakta ve atmosferik sera gazı birikiminin önemli bir kaynağı olarak görülmektedir. Ruminant hayvanlarda enterik fermentasyon olarak bilinen sindirim sürecinde üretilen ve yan ürün olarak geğirme yoluyla atmosfere salınan CH_4 emisyonları, bu hayvanların metabolizmasındaki enerji verimsizliğini yansıtmaktadır (Black ve ark. 2021; Maljugina ve ark. 2025). Yanı sıra hayvancılık işletmelerindeki gübre yönetimi uygulamaları da CH_4 emisyonu kaynaklarındandır (Zhang ve ark. 2021; Manono 2026). Hayvancılık sektöründen kaynaklanan sera gazı emisyonlarının yaklaşık 7.1 Gt CO_2 eşdeğeri olduğu ve küresel insan kaynaklı sera gazı emisyonlarının %14,5'ini oluşturduğu tahmin edilmektedir. Et (%41) ve süt üretimi (%20) ise sektör emisyonlarının büyük çoğunluğunu oluşturmaktadır. Yem üretimi ve işlenmesi ile geviş getiren hayvanlardan kaynaklanan bağırsak fermentasyonu, emisyonların iki ana kaynağıdır ve sırasıyla sektör emisyonlarının %45 ve %39'unu temsil etmektedir. Gübre depolama ve işleme ise bu emisyonların %10'unu oluşturmaktadır (Gerber ve ark. 2013). Bununla birlikte geviş getiren hayvan yetiştiriciliği

sistemleri, hem çevresel faktörlere hem de türlere (sığır, keçi, koyun) ve üretim amaçlarına (süt, et, yün) bağlı olarak değişmektedir. Bu farklılıklar, farklı yetiştiricilik sistemleri tarafından üretilen sera gazı emisyonlarını etkilemektedir. Örneğin, geviş getiren hayvan yetiştiriciliği içinde koyun ve keçiler küresel hayvancılık sektöründen kaynaklanan emisyonların yaklaşık %6,5'inden sorumludur (FAO 2016). Sığır yetiştiriciliğinden kaynaklanan sera gazı emisyonları, hayvancılık sektörünün toplam emisyonlarının yaklaşık %65'ini (4,6 gigaton CO₂ eşdeğeri) oluşturmaktadır ve bu da sığırları sektörün toplam emisyonlarına en büyük katkıyı sağlayan unsur yapmaktadır. Sığır eti üretimi, toplam sektör emisyonlarının %41'ini oluşturan 2,9 gigatonluk bir katkı sağlarken, süt üretiminden kaynaklanan emisyonlar 1,4 gigaton veya toplam sektör emisyonlarının %20'sini oluşturmaktadır (Gerber ve ark. 2013).

Bidoglio ve ark. (2024) hayvancılık üretiminin çevresel etki yoğunluklarının, üretim sistemleri ile büyük ölçüde değiştiğini bildirmiştir. Üretim sistemleri arasındaki bu farklılıkların; sistemlerin otlatmaya dayalı olup olmamasına, büyük miktarlarda ithal yeme bağımlı olup olmamasına ve yem maddelerinin nereden temin edildiğine bağlı olarak değiştiğini ortaya koymuştur. Örneğin yem türü ve üretim şekli, ortaya çıkan hayvansal ürünlerin etki yoğunluklarını değiştirir. Etki yoğunluklarındaki farklılıklar yem bitkisi üretimi için gereken alan ve yem girdilerinin hayvansal proteinlere dönüştürülme verimliliği gibi iki faktörden etkilenir. Geviş getiren hayvanların et ve süt üretimindeki yüksek etki yoğunlukları, saf otlatma sistemlerinde yüksek alan talebi ve düşük dönüşüm verimliliğinden kaynaklanır. Öte yandan Avrupa, Kuzey Amerika ve Çin gibi yoğun üretim sistemlerinde geviş getiren hayvanların yüksek kaliteli otlar ve protein açısından zengin konsantre yemlerle beslenmesiyle elde edilen et üretimi, yüksek üretim verimliliği gösterir (Herrero ve ark. 2013). Garnett ve ark. (2017) ise geviş getiren hayvanlara dayalı sistemde, toplam CO₂ eşdeğeri emisyonlarının yarısından fazlası bağırsak fermantasyon sürecinden kaynaklandığı için CH₄ emisyonlarının, entansif sistemlerde olduğu gibi üretim uygulamalarından ziyade çoğunlukla hayvan sayısına bağlı olduğunu bildirmiştir. Kothmann ve Pittroff (2025) CH₄ üretiminin rumen sindiriminin zorunlu bir ürünü olduğunu, yoğun yem kullanımının artırılmasının bireysel geviş getiren hayvan tarafından yayılan metanı bir dereceye kadar azaltacak olsa da konsantre yem üretiminin çevresel etkisiyle metan üretiminin dengeleneceğini bildirmiştir. Ayrıca meraların hayvanların ihtiyacını karşılamayacak düzeyde bozulmasının ve bunun nasıl düzeltileneceğinin tartışılması gerektiğine dikkat çekmiş ve küresel olarak gözlemlenen mera yönetimindeki bariz eksikliklerin bu kaynağın yok olmasına neden olmakla kalmadığını, aynı zamanda mera alanlarının devasa ölçeklerde mahsul üretimine dönüştürülmesinin de küresel ölçekte bir tehdit olduğunu bildirmiştir.

METAN EMİSYONLARININ ÇEVRESEL ETKİLERİ

CH₄ salınımı, hem küresel ısınma ve iklim değişikliği süreçlerinde kritik bir role sahiptir, hem de hayvancılık ekonomisi için ciddi bir kaynak kaybıdır (Bačéninaite ve ark. 2022). CH₄, atmosferde kızılötesi enerjiyi hapseden en önemli üç sera gazından (CH₄, CO₂ ve N₂O) biri olup (Wang ve ark. 2025), küresel ısınmanın yaklaşık %16-18'inden sorumludur (Wanapat ve ark. 2015; Lahoti ve ark. 2016; Demeyer ve Fievez 2000; Getabalew ve ark. 2019). Kızılötesi enerji emilimi CO₂'den çok daha yüksek olduğundan, gram başına küresel ısınmaya katkısı CO₂'den yaklaşık 30 kat daha fazladır (Bačéninaite ve ark. 2022; Tamminga 1996). Bu etki kısa vadeli düşünüldüğünde 80 katına kadar çıkmaktadır (Sobanaa ve ark. 2024). Atmosferdeki CH₄ konsantrasyonu 1950'den bu yana %70 oranında artmıştır (Bačéninaite ve ark. 2022). Bu durum, dünya genelinde sıcaklıkların yükselmesine, buzulların erimesine ve deniz seviyelerinin yükselmesine (21. yüzyılın sonuna kadar 0,18-0,59 metre) yol açmaktadır (Lahoti ve ark. 2016; Moss ve ark. 2000; Moncada ve ark. 2025).

Metan, sadece doğrudan bir sera gazı olarak hareket etmekle kalmaz, aynı zamanda atmosfer kimyası üzerinde de yıkıcı etkilere sahiptir. Metan, güneş ışığı varlığında OH radikalleri (OH) ve azot oksitlerle (NO_x) tepkimeye girerek troposferik ozon oluşumuna neden olur (Isaksen ve ark. 2014). Atmosferde CH₄ miktarı arttıkça, bu gazı parçalamaya çalışan OH tükenir (Moss ve ark. 2000). OH miktarı azaldığında, metan atmosferde daha uzun süre kalmaya başlar. Yani CH₄ artışı, kendi kendini yok etme mekanizmasını zayıflatarak atmosferdeki ömrünü dolaylı olarak uzatır (Broucek 2014; Moss ve ark. 2000). Troposferik ozon hem güçlü bir sera gazıdır hem de ciddi bir hava kirleticidir. İnsanlarda solunum

yolu hastalıklarını tetiklerken, bitkilerde stomalardan içeri girerek hücre hasarına ve fotosentez kapasitesinin düşmesine ve tarımsal verim kaybına neden olur (Manisalidis ve ark. 2000; Ming ve ark. 2022).

Stratosferdeki CH₄ oksidasyonu, su buharı oluşumuna neden olur. Yüksek irtifadaki su buharı da güçlü bir sera etkisi yaratarak ısınmayı tetikler (Broucek 2014). Artan sera gazı emisyonları su döngüsünü de bozmaktadır. Karasal bölgelerde yağışlar artık daha düzensiz ve uç noktada (ya aşırı kuraklık ya da ani sel felaketleri şeklinde) gerçekleşmektedir. Bu durum, yeraltı su rezervlerinin beslenmesini engellemekte (Ferreira ve ark. 2025), su kıtlığı, yağış rejimlerindeki düzensizlikler ve çölleşme gibi sonuçlar doğurarak ekosistemlerin dengesini bozmakta, aynı zamanda tarımsal zararlıların yayılmasına uygun zemin hazırlayarak gıda güvenliğini tehdit etmektedir (Moss ve ark. 2000). Topraktaki sıcaklık artışı, organik maddenin daha hızlı ayrışmasına neden olur. Bitki örtüsü zayıfladıkça toprak, rüzgâr ve su erozyonuna açık hale gelir, bu da geri dönüşü zor olan çölleşme sürecini başlatır. Bu çevresel stres faktörleri, tarımsal zararlıların ve patojenlerin yeni bölgelere yayılmasına neden olur. Aynı zamanda, su kıtlığı bitki örtüsünün kompozisyonunu değiştirir. Kuraklığa dayanıklı ancak besin değeri düşük bitkilerin istilası da, ruminantlar için kaliteli yem kaynaklarını yok eder (Kothmann ve Pittroff 2025). Özellikle iyi yönetilmeyen meralarda, bitki örtüsünün kaybı karbon yutaklarını yok etmekte ve toprakta depolanan karbonun atmosfere salınmasına neden olarak metan kaynaklı ısınmanın etkisini daha da şiddetlendirmektedir (Kothmann ve Pittroff 2025; Guyader 2016).

METAN EMİSYONLARINI AZALTMA STRATEJİLERİ

Ruminant yetiştiriciliğinden kaynaklanan sera gazı emisyonlarını azaltmak için etkin yönetim stratejilerinin geliştirilmesi gerekir. Özellikle de sera gazı azaltım çözümlerinin öncelikle nokta kaynaklara yönlendirilmesi ve hedefe yönelik olarak stratejilerin geliştirilmesi daha etkili olacaktır (Reisinger ve ark. 2021). Örneğin; daha yüksek süt verimi, bakım gereksinimlerinin seyreltilmesi hem daha iyi yem verimliliğine hem de üretilen kilogram süt başına metan emisyonlarının azalmasına yol açtığı için, gıda güvenliğini sağlama ve sera gazı emisyonlarını azaltma gibi küresel zorlukların üstesinden gelmek için önemli bir çözüm stratejisi olarak kabul edilmektedir (Capper ve ark. 2009). Bu stratejinin kullanılacağı bir çiftlikte yaklaşım, uygun melezleme programlarının uygulanması veya yüksek verimli hayvanların seçimi ve sürdürülmesidir. Bu, süt verimliliğini artırmaya ve dolayısıyla üretilen sütün karbon ayak izini düşürmeye yardımcı olabilir (Lalotis ve Bizelis 2025). Diğer yandan Hegarty ve ark. (2010) üreme performansının, metan yoğunluğundaki varyasyonun temel ve yaygın bir itici gücü olduğunu çünkü doğrudan yem alımında artışa yol açarak metan emisyonlarını artırdığını bildirmiştir. Ancak Gebbels ve ark. (2022) üreme performansının yüksek olduğu yani yavru sayısının arttığı bir sürüde artan yem tüketiminin yavruların beslenmesinden ziyade damızlık sürünün bakım ve beslenmesine atfedilmesi gerektiğini bu nedenle anne kaynaklı emisyonların daha fazla kilogram ürüne bölündüğü için tüm sürünün üreme oranını artıran müdahalelerin metan yoğunluğunda bir azalma meydana getirdiğini bildirmiştir. Dolayısıyla, ruminantlarda üreme performansının artışına odaklanılması, birim hayvan başına metan yoğunluğunun azaltılması açısından görece fayda sağlayacaktır. Bir diğer yöntem de üreticilerin dişi yavruları erken yaşta çiftleştirmesidir. Erken yaşta damızlık olarak hayvanların sürüye katılması durumunda metan yoğunluğunun %0,14-0,16 oranında azaltmak mümkündür. Bu azalma, yavruların erken yaşta damızlık sürüye katılmasıyla kuzu üretimine katkıda bulunmayan ancak metan üretimine katkıda bulunan sürü oranının azalmasından kaynaklanmaktadır (Alcock ve Hegarty 2006).

Bunların yanı sıra bir diğer çözüm de rasyon bileşiminin değiştirilerek rumende karbohidratların fermantasyonundan salınan metabolik hidrojenin uzaklaştırılmasıdır. CH₄ sentezinde bir azalma, H₂ salınım reaksiyonlarının engellenmesi veya fermantasyon sırasında H₂'nin uzaklaştırıldığı alternatif yolların teşvik edilmesiyle sağlanabilir. Rumende metan üretim hızı, özellikle karbohidrat türü (selüloz vs. nişasta), protein ve lipitler gibi rasyonun bileşimine ve aynı zamanda rumende sindirim maddelerinin kalma süresine bağlıdır. Bu amaçla rasyondaki kaba yem-konsantre yem oranının manipülasyonu en kolay ve en yaygın şekilde uygulanan azaltma stratejilerinden biridir. Kaba yeme göre konsantre yemlerin (yani nişasta veya yapısal olmayan karbohidrat açısından zengin yemler) oranının artırılması, rumen fermantasyonunun propiyonat üretimine doğru kaymasına yol açar ve böylece metabolik hidrojen

(H₂) oluşumu azalır, metanojenlerin kullanabileceği serbest H₂ azaldığı için CH₄ üretimi de azalır (Beauchemin ve ark. 2020). Ek olarak, kaba yemlerin kalitesi ve türü de metan üretimini etkiler. Olgun, yüksek lifli kaba yemlerin daha sindirilebilir kaba yemlerle (genç otlar, baklagiller) veya enerji yoğun silajlarla değiştirilmesi, kuru madde alımı birimi başına CH₄ verimini azaltabilir (Haque 2018). Yani yüksek kaliteli kaba yem metan üretimini azaltırken düşük kaliteli yem artırır (Nugrahaeningtyas ve ark. 2024). Aynı zamanda rasyondaki fermente edilen karbonhidrat türü, rumen mikrobiyomunun bileşimini de belirler (Patra ve ark. 2017). Geviş getiren hayvanlarda rumen mikrobiyotası; CH₄ üretimiyle yakından ilişkili ve sindirim için kritik öneme sahip, anaerobik koşullar altında metabolizmaya katılan bakteri, arkea, protozoa ve mantar içeren simbiyotik bir topluluktan oluşmaktadır. Dolayısıyla CH₄ emisyonlarının önemli bir kaynağı olan rumen mikrobiyal fermantasyonu, rumen mikroorganizmalarının çeşitliliğini, topluluk yapısını ve yem verimliliğini artırarak azaltılabilir (Wang ve ark. 2025). Yem modifikasyonu, mikrobiyal düzenleme ve katkı maddesi uygulaması gibi stratejiler, CH₄ azaltmada kullanılan potansiyel yöntemlerdir. Örneğin, rasyona yağ ve yağ asitlerinin eklenmesi ve probiyotiklerin kullanımı, rumen mikrobiyal topluluk yapısını değiştirerek yem sindirilebilirliğini artırır ve CH₄ üretimini azaltabilir (Guo 2020; Honan ve ark. 2022; Króliczewska ve ark. 2023; Pepeta ve ark. 2024). Hayvan beslemede spesifik kimyasal analogların ve bitki ikincil metabolitlerinin (uçucu yağlar, tanenler, saponinler ve flavonoidler) katkı maddesi olarak kullanılması da metanojenik arkelerin büyümesini spesifik olarak engelleyerek CH₄ üretimini azaltabilir (Ku-Vera ve ark. 2020; Berca ve ark. 2023; Belanche ve ark. 2025). Örneğin, tıbbi ve otsu bitkilerde yaygın olarak bulunan uçucu yağlar, rumendeki çoğu mikroorganizmanın büyümesini engelleyebilen aromatik lipofilik bileşiklerdir. Yapılarındaki aktif bileşenler antimikrobiyal aktiviteye sahip olduklarından doymamış yağ asitlerinin biyohidrojenasyonunu engelleyerek metanojenlerin hidrojen kullanılabilirliğini sınırlandırabilir (Tedeschi ve ark. 2021). Nane yağı ve tarçın yaprağı yağı kombinasyonları, rumen fermantasyonunu düzenlemede ve metan emisyonlarını azaltmada sinerjik etkiler göstererek sera gazı emisyonlarının azaltılması yoluyla hem çevresel sürdürülebilirlik hem de optimum beslenme performansı açısından sürdürülebilir hayvancılık üretimi için potansiyel sunmaktadır (Nasir ve ark. 2025). Ku-Vera ve ark. (2020) uçucu yağların, arkeaların enerji metabolizmasını bozarak geviş getiren hayvanların bağırsak metan emisyonlarında %26'ya varan azalma sağladığını bildirmiştir. Tanenler ya protozoa popülasyonunu inhibe ederek ya da metanojen-protozoa kompleksinin oluşumunu bozup türler arası hidrojen transferini azaltarak doğrudan veya dolaylı olarak rumende metan sentezini azaltma kapasitesine sahiptirler (Tavendale ve ark. 2055). Ku-Vera ve ark. (2020) sığırlarda yoğunlaştırılmış tanen içeren baklagillerle rasyon kuru maddesinin %30-35'ine kadar olan seviyelerde beslemenin metan azaltıcı etki gösterdiğini bildirmiştir. Anantasook ve ark. (2014), saponinlerin, protozoaları ve metanojenik arkeleri azaltarak rumen mikrobiyomunu değiştirmeye katkıda bulunduğunu ve bunun sonucunda CH₄ sentezinde %50'ye varan bir azalma meydana geldiğini bildirmiştir. Oskoueian ve ark. (2013) flavonoidlerin rumen mikrobiyal fermantasyonunda herhangi bir olumsuz etki olmaksızın protozoa ve metanojenlerin toplam popülasyonlarını azaltarak metan üretimini baskılayabilecek potansiyel metabolitler olduğunu bildirmiştir. Rasyon manipülasyonları yoluyla rumen optimizasyonu, metan emisyonlarını azaltmakla birlikte süt ve et üretimini artırmış, yem kullanım verimliliğini iyileştirerek yem maliyetini düşürmüştür ve sonuç olarak daha yüksek kârlılık sağlamıştır (Cappellozza ve ark. 2025; Nishimura ve Terada, 2025). Bir başka ifadeyle, ruminantlarda bağırsak kaynaklı metan emisyonlarının azaltılması, doğru besleme ve yönetsel müdahalelerin stratejik olarak uygulanmasıyla sağlanabilmektedir (Malyugina ve ark. 2025). Bununla birlikte bu rasyon stratejilerinin etkinliği ve pratik uygulanabilirliği büyük ölçüde üretim sistemine bağlıdır. Örneğin kapalı veya entansif yetiştiricilik yapılan sistemlerde rasyon formülasyonu, konsantrasyon takviyesi veya katkı maddesi eklenmesi hassas bir şekilde kontrol edilebilir ve tutarlı bir şekilde uygulanabilir, bu da azaltmayı güvenilir ve tahmin edilebilir hale getirir (Vargas ve ark. 2022). Buna karşılık, geviş getiren hayvanların büyük ölçüde meraya bağımlı olduğu sistemlerde, kuraklık dönemlerinde meralarda otlayan ve karbonhidrat, azot, vitamin ve mineraller açısından dengesiz, çok düşük kaliteli yemler tüketen hayvanlar metan emisyonlarına önemli ölçüde katkıda bulunmaktadır. Bu dönemde azot ve mineral takviyesi, rumen fermantasyonunu kötü bir durumdan iyileştirilmiş bir duruma geçirebilir ve bu da metan emisyonlarında %30'a varan bir azalmaya ve artan mikrobiyal kütle arzı yoluyla verimliliğin artmasına yol açabilir (Makkar 2026). Dolayısıyla meraya bağımlı sistemlerde yüksek konsantrasyonlu yemlerin, yağ takviyelerinin veya kimyasal inhibitörlerin kullanımı maliyet, arz, hayvan adaptasyonu ve sürdürülebilirlik dengeleri nedeniyle kısıtlanır. Çünkü otlatma koşulları altında CH₄ emisyonlarının

etkin azaltma stratejilerinin tasarlanması, otlak alanlarının yem bileşimindeki ve büyümesindeki heterojenlik ve mevsimsel değişim gibi kontrol edilemeyen durumlar nedeniyle önemli bir zorluk teşkil etmektedir (Vargas ve ark. 2022). Ruminant hayvan yetiştiriciliğinde hayvanların üretim aşamasına göre ihtiyaçlarının uygun şekilde karşılanması ve beslenmenin rasyonel yönetimi önemlidir. Tüm hayvan kategorileri için dengeli rasyonların uygun şekilde formüle edilmesi ve uygulanması, farklı otlatma alanlarındaki mevsimsel besin bulunabilirliği değişimlerini hesaba katarken, çiftlik düzeyinde etkili beslenme yönetimini destekleyebilir ve hayvanlarda hem yetersiz hem de aşırı beslenmeyi önleyebilir. Böylece, optimize edilmiş rasyon yönetimi verimliliği artırabilir ve nihai ürün birimi başına karbon ayak izini düşürebilir (Lalotis ve Bizelis 2025).

Piipponen ve ark. (2022) meralardaki hayvan yoğunluğunun azaltılmasının hem arazi üzerindeki baskıyı azaltacağını hem de biyoçeşitliliğin korunmasını destekleyeceğini bildirmiştir. Benzer şekilde Bielza ve ark. (2025) da meralarda hayvan yoğunluğunun sınırlandırılmasının, tarımın çevresel etkisini azaltmaya katkıda bulunabilecek önlemlerden biri olduğunu belirtmiştir. Avrupa Birliği, aşırı otlatmayı, toprak bozulmasını ve azot ve fosforun biyokimyasal döngülerinde aşırı değişiklikleri önlemek için hayvancılık işletmelerinin yoğunluğunu sınırlamaya yönelik düzenlemeler de dahil olmak üzere, çiftlik hayvanlarının refahı ve çevrenin korunması için kurallar ve standartlar belirlemiştir. Hektar başına hayvan birimi için azami sınırlar, çevresel hedeflere ulaşmayı destekleyen bir önlem olarak görülmektedir. Bu önlemin, özellikle nitrat sızıntısı ve bağırsak fermantasyonu ile gübre yönetiminden kaynaklanan CH₄ emisyonları açısından hayvancılık sektörünün çevresel performansını iyileştirmesi beklenmektedir (Eurostat 2023). Bielza ve ark. (2025) tarımda hayvan yoğunluğunun sınırlandırılmasının bölgesel emisyon üretimine katkıda bulunabileceğini ve yoğun hayvancılık sistemleriyle ilgili çevresel etkileri azaltabileceğini doğrulamakla birlikte, özellikle hayvan türleri arasındaki farklı etkiler ve emisyon sızıntısı potansiyeli açısından, politika uygulamasında çok yönlü bir yaklaşıma duyulan ihtiyacı vurgulamıştır. Ve tek taraflı bir eylem sonucu bir bölgede hayvancılık üretiminde meydana gelen azalmanın, küresel bağlamda başka bir yerdeki artışlarla dengelenerek (sızıntı etkisi) küresel sera gazı emisyon azaltımında mutlaka önemli bir etkiye yol açmayabileceğine dikkat çekmiştir.

Öte yandan CH₄ emisyonlarını azaltmak amacıyla hayvancılık sistemlerinde yapılan değişiklikler (örneğin, meraların tarım arazilerine dönüştürülmesi gibi stratejiler) beklenmedik ve ağır çevresel maliyetler doğurabilmektedir. Bu tür arazi kullanım dönüşümleri, kritik karbon yutaklarının yok olmasına ve toprakta depolanan büyük miktardaki karbonun atmosfere salınmasına neden olarak dolaylı ama önemli çevresel hasarlara yol açmaktadır (Guyader ve ark., 2016; Kothmann ve Pittroff, 2025). Oysa ekosistem temelli yaklaşımlar, çözümün tam tersi yönde olabileceğini göstermektedir; iyi yönetilen ve korunan meralar, yüksek karbon tutma kapasiteleri sayesinde ruminant kaynaklı CH₄ emisyonlarının olumsuz etkilerini kısmen dengeleyebilmekte ve iklim değişikliğiyle mücadelede doğal bir tampon görevi görebilmektedir (Guyader ve ark., 2016).

Dolayısıyla ruminant yetiştiriciliğinden kaynaklanan CH₄ üretimi sadece bir gaz salınımı değil, aslında hayvanın süt verimi veya canlı ağırlık artışı için kullanabileceği enerjinin doğrudan kaybı anlamına gelmektedir. Bu nedenle, boşa giden bu enerjinin metan yerine metabolik enerjiye (et veya süt üretimi) yönlendirilmesi hem hayvancılık işletmelerinin karlılığı hem de sektörün sürdürülebilirliği açısından temel bir stratejik hedeftir. Hayvansal üretimdeki bu enerji kaybını önlemek ve çevresel zararları en aza indirmek, modern hayvancılığın en öncelikli hedeflerinden biri haline gelmiştir. Bu kapsamda hem mikrobiyolojik süreçlere müdahale eden hem de besleme yönetimini optimize eden metan emisyonlarını azaltma stratejileri, sürdürülebilir bir gelecek için hayati önem taşımaktadır.

SONUÇ

Sera gazı emisyonlarını azaltmaya yönelik uygulamalar sadece tarımın çevresel sürdürülebilirliğini iyileştirmekle kalmaz, aynı zamanda farklı azaltma uygulamalarının göreceli etkinliğini karşılaştırma ve değerlendirme olanağı da sağlar. Ayrıca uygulanacak yönetim stratejileri, ruminantlardan kaynaklanan doğrudan enterik CH₄ emisyonlarını azaltmanın yanı sıra toprak kalitesini ve mera biyoçeşitliliğini de artırarak üretim sistemini sürdürülebilir hale getirir. Ek olarak, hayvanlara uygulanan besleme manipülasyonları, metan gazı emisyonlarını azaltmakla birlikte yem verimliliğini artırma,

atıkları azaltma ve hayvan saęlığını iyileřtirme potansiyeline de sahip bütüncül bir yaklaşımdır. Bununla birlikte ruminant yetiřtiricilięinden kaynaklanan sera gazı emisyonlarını azaltmayı amaçlayan stratejilerin küresel sonuçlara ulaşmasını saęlamak için hayvancılık üretimindeki ve yem talebindeki deęişimler de dahil olmak üzere daha geniş sistemik etkileri dikkate alan küresel ölçekli politikalar uygulanmalıdır.

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**GEOCHEMISTRY OF DEPLETED HARZBURGITES FROM THE KINIK OPHIOLITE,
WESTERN ANATOLIA, TÜRKİYE**

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ABSTRACT

Harzburgites are important ultramafic rocks that reflect the melting history and tectonic evolution of the mantle wedge. Particularly, examples preserved within ophiolitic sequences provide significant contributions to understanding the geodynamic evolution of the Neotethys. In this study, the whole-rock geochemistry of harzburgites belonging to the Kinik Ophiolite, located within the İzmir–Ankara–Erzincan Suture Zone, was investigated, and their origin, degrees of melting, and formation environments were determined. The data indicate that the samples are characterized by very high MgO contents (approximately 37–40 wt.%) and high Mg# values (>90); in contrast, Al_2O_3 (0.2–2.5 wt.%), CaO (0.2–2.2 wt.%), and TiO_2 (≤ 0.06 wt.%) contents are quite low. These features point to a highly refractory and strongly depleted mantle source formed as a result of extensive melt extraction. Trace element distributions exhibit a pronounced depletion, particularly in incompatible elements and high field strength elements. In chondrite-normalized rare earth element patterns, the depletion of light rare earth elements relative to heavy rare earth elements and low $(La/Yb)_N$ ratios indicate high-degree partial melting processes derived from a fertile mantle precursor. These geochemical findings reveal that the Kinik harzburgites are not only residues of a highly depleted mantle but also reflect mantle processes developed in a supra-subduction zone tectonic setting. In conclusion, the harzburgites of the Kinik Ophiolite provide strong evidence for high-degree melting and mantle depletion processes that occurred during the evolution of the Neotethyan oceanic lithosphere. This study was carried out within the scope of project no. 2025-04 supported by Kütahya Dumlupınar University.

Keywords: Harzburgite; Whole-rock geochemistry; Highly depleted mantle; Supra-subduction zone; Kinik Ophiolite.

**KINIK OFİYOLİTİ'NDEKİ TÜKENMİŞ HARZBURGİTLERİN JEOKİMYASAL
ÖZELLİKLERİ**

ÖZET

Harzburgitler, manto kamasının ergime geçmişini ve tektonik evrimini yansıtan önemli ultramafik kayalardır. Özellikle ofiyolitik dizilerde korunmuş örnekleri, Neotetis'in jeodinamik gelişiminin anlaşılmasına önemli katkılar sunar. Bu çalışmada, İzmir–Ankara–Erzincan Suture Zonu'nda yer alan Kinik Ofiyoliti'ne ait harzburgitlerin tüm kaya jeokimyası incelenmiş ve kökensel özellikleri, ergime dereceleri ile oluşum ortamları ortaya konmuştur. Veriler, örneklerin çok yüksek MgO içerikleri (yaklaşık %37–40 ağırlık) ve yüksek Mg# değerleri (>90) ile karakterize olduğunu; buna karşılık Al_2O_3 (%0,2–2,5 ağırlık), CaO (%0,2–2,2 ağırlık) ve TiO_2 ($\leq 0,06$ ağırlık) içeriklerinin oldukça düşük olduğunu göstermektedir. Bu özellikler, yoğun ergiyik ayrılması sonucu gelişmiş ileri derecede refrakter ve yüksek düzeyde tükenmiş bir manto kaynağına işaret eder. İz element dağılımları, özellikle uyumsuz elementler ve yüksek alan şiddetli elementler bakımından belirgin bir tükenme sergilemektedir.

Kondrite normalize edilmiş nadir toprak elementleri desenlerinde, hafif nadir toprak elementlerinin ağır nadir toprak elementlerine göre fakirleşmesi ve düşük $(La/Yb)_N$ oranları, verimli bir manto öncülünden türeyen yüksek dereceli kısmi ergime süreçlerine işaret etmektedir. Bu jeokimyasal bulgular, Kınık harzburjitlerinin yalnızca ileri derecede tükenmiş manto kalıntıları olmadığını, aynı zamanda yitim zonu üzeri (supra-subduction zone) bir tektonik ortamda gelişen manto süreçlerini de yansıttığını ortaya koymaktadır. Sonuç olarak, Kınık Ofiyoliti harzburjitleri, Neotetis okyanusal litosferinin evrimi sırasında gerçekleşen yüksek dereceli ergime ve manto tükenmesi süreçlerine güçlü kanıtlar sunmaktadır. Bu çalışma, Kütahya Dumlupınar Üniversitesi tarafından desteklenen 2025-04 numaralı proje kapsamında gerçekleştirilmiştir.

Anahtar Kelimeler: Harzburjit; Tüm kaya jeokimyası, Yüksek derecede tükenmiş manto; Yitim zonu üzeri, Kınık Ofiyoliti.

GİRİŞ

Ofiyolitik diziler, okyanusal litosferin oluşum ve evrim süreçleri ile üst manto dinamiklerini doğrudan kaydeden başlıca jeolojik birimlerdir (Furnes et al. 2020). Anadolu, Alp-Himalaya orojenik kuşağı içerisinde, Neotetis Okyanusu'nun farklı kollarının kapanma süreçlerini temsil eden çok sayıda ofiyolitik kütle barındırır (Parlak, 1996; Floyd et al. 2000; Robertson, 2002). İzmir-Ankara-Erzincan Suture Zonu (İAESZ) içerisindeki ofiyolitler ise, Sakarya Kıtası ile Anatolid-Torid Platformu arasındaki okyanusal alanın kapanma tarihçesini yansıtarak yitim zonu mekanizmalarının anlaşılmasında temel bir rol oynar (Bağcı et al. 2008; Bağcı and Parlak, 2009; Dilek and Thy, 2009).

Kütahya ve çevresi, İAESZ'nin batı uzantısında yer alan ve çok evreli tektonik süreçlerle şekillenmiş bir alandır. Bölgedeki ilk çalışmalar, Devoniyen-Üst Kretase yaşlı temel kayalar üzerine Neojen istifinin uyumsuzlukla yerleştiğini göstermektedir. Aynı çalışmalar, volkanizmanın Miyosen sonunda başlayıp Pliosen'de belirgin biçimde yoğunlaştığını ortaya koymaktadır (Kalafatçıoğlu, 1962, 1964). Ofiyolitik birimlerin bölgedeki dağılımı denizaltı volkanizması ve tektonik yerleşim süreçleriyle ilişkilidir ve bu birimlerin yerleşimi büyük ölçüde Maastrichtiyen'e tarihlenmektedir (Akkuş, 1962; Kalafatçıoğlu, 1962). Tavşanlı Zonu ise, yüksek basınç-düşük sıcaklık (YB/DS) koşullarını yansıtan mavişistler ve ilişkili peridotitleriyle dünya çapında tanınan bir metamorfik kuşaktır (Okay, 1984).

Kınık Ofiyoliti, bölgedeki ofiyolitik istifin başlıca temsilcilerinden biridir. Tabanda harzburjit ve dünitlerden oluşan tektonitler, üstte ise gabro ve spilitik diyabazlar yer alır. Allohton ofiyolit yerleşimi Üst Kretase'de gerçekleşmiş olup bu süreç kuzeydeki kıta kabuğunda belirgin kısalma ve kalınlaşma ile sonuçlanmıştır (Yılmaz, 1981). Göncüoğlu vd. (1992), Kınık Ofiyoliti'nin tektonik dokanakla yerleştiğini ve Tersiyer çökelleri tarafından uyumsuzlukla örtüldüğünü ortaya koymuştur. Ultramafik kayalar, özellikle harzburjitler, manto kamasındaki ergime derecesi ve ilişkili tektonik ortamın belirlenmesinde kritik göstergeler sunar. Bu bağlamda, Kınık Ofiyoliti içerisindeki harzburjitler, primer mineralojik bileşimleri ve katı hal deformasyon yapılarıyla Neotetis'in jeodinamik evrimine doğrudan kısıtlar sağlamaktadır.

Bu çalışma, Kütahya Dumlupınar Üniversitesi BAP (2025-04) projesi kapsamında yürütülmüştür. Çalışmanın amacı, Kınık Ofiyoliti'ne ait harzburjitlerin mineralojik ve tüm kaya jeokimyasal özelliklerini kullanarak manto ergime süreçlerini ve ilişkili tektonik ortamı kısıtlamaktır. Bu kapsamda, örneklerin primer mineralojik bileşimleri, dokusal özellikleri ve majör element içerikleri analiz edilmiştir. Elde edilen veriler, inceleme alanındaki ultramafik birimlerin petrografik ve jeokimyasal özelliklerini ortaya koyarak bölgenin jeodinamik evrimine ilişkin yorumlara temel sağlamaktadır.

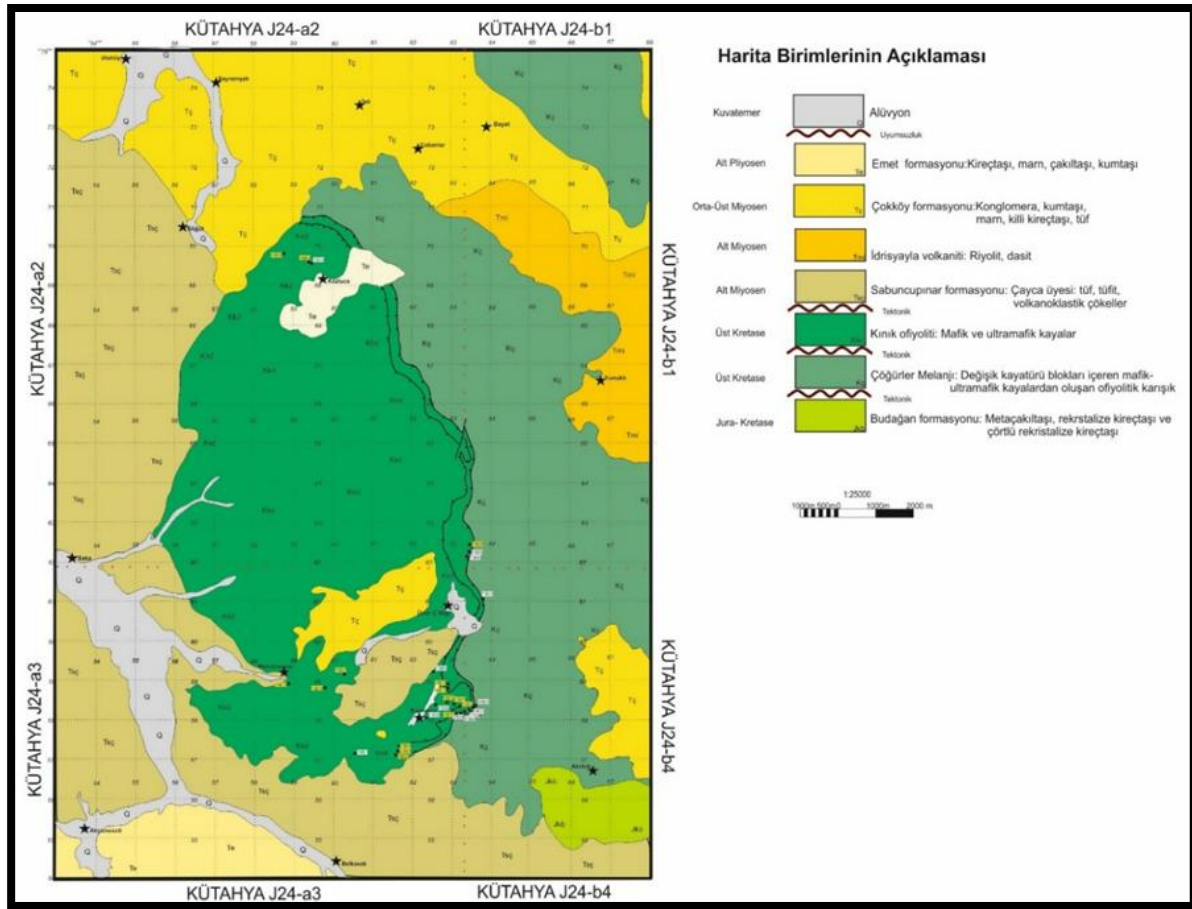
Çalışma Alanının Jeolojisi

İnceleme alanı, Paleozoyik'ten Senozoyik'e uzanan çok evreli bir jeolojik istifi temsil eder. Bölgenin temelini şist ve mermerlerden oluşan metamorfik birimler oluşturur ve bu birimler üzerine ofiyolitik kayalar tektonik dokanakla yerleşmiştir. Kütahya ve yakın çevresindeki metamorfik istifler, okyanusal kapanma sürecini yansıtan Tavşanlı ve Afyon zonları olarak iki ana tektonik birime ayrılır (Okay, 1984). Afyon Zonu, düşük dereceli bölgesel metamorfizma ürünü kuvarsit, şist ve mermerlerden oluşan

İscehisar Formasyonu ile Geç Permiyen–Triyas yaşlı metamorfik serileri içerir (Okay, 1986; Sherlock et al. 1999; Droop et al. 2005; Altunkaynak and Dilek, 2006).

Tavşanlı Zonu ise yaklaşık 250 km uzunluğunda doğu-batı uzanımlı bir kuşak olup yüksek basınç/düşük sıcaklık (YB/DS) koşullarında gelişmiş mavişistleri ve üzerleyen serpantinleşmiş peridotitleri içerir (Okay, 1986; Sherlock et al. 1999; Droop et al. 2005; Topuz et al. 2006). Bu zon içerisindeki ofiyolitik birimler, yaşlıdan gence doğru Kocasu Formasyonu, Çöğürler Karmaşığı ve Kınık Ofiyoliti olarak sıralanır. Çalışmanın odak birimi olan Kınık Ofiyoliti, peridotit, serpantinit, gabro ve bazik dayklardan oluşur. Birim yaklaşık 40 km²'lik bir alanda yüzeylenir ve Kretase yaşlı tektonitler bu istifin temelini oluşturur (Akkuş, 1962; Kalafatçıoğlu, 1962; Okay, 1981) (Şekil 1). Ofiyolitik dizinin üzerine açılal uyumsuzlukla gelen Senozoyik örtü birimleri, Sabuncupınar, Çökköy ve Emet formasyonlarıyla temsil edilir.

Şekil 1. Çalışma alanlarından Muhatboğazı bölgesine ait jeoloji haritası



YÖNTEM

Bu çalışma; literatür taraması, saha çalışmaları, laboratuvar analizleri ve veri değerlendirme aşamalarından oluşur. Saha çalışmaları kapsamında, Kınık ve Muhatboğazı köyleri çevresinde 1/25.000 ölçekli jeolojik haritalama gerçekleştirilmiş ve yapısal unsurlar sistematik olarak ölçülüp kaydedilmiştir. Petrografik ve jeokimyasal analizler için, farklı litolojik seviyeleri ve makroskopik özellikleri temsil eden sistematik örnekleme yapılmıştır. Petrografik analizler kapsamında hazırlanan ince kesitler, Dumlupınar Üniversitesi ve Yüzüncü Yıl Üniversitesi Mineraloji-Petrografi Laboratuvarlarında polarizan mikroskop altında incelenmiş; kayaçların mineral bileşimleri, dokusal özellikleri ve alterasyon dereceleri belirlenmiştir. Tüm kaya jeokimyasal özelliklerini belirlemek amacıyla, petrografik olarak uygun seçilen 21 örnek üzerinde majör, iz ve nadir toprak element (REE) analizleri gerçekleştirilmiştir. Örnek hazırlama

aşamasında numuneler, Dumlupınar Üniversitesi Jeokimya Laboratuvarında çeneli kırıcı ve agat havan kullanılarak 200 mesh tane boyutuna kadar öğütülmüştür. Hazırlanan örneklerin analizleri XRF ve ICP-MS yöntemleriyle akredite laboratuvarlarda tamamlanmıştır. Elde edilen veriler, tektonik ortam ayırtlama diyagramlarında değerlendirilerek harzburjitlerin evrimsel süreçleri yorumlanmıştır.

BULGULAR

Saha Gözlemleri

Kınık Ofiyoliti'ne ait ultramafik kayalar, inceleme alanında morfolojik olarak baskın olup yaklaşık 40 km²'lik bir alanda yüzeylenir. Saha gözlemlerine göre, taze mostralara masif görümlü olup koyu yeşil-siyah renkler baskındır; alterasyonun şiddetli olduğu zonlarda ise beyazımsı, sarımsı-yeşil ve yer yer kiremit kırmızısı renkler gelişmiştir. Tektonitler güçlü deformasyon izleri sergiler ve özellikle makaslama düzlemleri boyunca serpantinleşme yoğunlaşır. Serpantinleşmiş seviyeler bloklu ve keskin köşeli bir morfoloji sunarken, bazı zonlarda bu yapı yerini belirgin bir şistoziteye bırakır. Tektonitler içerisinde ağsı (stockwork) ve damar tipi manyezit oluşumları gözlenmiştir. Manyezit oluşumunu izleyen tektonik olaylar, bazı zonlarda yatakların ilksel geometrisini bozarak düzensiz bir yapı kazandırmıştır (Şekil 2).

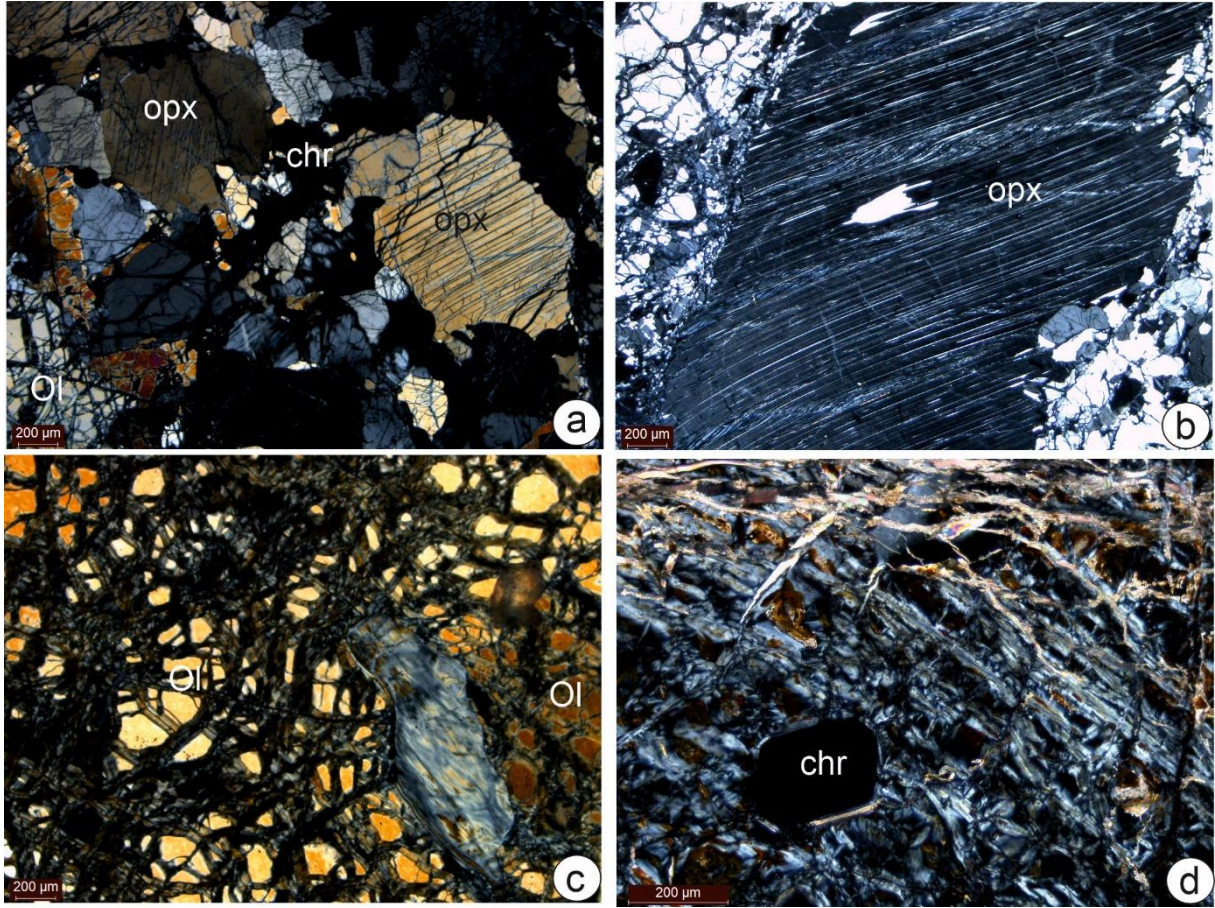
Şekil 2. Çalışma alanında gözlenen tektonitlerden görünüm.



Petrografik Bulgular

Mikroskobik incelemeler, Kınık Ofiyoliti'ne ait ultramafik kayaların tipik bir harzburjit parajenezine sahip olduğunu ortaya koymaktadır. Kayaların ana mineral fazlarını %65–75 oranında olivin ve %20–30 oranında ortopiroksen oluşturur. Klinikopiroksenin %5'in altında olması, bu birimlerin yüksek derecede ergimeye uğramış üst manto kalıntılarını temsil ettiğini gösterir (Şekil 3). Kayalar granüler-subgranüler doku gösterir ve ortopiroksenler genellikle iri taneli porfiroklastlar şeklinde bulunur. Bu porfiroklastlarda gözlenen dalgalı sönme, iç bantlanma ve lamelli deformasyon, minerallerin katı hal plastik deformasyon geçirdiğini ortaya koyar. Olivin kristalleri, ikincil hidrotermal süreçler sonucunda yaygın biçimde serpantinleşmiş ve karakteristik ağ (mesh) dokusu geliştirmiştir. Aksesuar kromit kristalleri ise serpantinleşmiş matris içerisinde subhedral–anhedral morfolojilerini koruyarak birincil dokusal özelliklerini muhafaza etmiştir.

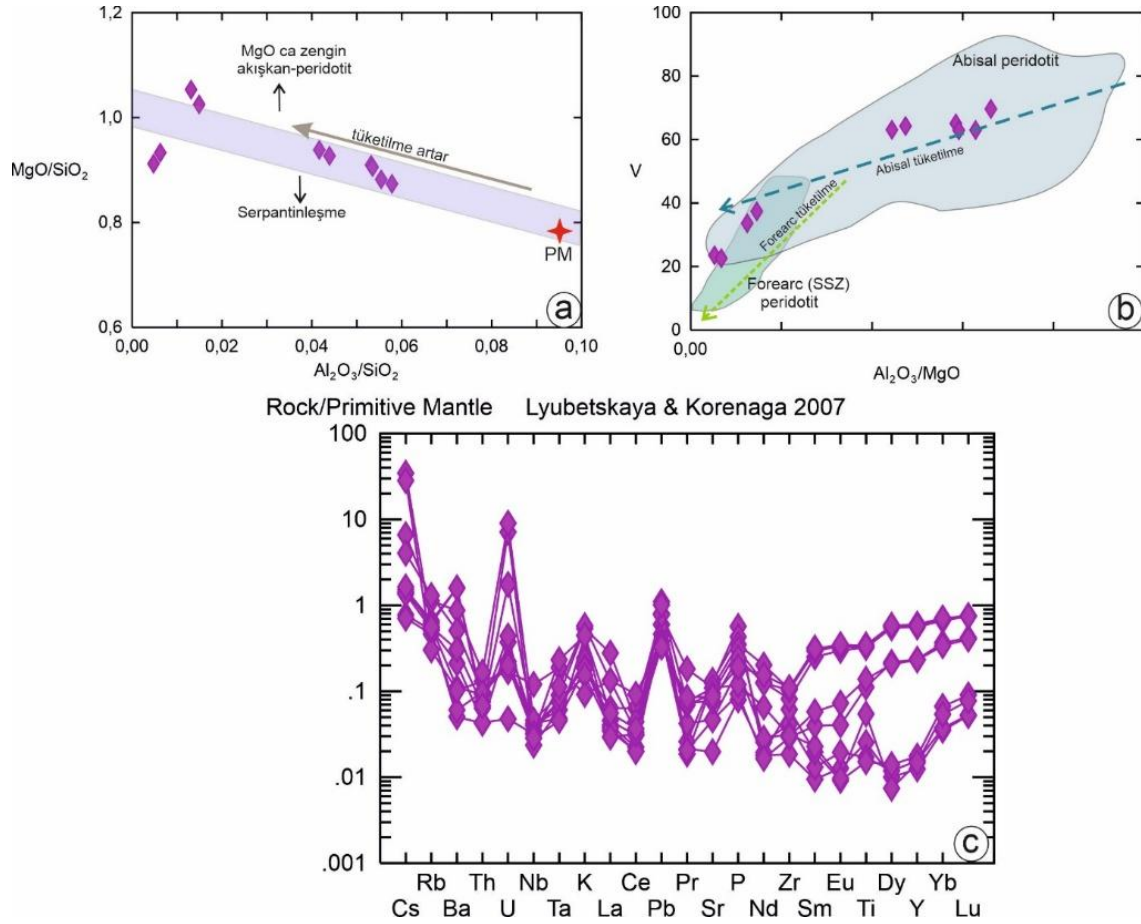
Şekil 3. Kınık ofiyolitine ait ultramafik kayaların mineralojik ve dokusal özelliklerini gösteren incekesit görüntüleri



Jeokimyasal Karakterizasyon

Kınık harzburgitinin tüm kaya majör element bileşimleri, birimin refrakter manto karakterini güçlü biçimde desteklemektedir. Örneklerin MgO içerikleri ağırlıkça %37–40, SiO₂ içerikleri ise %38–43 aralığında değişmektedir. Buna karşılık, bazaltik ergiğin ayrılmasıyla sistemden uzaklaşan Al₂O₃ (%0,2–2,5) ve CaO (%0,2–2,2) derişimleri son derece düşüktür. Örneklerin Mg# değerlerinin 90'ın üzerinde olması ve TiO₂ (≤%0,06) ile alkali oksit içeriklerinin düşük olması, birimin ileri derecede tükenmiş bir manto kaynağına işaret etmektedir. MgO/SiO₂ – Al₂O₃/SiO₂ varyasyon diyagramında (Şekil 4a), örneklerin tamamı MgO bakımından zengin, Al₂O₃ ve SiO₂ bakımından fakir peridotit alanında yer almaktadır. Serpantinleşme süreçlerine bağlı olarak gelişen ikincil SiO₂ ve LOI (ateş yayıtı) değişimleri, birimin primer ultramafik kimyasal imzasını maskeleyecek düzeyde değildir. Al₂O₃/MgO – V diyagramındaki (Şekil 4b) dağılım, örneklerin abyssal lherzolitlerden uzaklaşarak bazaltik ergiyik ayrılmasıyla klinopiroksen bakımından fakirleşmiş rezidüel peridotit trendi üzerinde yoğunlaştığını göstermektedir. İz element verileri, manto kökenli bir protolit ile uyumlu yüksek Cr (2500–3500 ppm) ve Ni (1800–2150 ppm) içeriklerini göstermektedir. İlkse mantoya (Primitive Mantle) normalize edilmiş spider diyagramında gözlenen uyumsuz elementlerdeki güçlü tükenme, Nb–Ta negatif anomalileri ve spinel peridotit stabilite alanını yansıtan hafif yükselen HREE deseni, birimin ileri derecede tükenmiş üst manto bileşimini açıkça yansıtır (Şekil 4c). Genel jeokimyasal veriler, incelenen kayaların yüksek derecede kısmi ergimeye maruz kalmış ve klinopiroksen bakımından fakir harzburgit karakterini göstermektedir.

Şekil 4. Harzburgit örneklerinin jeokimyasal özellikleri: (a) MgO/SiO₂ – Al₂O₃/SiO₂ diyagramında gözlenen yüksek derecede tükenmiş peridotit karakteri; (b) Al₂O₃/MgO – V diyagramında yüksek dereceli kısmi ergimeye işaret eden kalıntı peridotit trendi; (c) İlkse mantoya normalize edilmiş iz element diyagramında saptanan Nb–Ta negatif anomalileri ve rezidüel üst manto bileşimini yansıtan karakteristik desenler.



TARTIŞMA VE SONUÇ

Kınık Ofiyoliti'ne ait harzburjitten elde edilen mineralojik ve jeokimyasal veriler, bu birimin Neotetis okyanusal litosferinin evrimi sırasında yüksek dereceli ergime süreçlerine maruz kalmış refrakter bir üst manto kalıntısı olduğunu göstermektedir. Petrografik incelemelerde saptanan ortopiroksen porfiroklastlarındaki lamelli deformasyon yapıları ve olivinlerdeki dalgali sönme izleri, kayaların yerleşim öncesinde manto derinliklerinde katı hal plastik deformasyon süreçlerinden geçtiğini göstermektedir. Bu dokusal özellikler, bölgedeki ofiyolitik birimlerin yüksek sıcaklıklı manto akışını yansıtan karakteristik verilerdir. Saha gözlemleriyle desteklenen ve makaslama zonları boyunca yoğunlaşan serpantinleşme süreçleri, primer ultramafik yapının yerleşim sonrası evrede hidrotermal etkilerle ikincil alterasyona uğradığını göstermektedir. Kalafatçıoğlu (1962)'nin de belirttiği üzere, bölgedeki serpantinleşme ofiyolit yerleşiminin geniş çaplı tektonik sonuçlarından biridir.

Jeokimyasal açıdan saptanan yüksek Mg# değerleri (>90) ile son derece düşük TiO₂ (≤%0,06) ve alkali oksit derişimleri, birimin yitim zonu üzeri (SSZ – Supra-Subduction Zone) bir tektonik ortamda evrimleştiğine işaret etmektedir. Elde edilen Al₂O₃/MgO – V dağılımı, Kınık harzburjitinin abyssal peridotitlerden farklı olarak daha ileri derecede tükenmiş bir nitelik taşıdığını göstermektedir. Bu özellikler, İzmir–Ankara–Erzincan Sütur Zonu (İAESZ) içerisindeki diğer ofiyolit kütleleri için önerilen bölgesel jeolojik modellerle genel olarak uyumludur. İz element desenlerinde gözlenen uyumsuz elementlerdeki güçlü tükenme ve Nb–Ta negatif anomalileri, birimin verimli bir manto öncülünden türeyen bazaltik ergiyiklerin ayrılması sonrası geride kalan rezidüel bir üst manto bileşimini yansıtmaktadır.

Sonuç olarak, bu çalışma kapsamında sunulan veriler, Kütahya bölgesindeki ofiyolitik istifin tabanını oluşturan harzburjitin refrakter karakterini ve yitimle ilişkili kökenini tanımlamaktadır. Saha, petrografi ve majör element verilerinin birlikte değerlendirilmesi, bölgedeki ultramafik birimlerin petrolojik karakterizasyonu için temel bir veri seti sunmaktadır. Elde edilen bulgular, bölgedeki okyanusal evrim

süreçlerinin anlaşılmasına katkı sağlamakta ve gelecekte yapılacak daha ayrıntılı modelleme çalışmaları için bir temel oluşturmaktadır.

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**FITNESS-ORIENTED SOCIAL MEDIA AND BODY IMAGE: A NARRATIVE REVIEW OF
RISK MECHANISMS, PROTECTIVE FACTORS, AND FINDINGS FROM TÜRKİYE
AMONG UNIVERSITY STUDENTS**

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ABSTRACT

This study examines the effects of fitness-oriented social media content on body image among university students using a narrative review approach. Full-text studies published in Turkish and English up to March 2026 were identified through keywords including fitspiration, body image, appearance comparison, self-objectification, body appreciation, university students, and instagram/tiktok. Priority was given to research focusing on individuals aged 18–30, university samples, and outcomes related to appearance-focused social media use. Findings indicate that negative effects are more strongly associated with the nature of the content encountered rather than the total duration of social media use. Content that normalizes thin, fit, or excessively muscular bodies may increase body dissatisfaction through mechanisms such as appearance comparison, internalization of the ideal body, self-objectification, and negative affect. In contrast, self-compassion, a focus on body functionality, critical media literacy, conscious curation of social media feeds, and text-based body-positive content appear to have protective effects. Studies conducted in Türkiye also report significant associations between social media addiction, appearance comparison, and low body image. Furthermore, these studies suggest that positive body image can be strengthened through mindful use, a sense of competence, and exposure to affirming content. In conclusion, the primary source of risk for university students is not mere exposure to social media, but rather appearance-centered patterns of digital use in which the body is continuously evaluated and performance is intertwined with aesthetics. Therefore, campus-based interventions are recommended to simultaneously target digital media literacy, self-compassion, and awareness of body functionality.

Keywords: Body image; fitspiration; social media; appearance comparison; self-objectification; university students

**FITNESS ODAKLI SOSYAL MEDYA VE BEDEN ALGISI: ÜNİVERSİTE
ÖĞRENCİLERİNDE RİSK MEKANİZMALARI, KORUYUCU ETKENLER VE
TÜRKİYE'DEN BULGULAR ÜZERİNE BİR ANLATI DERLEMESİ**

ÖZET

Bu çalışma, üniversite öğrencilerinde fitness odaklı sosyal medya içeriklerinin beden algısı üzerindeki etkilerini anlatı derlemesi yaklaşımıyla incelemektedir. Mart 2026'ya kadar yayımlanmış Türkçe ve İngilizce tam metin çalışmalar; fitspiration, body image, appearance comparison, self-objectification, body appreciation, üniversite öğrencileri ve instagram/tiktok anahtar sözcükleri üzerinden taranmış; özellikle 18-30 yaş grubunu, üniversite örneklemelerini ve sosyal medyanın görünüş odaklı kullanımıyla ilişkili sonuçları raporlayan araştırmalara öncelik verilmiştir. Bulgular, olumsuz etkinin çoğu zaman toplam kullanım süresinden çok maruz kalınan içeriğin niteliğiyle ilişkili olduğunu göstermektedir. İnce, fit ya da aşırı kaslı bedenleri normlaştıran içerikler; görünüş karşılaştırması, ideal bedenin içselleştirilmesi, öz-nesneleştirme ve olumsuz duygulanım üzerinden beden memnuniyetsizliğini artırabilmektedir. Buna karşılık öz-şefkat, beden işlevselliğine odaklanma, eleştirel medya

okuryazarlığı, takip edilen akışın bilinçli biçimde düzenlenmesi ve metin temelli beden olumlama içerikleri daha koruyucu görünmektedir. Türkiye'den çalışmalar da sosyal medya bağımlılığı, görünüş karşılaştırması ve düşük beden algısı arasında anlamlı ilişkiler rapor etmekte; olumlu beden algısının ise bilinçli kullanım, yeterlilik hissi ve olumlayıcı içeriklerle güçlenebileceğine işaret etmektedir. Sonuç olarak üniversite öğrencilerinde riskin asıl kaynağı, sosyal medyaya salt maruz kalma değil; bedenini sürekli değerlendirildiği, performans ve estetiğin birleştirildiği görünüş merkezli dijital kullanım örüntüsüdür. Bu nedenle kampüs temelli müdahalelerin dijital medya okuryazarlığını, öz-şefkati ve beden işlevselliği farkındalığını birlikte hedeflemesi önerilmektedir.

Anahtar Kelimeler: Beden algısı; fitspiration; sosyal medya; görünüş karşılaştırması; öz-nesneleştirme; üniversite öğrencileri

GİRİŞ

Fitness kültürü sosyal medyada yalnızca egzersiz önerilerinin dolaştığı bir alan değildir; aynı zamanda bedeni disiplin, başarı, estetik ve özdenetim üzerinden yeniden kodlayan bir temsil rejimidir. Özellikle görsel ağırlıklı platformlarda dolaşıma giren fitspiration içerikleri, sağlıklı yaşam söylemini çoğu zaman ince, yağsız ya da aşırı kaslı beden imgeleriyle birleştirir. Bu nedenle literatürde fitspiration, başlangıçtaki motive edici görünümüne rağmen beden memnuniyetsizliği ve yeme davranışı riskleriyle birlikte tartışılmaktadır (Cataldo et al., 2021; Jerónimo & Carraça, 2022).

Üniversite dönemi, bu etkinin belirginleştiği bir gelişimsel evredir. Kimlik inşası, akran onayı, romantik görünürlük, sosyal kabul ve özsunum baskısı aynı dönemde yoğunlaştığı için genç yetişkinler bedensel değerlendirmelere daha hassas hâle gelebilmektedir. Üniversite öğrencileri üzerinde yapılan çalışmalar, instagram gibi platformlarda geçirilen sürenin tek başına yeterli bir açıklama sunmadığını; asıl belirleyicinin görünüş odaklı hesapları takip etme, kendini başkalarıyla kıyaslama ve bedeni düzenlenebilir bir proje gibi görme eğilimi olduğunu göstermektedir (Alfonso-Fuertes et al., 2023; Sanzari et al., 2023; Yılmaz et al., 2026).

Bu alanın dikkat çekici yanı, etkilerin tek yönlü olmamasıdır. Bazı kullanıcılar fitspiration içeriklerini egzersize başlamak, tarif bulmak ya da rutin sürdürmek için yararlı bulurken; aynı içerikler başka kullanıcılar için yetersizlik, utanma, zorunluluk hissi ve bedene yabancılaşma üretebilmektedir. Gençlerle yapılan nitel çalışmalar, fitspiration deneyiminin aynı anda hem çekici hem de tüketici olabildiğini; özellikle kadınlarda ince ama biçimli, erkeklerde ise kaslı ve düşük yağ oranlı beden ideallerini pekiştirdiğini ortaya koymaktadır (Easton et al., 2018; Mayoh & Jones, 2021).

Bu anlatı derlemesinin amacı üç soruya yanıt vermektir: (i) fitness odaklı sosyal medya içerikleri üniversite öğrencilerinde beden algısını hangi psikososyal mekanizmalar üzerinden etkiler, (ii) hangi bireysel ya da dijital kullanım örüntüleri riski artırır, (iii) hangi koruyucu faktörler ve kampüs temelli önlemler daha uygulanabilir görünmektedir?

ARAŞTIRMA VE BULGULAR

1. Derleme Yaklaşımı ve Kapsamı

Bu metin, sistematik derleme iddiası taşımayan ancak seçimi açık ölçütlerle yapılmış bir anlatı derlemesidir. Taramada PubMed, PubMed Central, Google Scholar, JMIR, BMC ve DergiPark dizinlerinde yer alan Türkçe ve İngilizce çalışmalar dikkate alınmıştır. 2017-2026 döneminde yayımlanmış, tam metnine erişilebilen ve sosyal medya kullanımı ile beden algısı, beden memnuniyetsizliği, olumlu beden algısı, görünüş karşılaştırması, öz-nesneleştirme veya ilişkili yeme davranışı sonuçları arasında bağlantı kuran çalışmalar önceliklendirilmiştir.

Üniversite öğrencileri çalışmanın odak grubunu oluşturduğu için, doğrudan üniversite örneklemini kullanan araştırmalar özellikle öne alınmıştır. Bununla birlikte, mekanizmaları açıklayan ve üniversite çağına aktarılabilir nitelikteki bazı nitel çalışmalar, sistematik derlemeler ve fitspiration içerik analizleri de kanıt örgüsünü güçlendirmek amacıyla değerlendirilmiştir. Derlemenin temel iddiası, sosyal medyanın etkisini süreden ziyade içerik, etkileşim biçimi ve kullanıcı yorumu üzerinden açıklamaktır.

Tablo 1. Seçili Çalışmaların Kısa Sentezi

Çalışma	Örneklem / Tasarım	Temel Bulgu
Carrotte et al. (2017)	İçerik analizi	Kadınlara dönük içeriklerde ince/atletik; erkeklere dönük içeriklerde kaslı beden idealinin baskın olduğu gösterilmiştir.
Arigo et al. (2021)	Kolej öğrencileri / deneysel	Mesaj türü değişse de fitspiration maruziyeti beden doyumu ve egzersiz motivasyonunu farklı biçimlerde etkileyebilmektedir.
Alfonso-Fuertes et al. (2023)	Genç yetişkinler / gözlemsel	Instagram süresi kadar fiziksel karşılaştırma ve özsaygı düzeyi belirleyici görünmektedir.
Sanzari et al. (2023)	Derleme	İçerik niteliği, maruz kalma süresinden daha güçlü bir risk göstergesi olarak öne çıkmıştır.
Varaona et al. (2024)	Gözlemsel çalışma	Instagram kullanımı, öz-eleştiri ve beden memnuniyetsizliği ile ilişkiliyken öz-şefkat koruyucu görünmektedir.
Tayhan (2023)	Üniversite öğrencileri / kesitsel	Sosyal medya bağımlılığı yüksek olan öğrencilerde düşük beden algısı ve yeme bozukluğu riski daha sık raporlanmıştır.

2. Risk Üreten Mekanizmalar

Fitspiration içeriklerinin etkisini açıklayan ilk halka, görünüş karşılaştırmasıdır. Sosyal medya, karşılaştırmayı yalnızca mümkün kılmaz; onu sürekli, hızlı ve algoritmik bir akış içine yerleştirir. Fitspiration imgeleri çoğu zaman bedeni karşılaştırılabilir parçalara böler; karın kası, bel inceliği, bacak formu ya da omuz genişliği gibi ölçülebilir görsel göstergeler öne çıkarılır. Görsel örüntünün kendisi bile toplumsal cinsiyete göre farklılaşır: kadınlara dönük içerikler daha sık ince ama biçimli bedeni, erkeklere dönük içerikler ise kaslı ve hacimli bedeni normlaştırır (Carrotte et al., 2017; Mayoh & Jones, 2021).

İkinci halka, ideal bedenin içselleştirilmesi ve öz-nesneleştirilmedir. Kullanıcı sosyal medyayı yalnızca izleyen bir konumda kalmadığında, kendi bedenini de sergilenecek, düzeltilecek ve değerlendirilecek bir nesne gibi görmeye başlayabilir. Influencer odaklı çalışmalar, sağlık ve egzersiz söyleminin çoğu zaman ürün tanıtımı, estetik başarı ve görünüş mükemmelliğiyle iç içe geçtiğini; bunun da kullanıcıda 'sağlıklı olmak için böyle görünmeliyim' düşüncesini güçlendirdiğini göstermektedir (Pilgrim & Bohnet-Joschko, 2019; Cataldo et al., 2021). Bu çerçevede, bedenin işlevinden çok görünüş değerine odaklanan bir özdenetim baskısı üretmektedir.

Üçüncü halka, duygulanım ve davranış boyutudur. Derlemeler ve deneysel çalışmalar, fitspiration maruziyetinin her kullanıcıda aynı şiddette sonuç üretmediğini; ancak belirli kırılganlıklarda olumsuz duygulanım, utanma, öz-eleştiri ve düzensiz yeme riskini artırabildiğini bildirmektedir (Jerónimo & Carraça, 2022; Sanzari et al., 2023). Nitel araştırmalarda gençler fitspiration içeriklerini bir yandan motive edici, diğer yandan da 'asla yeterli hissettirmeyen' bir akış olarak tanımlamaktadır (Easton et al., 2018; DiBisceglie et al., 2021). Özellikle görünüş takibi, beğeni sayılarına odaklanma ve bedeni düzenleme davranışları yoğunlaştığında etkiler daha olumsuz bir çizgiye kaymaktadır.

Bu nedenle riskin anahtarı kullanım süresinden çok kullanımın niteliğidir. Instagram süresi ile beden algısı arasındaki ilişkiyi inceleyen çalışmalar, fiziksel karşılaştırmanın ve özsaygının araya girdiği durumlarda olumsuz sonucun daha belirgin olduğunu göstermektedir (Alfonso-Fuertes et al., 2023). Benzer biçimde içerik temelli derlemeler, beden imgesi ve yeme davranışı açısından asıl sorunlu alanın görünüş merkezli, kilo kaybını ya da biçimlenmiş kas görünümünü idealize eden akışlar olduğunu vurgulamaktadır (Sanzari et al., 2023).

3. Koruyucu Faktörler ve Azaltım Stratejileri

Literatür yalnızca riskleri değil, belirli koruyucu etkenleri de görünür kılmaktadır. Bunların başında öz-şefkat gelmektedir. Öz-şefkat düzeyi arttıkça bireyin bedeni kusursuzluk ölçütüyle değil, insan deneyiminin doğal bir parçası olarak değerlendirme eğilimi güçlenmektedir. Bu da görünüş karşılaştırmasının ve öz-eleştirmenin şiddetini azaltabilmektedir. Gözlemsel ve derleme bulguları, öz-şefkatin beden memnuniyetsizliği ve öz-nesneleştirme üzerinde tamponlayıcı rol oynayabildiğini göstermektedir (Sarda et al., 2025; Varaona et al., 2024). Ayrıca fitspiration görsellerine eşlik eden öz-şefkat temelli mesajların, geleneksel fitspiration mesajlarına kıyasla daha dengeli sonuçlar üretebildiği deneysel olarak da gösterilmiştir (Arigo et al., 2021).

İkinci koruyucu alan, olumlu beden algısı ve beden işlevselliğine yönelmedir. Bedeni yalnızca görünen bir nesne olarak değil, hareket eden, güç üreten, dinlenen, iyileşen ve günlük yaşamı mümkün kılan bir yapı olarak düşünmek; estetik kıyaslamaların baskısını azaltmaktadır. Türkiye'de beden olumlama gönderileri üzerine yapılan derleme, görsel beden sunumundan çok metin temelli kabul ve işlevsellik vurgusunun daha besleyici olduğunu ortaya koymaktadır (Önal, 2025). Benzer biçimde üniversite öğrencileri üzerinde yapılan Türkçe araştırmalar, sosyal medya yeterliliği ve bilinçli kullanım arttıkça olumlu beden algısının daha yüksek olabildiğini rapor etmektedir (Öngören & İntizamoğlu, 2025).

Üçüncü koruyucu alan, dijital akışın aktif biçimde yönetilmesidir. Fitspiration kullanıcılarıyla yapılan araştırmalar, takip edilen hesapların niteliğinin ve kullanıcı motivasyonunun belirleyici olduğunu; bilgi edinme ve sağlık farkındalığı amacıyla kullanılan içeriklerin bile görünüş baskısı taşıdığına riskli bir forma bürünebildiğini göstermektedir (Limniou et al., 2021; Mayoh & Jones, 2021). Bu nedenle algoritmik akışı rastlantısal kabul etmek yerine, tetikleyici hesapları ayıklama, beden çeşitliliği sunan kaynakları seçme ve içerik tüketimi sonrasında duygusal tepkiyi fark etme becerileri önem taşımaktadır. Müdahale literatürü de medya okuryazarlığı, öz-şefkat ve beden olumlama eksenlerinin birlikte ele alınmasının daha işlevsel olabileceğini vurgulamaktadır (Mazzeo et al., 2024).

4. Türkiye Bağlamında Seçili Bulgular

Türkiye'den elde edilen bulgular uluslararası eğilimlerle büyük ölçüde uyumludur. Dergipark'ta yayımlanan çalışmalar, sosyal medya bağımlılığı arttıkça beden algısının zayıflayabildiğini, görünüş karşılaştırmalarının bedeni beğenmeyi düşürebildiğini ve bazı örneklerde yeme bozukluğu riskinin eşzamanlı olarak yükseldiğini göstermektedir (Özgür & Uçar, 2020; Tayhan, 2023). Özellikle üniversite öğrencileri arasında yürütülen araştırmalarda kadın ve erkek öğrencilerin etkilenme biçimlerinin farklılaştığı; ancak görünüşe odaklı kullanım örüntülerinin her iki cinsiyet için de önemli olduğu görülmektedir (Yılmaz et al., 2026).

Türkçe literatürün dikkat çekici katkılarından biri, fitspiration ile beden imgesi arasındaki ilişkiyi kavramsal düzeyde erken dönemde tartışmış olmasıdır. Bayköse ve Esin (2020), fit olmayı teşvik eden içeriklerin egzersiz ve sağlıklı yaşam çağrısı taşısa da beden tatminsizliği, sosyal karşılaştırma ve nesneleştirici bakış açısından bağımsız okunamayacağını vurgulamaktadır. Tosun ve Çoban'ın (2020) bulguları da sosyal ağlardaki yukarı yönlü fiziksel görünüm karşılaştırmalarının bedeni beğenmeyi düşürdüğünü ve depresif duygulanımla dolaylı bağlantılar kurabildiğini göstermektedir.

Diğer yandan Türkçe çalışmalar koruyucu bir çerçeve de sunmaktadır. Pozitif beden algısına odaklanan son dönem araştırmalar, sosyal medya kullanımının yalnızca bir risk alanı olmadığını; yeterlilik hissi, eleştirel farkındalık ve olumlu içerik tercihleriyle daha dengeli bir deneyim üretilebileceğini ortaya koymaktadır (Öngören & İntizamoğlu, 2025; Önal, 2025). Bu nedenle Türkiye bağlamında üniversiteler

için en işlevsel yaklaşım, öğrencileri platformlardan bütünüyle uzaklaştırmaya çalışmak değil; dijital beden kültürünü çözümleyebilen ve kendi akışını yönetebilen kullanıcılar hâline getirmektir.

SONUÇ

Bu anlatı derlemesi, üniversite öğrencilerinde fitness odaklı sosyal medya kullanımının beden algısı üzerindeki etkisinin tek bir değişkenle açıklanamayacağını göstermektedir. Risk, en güçlü biçimde görünüş karşılaştırması, ideal bedenin içselleştirilmesi, öz-nesneleştirme ve olumsuz duygulanımın bir araya geldiği durumlarda ortaya çıkmaktadır. Dolayısıyla 'çok kullanan zarar görür' biçimindeki basit açıklama yetersizdir; asıl mesele, hangi içerikle ne tür bir psikolojik ilişki kurulduğudur.

Koruyucu tarafta ise öz-şefkat, olumlu beden algısı, beden işlevselliğine odaklanma, medya okuryazarlığı ve dijital akışı düzenleme becerileri öne çıkmaktadır. Üniversitelerde yürütülecek seminerler, danışmanlık programları ve ders içi etkinlikler bu bileşenleri birlikte hedeflediğinde daha etkili olabilir. Kampüs sağlık birimleri, psikolojik danışmanlık merkezleri ve spor birimleri arasında kurulacak iş birliği; beden yalnızca estetik bir proje değil, işlevsel ve yaşantısal bir bütün olduğu fikrini güçlendirebilir.

Çalışmanın temel sınırlılığı, anlatı derlemesi oluşu nedeniyle meta-analitik bir nicel sentez sunmamasıdır. Buna rağmen Türkçe ve İngilizce güncel literatürü aynı çerçevede bir araya getirmesi, özellikle Türkiye'deki üniversite öğrencilerine yönelik uygulamalar için pratik bir yol haritası sunmaktadır. Gelecek araştırmalarda Türkiye örneğinde fitspiration, beden olumlama, öz-şefkat ve beden işlevselliğini birlikte ele alan boylamsal ve deneysel çalışmaların çoğaltması alanı belirgin biçimde güçlendirecektir.

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ANFIS-BASED MODELING OF A WASTEWATER TREATMENT BIOREACTOR: EFFECT OF RULE NUMBER ON MODEL ACCURACY

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ABSTRACT

Interest in optimizing ecosystem processes is currently growing. One key example is the application of fuzzy logic modeling methods to wastewater treatment. Biological wastewater treatment is a nonlinear and dynamic process, and traditional mathematical models face challenges. These challenges include inaccuracies in modeling, forecasting, and decision making. In this study, a wastewater treatment bioreactor model was developed using the adaptive neuro-fuzzy inference (ANFIS) modeling method.

An analysis was conducted to determine the impact of the number of rules on the prediction accuracy of this bioreactor model. Subtractive clustering was used to model the structure of different rule numbers. The root means square error (RMSE) and mean absolute percentage error (MAPE) were used to determine the quality of the resulting model. Both metrics were used for training and testing. The study found that increasing the number of rules also improved the model's accuracy. It should be noted that the minimum error value was obtained with a rule count of 8-10, demonstrating the best balance between model complexity and generalization ability. The results suggest that rule base optimization is an important factor in building reliable ANFIS models for wastewater treatment systems. The proposed approach can be effectively used for intelligent monitoring and the development of digital twins of biological treatment processes.

Keywords: Anfis, RMSE and MAPE Error Metrics, bioreactor, Fuzzy Rule Optimization, wastewater treatment.

INTRODUCTION

The biological wastewater treatment process is based on the activity of microorganisms. Microorganisms utilize organic matter in wastewater as a source of energy and carbon. Activated sludge is the key element in this study. Heterotrophic microorganisms form the biomass of activated sludge. Biomass concentration is denoted as (X_H). X_H represents the mass of heterotrophic bacteria present in the bioreactor. This parameter is typically measured in mg/L or g/m³ and characterizes the number of microorganisms directly involved in the decomposition of organic contaminants [1].

It should be noted that this value reflects the growth of microorganisms due to the consumption of organic substrate. Biomass is one of the most important parameters of biological activity in a bioreactor and is directly related to the efficiency of organic contaminant removal. Traditional mathematical models of biological wastewater treatment processes describe biomass dynamics using systems of nonlinear differential equations [2].

However, the practical application of such models is often complicated by the need to accurately determine a large number of kinetic parameters, as well as by high sensitivity to changes in input conditions and reactor operating modes.

Due to these shortcomings, intelligent modeling methods based on fuzzy logic, artificial intelligence, and soft computing are increasingly being used [3]. One such promising tool is the Adaptive Neuro-Fuzzy Inference System (ANFIS), which combines the advantages of neural networks and fuzzy logic. This modeling method enables the construction of models of complex nonlinear processes based on experimental data, automatically generating inference rules and adapting model parameters during the training process.

In this study, ANFIS is used to model biomass dynamics in a wastewater treatment bioreactor. The modeled object is the derivative of the heterotrophic biomass concentration (dX_H/dt), which reflects the microbial growth rate in the reactor [4]. A dataset containing approximately 3,000 observations obtained from simulating a biological treatment process was used to build and train the model.

It should be noted that the study analyzed the impact of the number of fuzzy rules on the accuracy of the ANFIS model. Various model structures were formed using a subtractive clustering method, which automatically determines the number of rules based on the data structure. To assess the quality of the modeling, RMSE (Root Mean Square Error) and MAPE (Mean Absolute Percentage Error) metrics were used for the training and test sets [5].

The primary objective of this study was to determine the optimal number of fuzzy rules that would provide the best balance between prediction accuracy and model complexity when describing biomass dynamics in a wastewater treatment bioreactor. The results obtained can be used to develop intelligent monitoring systems and create digital twins of biological treatment processes.

METHODOLOGY

The biological wastewater treatment process in activated sludge bioreactors is primarily governed by the growth and decay dynamics of heterotrophic microorganisms responsible for the degradation of organic pollutants. The concentration of heterotrophic biomass X_H is a crucial parameters of variable that characterizes the biological activity within the reactor [6]. The temporal evolution of this biomass is commonly described by the following differential equation:

$$\frac{dX_H}{dt} = \frac{q_F}{V} X_{HF} - \frac{q_{tr}}{V} X_H + \left(\frac{q_F + q_R}{q_{tr} + q_R} \right) X_H - \frac{\mu_H}{Y_H} \left(\frac{S_S}{K_S + S_S} \right) \left(\frac{S_O}{K_{OH} + S_O} \right) X_H + (1 - f_P) b_H X_H \quad (1)$$

where:

- X_H — concentration of heterotrophic biomass (mg/L)
- q_F — influent wastewater flow rate
- q_R — recycle flow rate
- q_t — treated water outflow rate
- V — bioreactor volume
- X_{HF} — biomass concentration in the influent flow
- μ_H — maximum specific growth rate of heterotrophic microorganisms
- Y_H — biomass yield coefficient
- S_S — readily biodegradable substrate concentration
- K_S — half-saturation constant for substrate utilization
- S_{OS} — dissolved oxygen concentration
- K_{OH} — half-saturation constant for oxygen
- b_H — endogenous respiration (decay) coefficient
- f_P — fraction of biomass converted into particulate products

The first two terms in the equation describe biomass transport due to influent and effluent flows. The third term represents the recirculation of biomass within the treatment system. The fourth term corresponds to biomass growth, which depends on substrate availability and dissolved oxygen concentration and follows Monod-type kinetics [7]. The final term represents endogenous decay and transformation of biomass. This differential equation describes the rate of change of biomass concentration, which is directly linked to the efficiency of organic pollutant removal in the bioreactor.

Specifically, a dataset consisting of 3,000 observations was collected for model construction. These observations were obtained through modeling using differential equations. Each observation corresponds to a specific operating state of the bioreactor, taking into account the effects of microorganism growth and biomass concentration dynamics. The next step was to split the data into a training dataset and a test dataset. The training dataset is used to build the ANFIS model, and the test dataset is used to evaluate forecasting accuracy [8].

RESULTS

An adaptive neuro-fuzzy inference system (ANFIS) was used to approximate the nonlinear relationship between process variables and biomass growth dynamics. This ANFIS modeling method combines fuzzy logic with neural network-based learning capabilities [9]. The modeling consists of five computational layers: a fuzzification layer, a rule layer, a normalization layer, a defuzzification layer, and an output layer. In this study, the fuzzy rule base was generated using a subtractive clustering algorithm, which automatically identifies clusters in a dataset and generates corresponding fuzzy rules.

The key parameter of the ANFIS model is the number of fuzzy rules (clusters). Increasing the number of rules improves the model's ability to capture nonlinear dependencies in the system. In this study, several ANFIS models with rules ranging from 2 to 10 clusters were constructed. The root mean square error (RMSE) and mean absolute percentage error (MAPE) were used to determine forecast accuracy. Figure 1 is one of the figures obtained from the analysis. This figure shows the relationship between the number of fuzzy rules and the RMSE values for the training and test datasets.

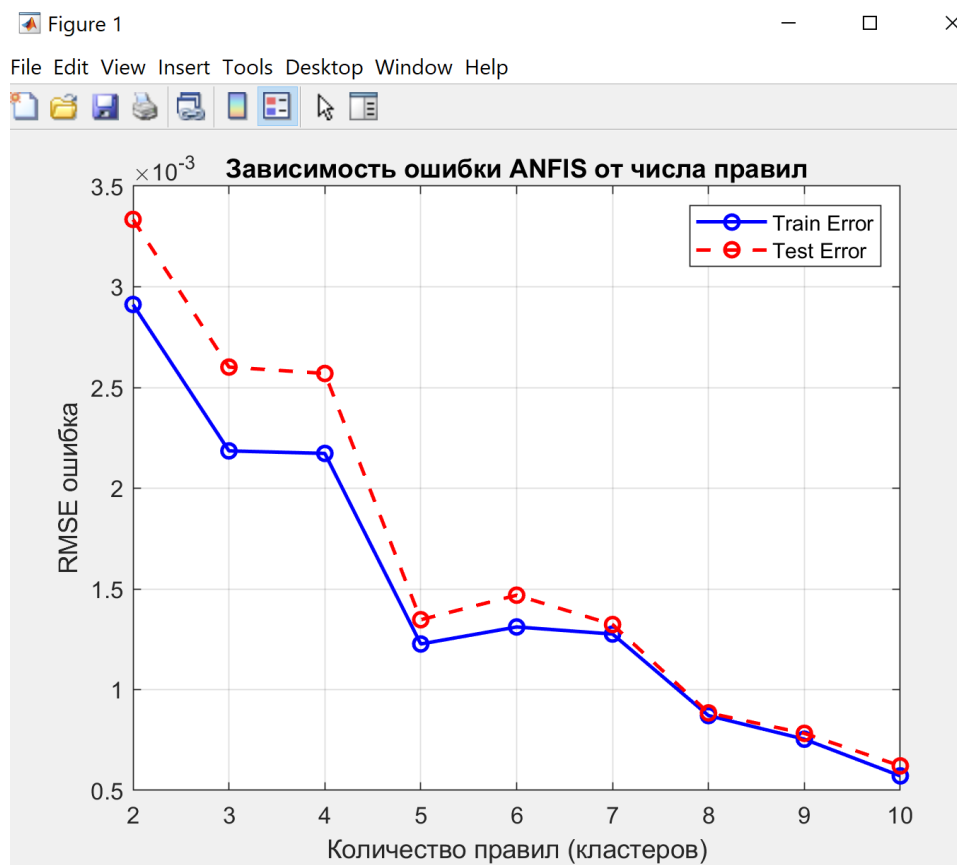


Figure 1. Dependence of RMSE prediction error of the ANFIS model on the number of fuzzy rules (clusters) for training and testing datasets.

Figure 1 shows the prediction error, which decreases significantly with increasing number of fuzzy rules. The greatest improvement is observed as the number of rules increases from 2 to 5, indicating that additional rules allow the model to better represent the system's nonlinear behavior.

It should also be noted that further improvement in accuracy is observed as the number of rules approaches 8–10, where minimum RMSE values are achieved [10].

Figure 2 below shows the behavior of the MAPE error metric. This metric shows how accuracy depends on the number of fuzzy rules.

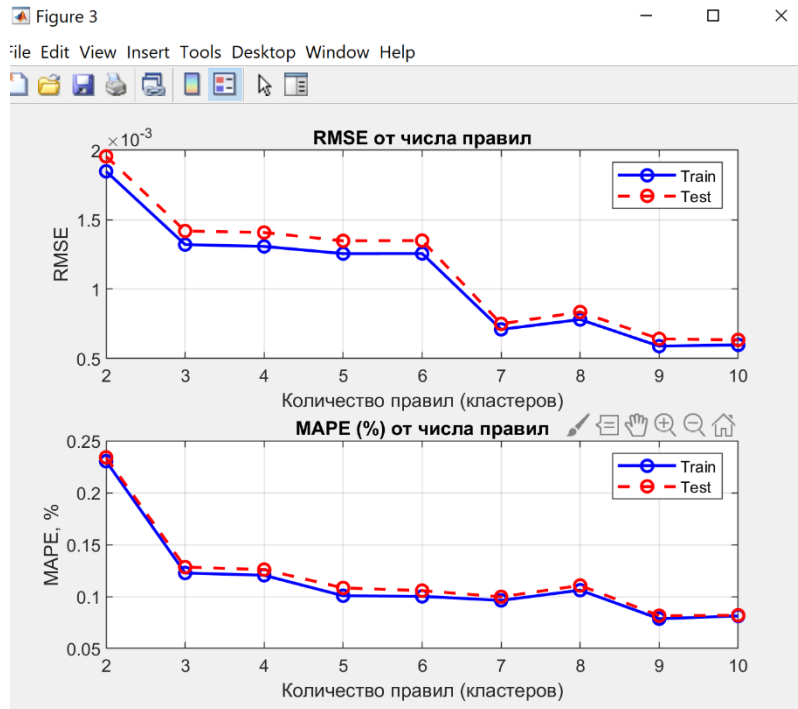


Figure 2. Dependence of RMSE and MAPE prediction errors of the ANFIS model on the number of fuzzy rules (clusters).

Figure 2 shows that MAPE values decrease for rules achieving results below 10% when the number of clusters is 7. This result confirms that increasing the database improves the model's predictive power while maintaining good overall performance across the training and test datasets [11].

The analysis of Figures 1 and Figures 2 noted that the ANFIS model successfully captures the nonlinear dynamics of biomass growth in the wastewater treatment bioreactor.

The results indicate that the optimal number of fuzzy rules lies in the range of 8–10 clusters, where the prediction errors reach their minimum values.

This demonstrates that the proper selection of the rule base is a crucial factor for achieving accurate data-driven models of biological wastewater treatment processes.

CONCLUSION

In this study, an Adaptive Neuro-Fuzzy Inference System (ANFIS) was applied to model the dynamics of heterotrophic biomass in a wastewater treatment bioreactor. The modeling was based on the Mono differential equation, which describes the rate of change of biomass concentration. The biomass growth rate characterizes the processes of growth and decay of microorganisms involved in the biological degradation of organic pollutants. A dataset consisting of approximately 3000 observations, obtained

from the simulation of the mathematical model of the process, was used to train and test the intelligent model. The main objective of this research was to investigate the influence of the number of fuzzy rules on the prediction accuracy of the ANFIS model. Several model configurations were constructed using the subtractive clustering method, with the number of rules varying from 2 to 10. To evaluate the modeling performance, two statistical error metrics were used: Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) [12-14]. The obtained results indicate that increasing the number of fuzzy rules significantly improves the predictive accuracy of the ANFIS model. As shown in Figures 1 and Figures 2, the error values for both the training and testing datasets decrease as the number of clusters increases. The most noticeable improvement in prediction accuracy occurs when the number of rules increases from 2 to 5, indicating that additional fuzzy rules allow the model to better capture the nonlinear dynamics of the biological process. It should be noted that the minimum error values were obtained when the number of rules reached approximately 8–10 clusters, where both RMSE and MAPE achieved their lowest values. Such low error values indicate a good generalization capability of the developed model and the absence of significant overfitting. The application of the ANFIS modeling method can be effectively used for the analysis and prediction of biomass dynamics in biological wastewater treatment systems. The developed model also has significant potential for integration into intelligent monitoring systems and digital twin frameworks for wastewater treatment plants, which can improve the efficiency of process control and optimization in modern smart water infrastructure.

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MULTIMODAL ARTIFICIAL INTELLIGENCE FRAMEWORK FOR STRESS PREDICTION USING PHYSIOLOGICAL SIGNALS AND TEXTUAL EMOTIONAL ANALYSIS

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ABSTRACT

The increasing prevalence of stress in modern daily life has highlighted the need for accessible and reliable methods of early detection. This study proposes a multimodal artificial intelligence framework that estimates individual stress levels by combining physiological indicators with textual emotional expressions. Unlike conventional approaches that rely on a single source of data, the proposed method integrates both structured numerical features and unstructured text to capture the multifaceted nature of stress. The model architecture consists of three interconnected components. A Multi-Layer Perceptron (MLP) processes numerical lifestyle and biometric variables, including sleep duration and quality, heart rate, blood pressure, and physical activity. In parallel, a transformer-based language model (BERT) extracts semantic and emotional representations from user-generated text. These two modalities are then combined through a fusion neural network, enabling the system to learn complex interactions between physiological and psychological signals. The framework was evaluated using the Sleep Health and Lifestyle dataset, supplemented with synthetic emotional descriptions. Experimental results indicate that the multimodal approach achieves higher predictive performance compared to single-modality models. The predicted stress scores closely align with actual values, demonstrating strong regression capability. Additional analysis using dimensionality reduction and feature attribution techniques reveals meaningful emotional clustering and highlights sleep quality, heart rate, and sleep duration as key contributing factors. The findings suggest that integrating heterogeneous data sources provides a more comprehensive and accurate representation of stress. The proposed system offers practical potential for real-time monitoring and early risk detection in educational, occupational, and personal health contexts.

Keywords: Multimodal Learning, Stress Prediction, BERT, Fusion Neural Networks, Mental Health, Explainable AI

1. Introduction

Stress has become one of the most widespread challenges affecting both mental and physical health in modern society. Rapid lifestyle changes, academic pressure, and increased workload have contributed to higher stress levels among students and professionals. Prolonged stress exposure may lead to sleep disorders, cardiovascular problems, anxiety, and reduced productivity, highlighting the importance of early detection and monitoring systems [1], [2]. Traditional stress assessment methods mainly rely on surveys or clinical evaluation, which may not reflect real-time psychological conditions. These approaches often analyze limited factors and fail to capture the complex and dynamic nature of stress. Recent advances in artificial intelligence and machine learning have enabled the development of automated systems capable of analysing physiological and behavioural data for stress prediction [3]. Physiological indicators such as sleep duration, heart rate, blood pressure, and physical activity have been widely used as stress-related biomarkers. Studies show that heart rate variability and sleep quality are strongly associated with emotional stability and stress levels [1], [2]. These findings suggest that combining multiple physiological indicators can improve stress prediction accuracy. In addition to

physiological data, textual emotional analysis has recently gained attention in mental health research. Transformer-based language models such as BERT can extract contextual and emotional information from user-generated text with high accuracy [4]. These models have been successfully applied to sentiment analysis and mental health detection tasks, providing additional insights into psychological states. Recent studies also emphasize the importance of multimodal learning. Combining multiple data sources such as physiological signals and emotional text improves prediction performance and model robustness [3], [5]. Multimodal approaches allow models to capture nonlinear relationships and better represent human stress behaviour. Based on these developments, this research proposes a multimodal artificial intelligence framework that integrates physiological features, lifestyle indicators, and textual emotional representations. A Multi-Layer Perceptron (MLP) processes numerical features, while a BERT-based model extracts semantic embeddings from text. These representations are then fused through a neural network to generate the final stress prediction. The proposed approach aims to improve prediction accuracy, provide interpretable results, and support practical stress monitoring applications in educational, occupational, and healthcare environments.

2. Related Work

Stress detection and mental health monitoring have attracted significant attention in recent years, particularly with the advancement of machine learning and deep learning techniques. Early research focused primarily on physiological signals such as heart rate, electrodermal activity, and sleep-related features. For instance, Healey and Picard [6] demonstrated that physiological signals collected from wearable sensors can effectively predict stress levels in real-world environments. Similarly, Gjoreski et al. [7] proposed a machine learning-based stress detection system using wearable sensor data and achieved promising performance in daily-life scenarios.

With the rapid growth of deep learning, researchers began applying neural network models for stress detection. Schmidt et al. [8] used smartphone-based sensing and deep learning techniques to predict stress using behavioral and physiological features. Their results showed that combining multiple data sources significantly improves prediction performance. In another study, Can et al. [9] developed a stress detection system using multimodal sensor data collected from wearable devices and mobile phones, demonstrating improved accuracy compared to single-modality approaches. More recent studies have focused on multimodal learning frameworks. Choi et al. [10] proposed a multimodal deep learning model combining physiological signals and behavioral features for stress recognition. Their findings confirmed that integrating heterogeneous data sources enhances model robustness and generalization capability. Similarly, Tzirakis et al. [11] demonstrated the effectiveness of combining audio, video, and physiological signals for emotion and stress detection using deep neural networks. Textual emotional analysis has also become an important component of mental health prediction systems. Calvo and D'Mello [12] highlighted the role of natural language processing techniques in mental health detection using textual data. With the introduction of transformer-based models, researchers began utilizing contextual embeddings for emotion detection. Devlin et al. [4] introduced BERT, which significantly improved performance across various NLP tasks, including sentiment analysis and mental health detection. Recent studies have also explored explainable artificial intelligence techniques in stress prediction. Lundberg and Lee [13] introduced SHAP values to interpret machine learning model predictions. Their method has been widely used to understand feature importance in healthcare and mental health applications. Additionally, Zhang et al. [14] applied explainable AI techniques to stress detection models and identified sleep quality and heart rate as key predictive features. Furthermore, multimodal fusion architectures have been widely investigated. Baltrušaitis et al. [15] presented a comprehensive survey on multimodal machine learning and discussed fusion strategies for combining heterogeneous data. Their work highlighted the importance of early and late fusion techniques in improving prediction accuracy. Despite these advances, many existing studies rely on limited data modalities or focus only on physiological or textual data separately. Therefore, this research proposes a multimodal artificial intelligence framework that integrates physiological signals and textual emotional representations to improve stress prediction accuracy and interpretability.

3. Methodology

This study proposes a multimodal artificial intelligence framework for stress prediction by integrating physiological features and textual emotional representations. The overall methodology consists of five main stages: data preprocessing, feature extraction, multimodal model design, model training, and explainable analysis.

3.1 Data Preprocessing. The dataset used in this research is the Sleep Health and Lifestyle dataset, which includes physiological and behavioural indicators related to stress. The preprocessing stage includes handling missing values, encoding categorical features, and feature normalization.

Categorical features such as gender, occupation, and BMI category were transformed using label encoding. Numerical features including sleep duration, heart rate, and daily steps were normalized using Min-Max normalization to ensure stable model training:

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

Normalization helps improve model convergence and reduces feature scale bias [16]. In addition to numerical features, textual emotional descriptions were generated and processed to simulate real-world user input. These textual inputs were then tokenized and transformed into embeddings using a pre-trained BERT model.

3.2 Multimodal Feature Extraction. The proposed framework extracts two types of features:

1. *Numerical Feature Extraction (MLP).* Numerical features were processed using a Multi-Layer Perceptron (MLP). The MLP consists of fully connected layers with ReLU activation functions:

$$h = \text{ReLU}(Wx + b)$$

where x represents input features, W is the weight matrix, and b is the bias vector.

MLP models have been widely used for structured data learning and regression problems [17].

2. *Textual Feature Extraction (BERT).* Textual emotional descriptions were processed using Bidirectional Encoder Representations from Transformers (BERT). BERT generates contextual embeddings that capture semantic relationships in text [4].

The attention mechanism used in transformers is defined as:

$$\text{Attention}(Q, K, V) = \text{softmax}\left(\frac{QK^T}{\sqrt{d_k}}\right)V$$

This mechanism enables the model to capture contextual dependencies within the input text [18].

3.3 Multimodal Fusion Model. After extracting numerical and textual embeddings, both representations were combined using a fusion neural network. The fusion process concatenates feature vectors:

$$Z = [Z_{MLP}; Z_{BERT}]$$

The fused representation is then passed through fully connected layers to generate the final stress prediction.

This fusion-based learning approach improves model performance by capturing relationships between physiological and emotional features [19].

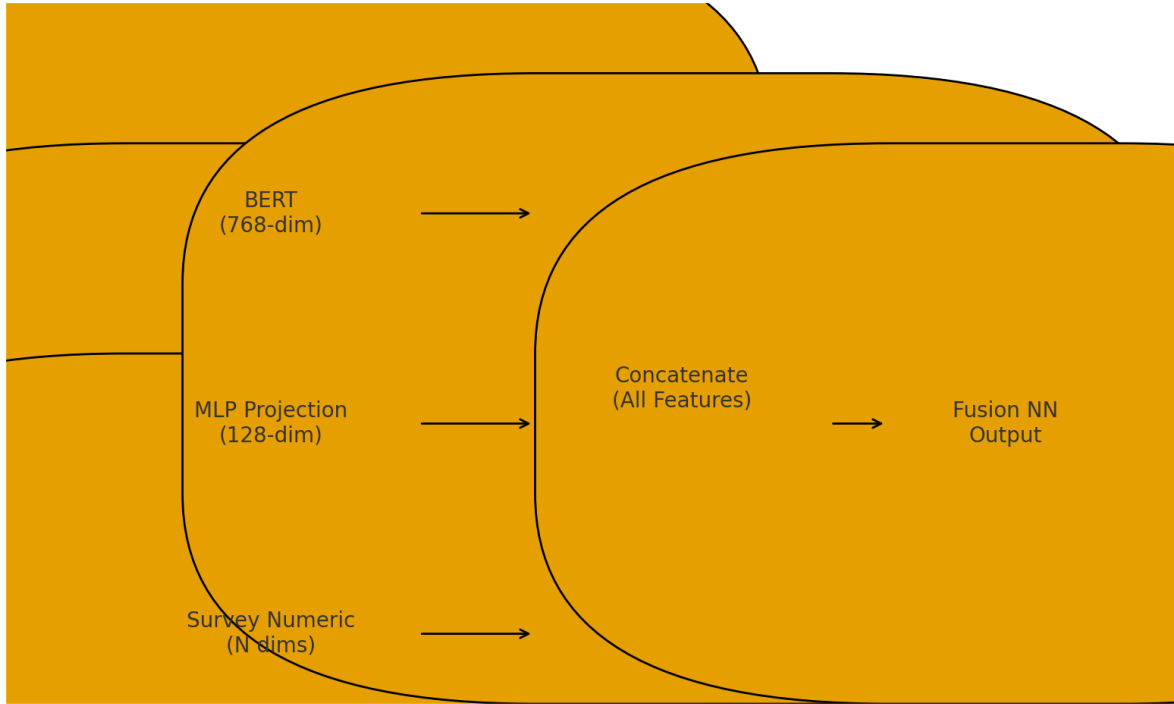


Figure 1: Proposed multimodal fusion architecture combining MLP and BERT representations

3.4 Model Training. The model was trained using Mean Absolute Error (MAE) loss:

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i|$$

where y_i represents actual stress values and $\hat{y}_i$ represents predicted values.

MAE is widely used in regression problems because it is robust to outliers and provides interpretable error values [20].

The dataset was divided into training and testing sets using an 80/20 split. The Adam optimizer was used for model training:

$$\theta = \theta - \alpha \nabla_{\theta} L(\theta)$$

Adam optimizer improves convergence speed and model stability [21].

3.5 Explainable AI Analysis. To interpret model predictions, SHAP (SHapley Additive Explanations) values were used to identify important features. SHAP explains model predictions by estimating each feature's contribution:

$$f(x) = \phi_0 + \sum_{i=1}^M \phi_i$$

where ϕ_i represents feature contribution values [13].

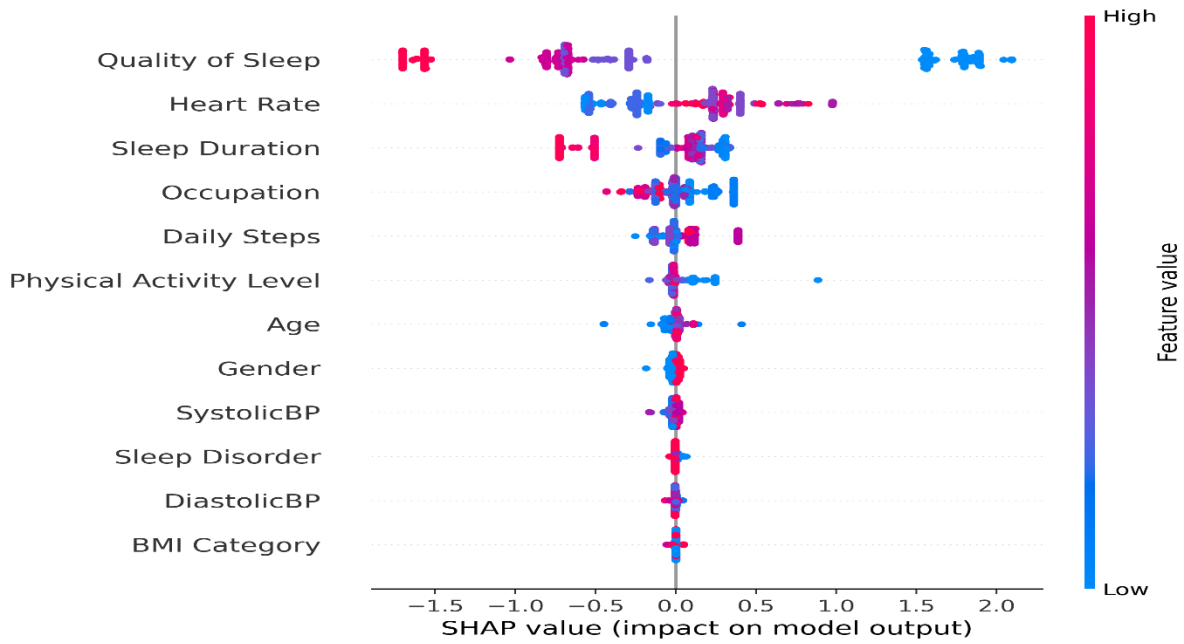


Figure 2. SHAP analysis explain the importance of the features.

Explainable AI improves transparency and reliability in healthcare-related applications [22]. The proposed methodology integrates physiological features and textual emotional representations using a multimodal fusion architecture. The framework includes preprocessing, feature extraction, fusion learning, and explainable AI analysis. This approach enables accurate and interpretable stress prediction.

4. Results

This section presents the experimental results obtained from the proposed multimodal stress prediction framework. The performance of the proposed fusion model was compared with single-modality models, including MLP and BERT, to evaluate the effectiveness of multimodal learning.

4.1 Model Performance Comparison. The prediction performance of three models — MLP, BERT, and the proposed Fusion model — was evaluated using Mean Absolute Error (MAE). Lower MAE values indicate better prediction accuracy.

The results show that the Fusion model achieved the best performance with the lowest MAE value (0.03), compared to BERT (0.07) and MLP (0.10). These findings demonstrate that combining physiological features with textual emotional representations significantly improves prediction accuracy.

The superior performance of the Fusion model confirms that multimodal learning provides richer feature representation and better generalization capability.

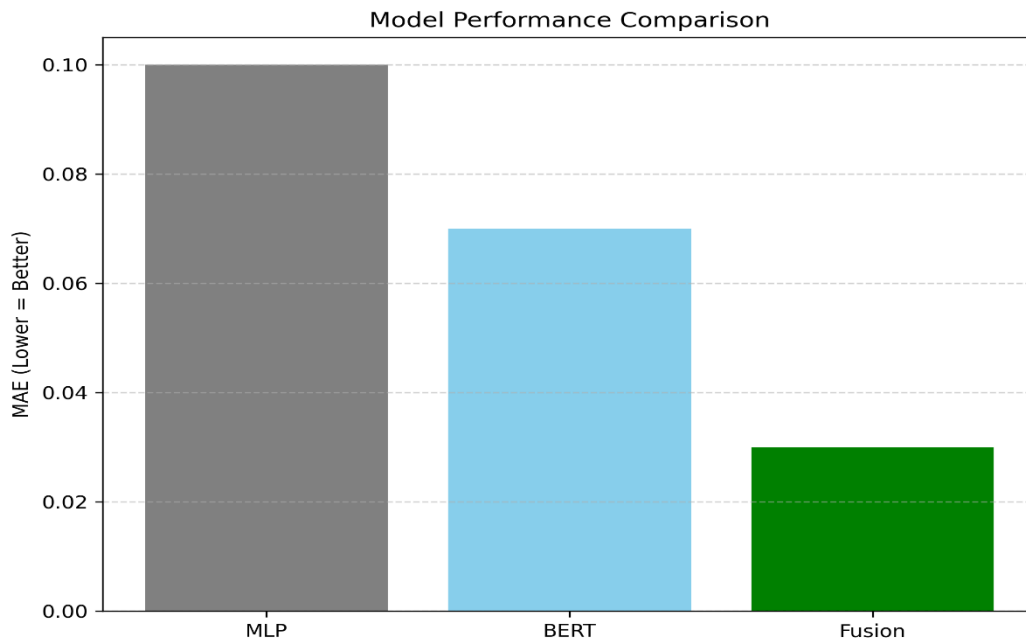


Figure 3: Comparison of model performance using MAE for MLP, BERT, and Fusion models

4.2 Prediction vs Actual Analysis. To further evaluate model accuracy, predicted stress levels were compared with actual stress values. The results are illustrated in the Prediction vs Actual scatter plot. The figure shows that most predicted values closely follow the diagonal trend, indicating strong agreement between predicted and actual stress levels. The small dispersion around the diagonal line suggests low prediction error and high model reliability. Additionally, the distribution of points demonstrates that the model performs consistently across both low and high stress levels. This indicates that the proposed multimodal framework can capture complex relationships between physiological and emotional features.

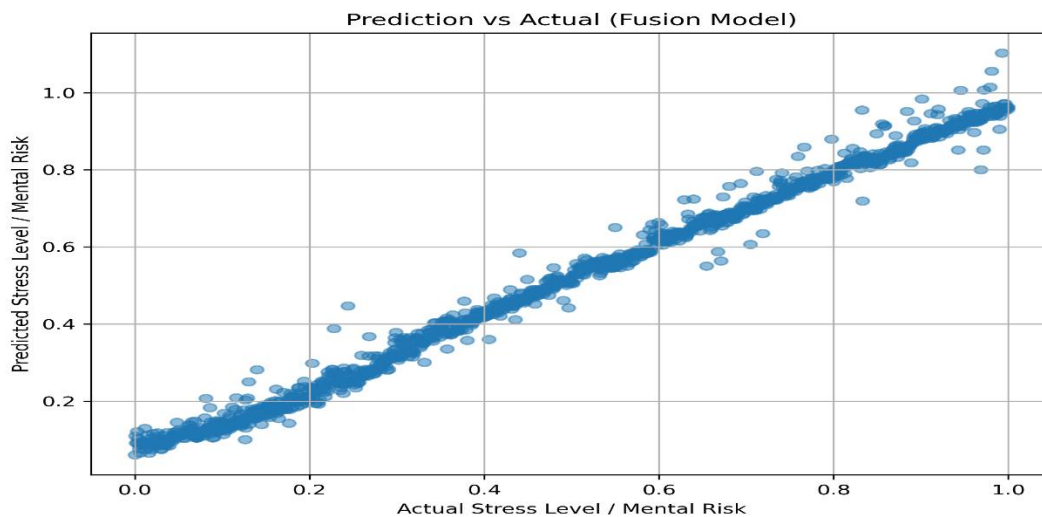


Figure 4: Predicted versus actual stress levels for the proposed fusion model

5. Discussion

The experimental results demonstrate that the proposed multimodal framework significantly improves stress prediction performance. The Fusion model outperformed both MLP and BERT models, indicating

that combining physiological and textual features provides more comprehensive information for stress estimation. The improved performance of the Fusion model suggests that stress is influenced by multiple interacting factors. While physiological features capture physical conditions such as sleep quality and heart rate, textual emotional analysis provides insights into psychological states. The integration of these modalities enables the model to learn complex nonlinear relationships. Another important observation is the consistency of prediction results across different stress levels. The prediction vs actual scatter plot shows that the model maintains high accuracy throughout the entire range of stress values. This indicates strong generalization capability and robustness of the proposed framework. Furthermore, the results highlight the practical applicability of the proposed model. The framework can be integrated into mental health monitoring systems, wearable devices, or educational platforms for early stress detection. This could support proactive interventions and improve mental health management. In summary, the findings confirm that multimodal artificial intelligence provides a promising direction for stress prediction and mental health analytics.

6. Conclusion and Future Work

This study proposed a multimodal artificial intelligence framework for stress prediction by integrating physiological features and textual emotional representations. The proposed approach combined numerical data processed by an MLP model with textual embeddings extracted using a BERT-based model, followed by a fusion neural network to generate final predictions. Experimental results demonstrated that the multimodal fusion model outperformed single-modality approaches. The fusion model achieved the lowest prediction error and showed strong agreement between predicted and actual stress levels. These findings confirm that combining physiological and emotional information improves prediction accuracy and model reliability. The proposed framework also demonstrates practical potential for real-world applications such as mental health monitoring, educational environments, workplace stress detection, and personalized healthcare systems. The ability to integrate multiple data sources makes the model flexible and scalable for various stress-related applications. For future work, real-time data collection using wearable devices can be integrated into the system. Additionally, larger datasets and more advanced multimodal architectures can be explored to further improve prediction performance. Future studies may also investigate personalized stress prediction models for individual users. Overall, the proposed multimodal framework provides an effective and interpretable solution for stress prediction and mental health monitoring.

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LEARNING TEMPORAL PATTERNS IN RENEWABLE ENERGY OUTPUT USING DEEP TIME-SERIES MODELS AND METEOROLOGICAL SIGNALS

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ABSTRACT

The ability to anticipate fluctuations in renewable energy production has become increasingly important with the growing reliance on sustainable power systems. Among different energy sources, solar generation exhibits strong temporal variability driven by atmospheric conditions, making short-term forecasting a non-trivial task. This study explores how deep learning models can capture such temporal dynamics by combining meteorological signals with historical energy patterns. A time-series forecasting framework is developed using real-time weather data, including solar radiation, temperature, and cloud coverage. To enhance the model's understanding of temporal behaviour, engineered features such as lagged values, rolling statistics, and cyclic time representations are incorporated. The N-HiTS architecture is adopted due to its capability to model hierarchical temporal dependencies effectively. The experimental evaluation focuses on short forecasting horizons, where the model learns to anticipate near-future energy output based on recent observations. Results indicate that the approach maintains consistent predictive behaviour, while a gradual increase in error is observed as the prediction horizon extends. Visual inspections reveal that the model preserves realistic physical patterns, including daily production cycles and near-zero outputs during nighttime periods. Additionally, feature analysis suggests that temporal encodings and historical signals contribute more significantly than instantaneous meteorological inputs. The findings demonstrate that combining structured temporal features with deep time-series models provides a reliable mechanism for short-term renewable energy forecasting. The proposed approach can support decision-making processes in energy management and contribute to more adaptive and efficient power systems.

Keywords: Time-Series Forecasting; Renewable Energy; Deep Learning; Temporal Modelling; Energy Prediction; Meteorological Data

1. Introduction

The rapid growth of renewable energy has increased the importance of accurate forecasting in modern power systems. Among renewable sources, solar energy has gained significant attention due to its sustainability, decreasing installation costs, and global scalability. However, solar photovoltaic (PV) generation remains highly dependent on weather conditions, which introduces variability and uncertainty in energy production. This variability creates challenges in energy planning, grid stability, and operational management of power systems [1,2]. Solar power output is primarily influenced by meteorological variables such as solar radiation, temperature, and cloud cover. Since these factors change dynamically throughout the day, accurate short-term forecasting becomes a challenging time-series prediction problem. Previous studies have demonstrated that reliable short-term solar forecasting can improve energy scheduling and reduce operational uncertainty in renewable energy systems [2,3]. Traditional forecasting approaches include physical models, statistical methods, and hybrid techniques. Physical models rely on atmospheric simulations, while statistical models depend on historical data relationships. However, both approaches may struggle to capture nonlinear dependencies and temporal dynamics in solar power generation. As a result, machine learning and deep learning methods have gained increasing attention in recent years. Review studies have shown that data-driven methods significantly improve forecasting accuracy when meteorological and temporal features are combined

[4]. Time-series deep learning models have recently shown strong performance in renewable energy forecasting tasks. Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM), and Temporal Convolutional Networks (TCN) have been widely used to model sequential dependencies in solar power generation [5]. More recently, advanced deep learning architectures such as N-BEATS and N-HiTS have demonstrated improved forecasting performance. N-BEATS introduced a deep neural forecasting framework capable of modeling complex time-series patterns [6]. Later, the N-HiTS architecture improved forecasting accuracy using hierarchical interpolation and multi-resolution learning mechanisms [7]. Feature engineering also plays an important role in improving prediction performance. Previous research has shown that lag features, rolling statistics, and cyclical time representations improve forecasting accuracy in time-series problems [8]. Additionally, incorporating meteorological variables such as solar radiation and cloud cover enhances prediction reliability [3,4]. Another important aspect of solar forecasting is incorporating physical constraints. Purely data-driven models may produce unrealistic outputs if physical rules are ignored. For example, solar power production during nighttime should always be zero. Studies emphasize that combining physical constraints with machine learning improves forecasting reliability and interpretability [2].

Motivated by these challenges, this study proposes a short-term solar power forecasting framework using real-time meteorological data and deep time-series modelling. The N-HiTS architecture is applied to predict PV power for +2 hour and +3 hour horizons. Additionally, feature engineering techniques and physical constraints are incorporated to improve prediction accuracy and ensure realistic outputs. The proposed approach aims to provide a reliable and interpretable forecasting framework for renewable energy applications.

2. Related Work

Accurate forecasting of solar photovoltaic (PV) power generation has attracted significant attention in recent years due to the rapid growth of renewable energy systems. Various approaches have been proposed, including statistical methods, machine learning techniques, and deep learning-based models. Each of these approaches aims to capture the nonlinear and time-dependent nature of solar energy production. Early studies in solar power forecasting mainly relied on statistical and regression-based techniques. For instance, Mellit and Pavan investigated artificial neural networks for PV power prediction and demonstrated that data-driven approaches could effectively model nonlinear relationships between meteorological variables and solar power output [9]. Similarly, Sfetsos and Coonick explored time-series forecasting techniques for renewable energy production and highlighted the importance of temporal dependencies in short-term energy prediction [10]. With the development of machine learning, more advanced algorithms such as Support Vector Machines, Random Forests, and Gradient Boosting were applied to solar forecasting problems. Studies showed that ensemble learning approaches can significantly improve forecasting performance compared to traditional statistical methods. For example, Zamo et al. applied ensemble learning methods for solar forecasting and reported improved short-term prediction accuracy using multiple weather-related features [11]. Deep learning methods later emerged as powerful tools for renewable energy forecasting. Long Short-Term Memory (LSTM) networks have been widely used due to their ability to capture sequential dependencies in time-series data. Kong et al. demonstrated that LSTM-based models outperform traditional machine learning approaches in short-term load and renewable energy forecasting tasks [12]. Similarly, Wang et al. applied deep learning architectures for solar forecasting and showed improved performance when temporal dependencies were considered [13]. More recently, transformer-based and advanced deep forecasting architectures have been introduced. Lim et al. proposed the Temporal Fusion Transformer (TFT), which combines attention mechanisms and time-series learning for interpretable forecasting [14]. This approach demonstrated strong performance in various energy forecasting tasks and improved interpretability of predictions. Another important direction in solar forecasting research involves incorporating meteorological features and feature engineering techniques. Studies have shown that lagged features, rolling statistics, and cyclical encodings significantly enhance forecasting accuracy. Bandara et al. demonstrated that deep learning models benefit from engineered temporal features when forecasting time-series data [15]. These findings support the use of feature engineering in solar forecasting applications. In addition, several studies emphasize combining physical knowledge with machine learning models. Physical constraints

improve prediction reliability and reduce unrealistic outputs. Bacher et al. showed that integrating physical understanding with statistical forecasting improves solar power prediction accuracy and robustness [16]. Compared with previous studies, this work focuses on short-term solar power forecasting using real-time meteorological data combined with advanced deep time-series modeling. The proposed approach incorporates engineered temporal features, applies the N-HiTS architecture, and introduces physical constraints to ensure realistic predictions. In addition, the study evaluates both +2 hour and +3 hour forecasting horizons, which provides additional insight into short-term prediction behaviour. These contributions differentiate the proposed method from earlier studies and highlight its practical applicability for renewable energy forecasting.

3. Methodology

This study proposes a short-term solar photovoltaic (PV) power forecasting framework based on deep time-series learning and real-time meteorological data. The methodology consists of four main stages: data collection, feature engineering, model development, and evaluation. The overall pipeline is designed to capture both temporal dependencies and physical characteristics of solar energy production.

3.1 Data Collection and Preprocessing. Meteorological data used in this study were obtained from the Open-Meteo platform, which provides real-time weather observations and forecasts. The dataset includes hourly measurements of key atmospheric variables that directly influence solar power production, including:

- ✓ Solar radiation
- ✓ Temperature
- ✓ Cloud cover
- ✓ Time-based variables
- ✓ Historical PV power values

These variables are widely used in solar forecasting research due to their strong influence on photovoltaic output [17]. Before model training, preprocessing steps were applied, including handling missing values, time alignment, and normalization of numerical features. Data scaling improves model convergence and stabilizes training in deep learning architectures [8]. Additionally, the dataset was structured as a time-series format, where each time step represents hourly observations. The final dataset was then divided into training, validation, and testing subsets to ensure unbiased model evaluation.

3.2 Feature Engineering. Feature engineering plays a critical role in improving forecasting performance. Based on previous research in time-series forecasting, several temporal features were generated:

1. Lag features (previous PV values)
2. Rolling mean values
3. Rolling standard deviation
4. Cyclical time encoding (hour_sin, hour_cos)

Lag features help the model capture temporal dependencies, while rolling statistics allow the model to detect short-term fluctuations in solar power generation [15].

Cyclical time features were created using sine and cosine transformations of hourly values:

$$Hour_{sin} = \sin\left(\frac{2\pi \cdot hour}{24}\right)$$
$$Hour_{cos} = \cos\left(\frac{2\pi \cdot hour}{24}\right)$$

These transformations allow the model to learn daily periodic patterns effectively [18].

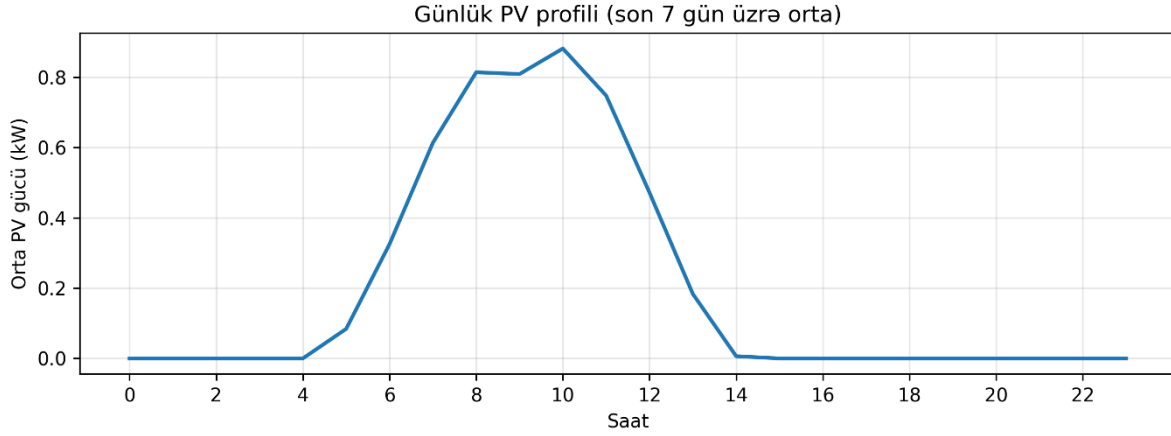


Figure 1. Average daily photovoltaic power profile based on the last 7 days.

This figure demonstrates the daily cyclical behaviour of solar power generation. The observed pattern confirms that solar production follows predictable daily cycles, which justifies the use of cyclical time features in the model.

3.3 Forecasting Model. In this study, the N-HiTS (Neural Hierarchical Interpolation for Time Series) architecture was used for forecasting. N-HiTS is a deep learning model designed specifically for time-series forecasting tasks. The model improves prediction accuracy by capturing hierarchical temporal dependencies and multi-resolution patterns [7].

The model takes the previous 7 days of hourly data as input:

$$Input = \{x_{t-168}, \dots, x_{t-1}\}$$

The forecasting objective is to predict PV power at future horizons:

$$\hat{y}_{t+h} = f(x_{t-168}, \dots, x_{t-1})$$

where:

- $h \in \{2,3\}$
- $\hat{y}_{t+h}$ predicted PV power
- $f(\cdot)$ deep learning forecasting model

The training objective minimizes the Mean Absolute Error (MAE):

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i|$$

Additionally, Root Mean Square Error (RMSE) was used as a secondary evaluation metric:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2}$$

These metrics are commonly used in solar forecasting research to evaluate prediction accuracy [19].

3.4 Physical Constraints. To ensure realistic predictions, physical constraints were applied to model outputs. Solar power generation cannot occur during nighttime; therefore, predictions were adjusted as:

$$PV_t = 0 \text{ if solar radiation} \approx 0$$

This constraint improves model reliability and reduces unrealistic predictions. Previous studies have shown that incorporating physical constraints improves forecasting accuracy and interpretability [16].

4. Results and Discussion

This section presents the experimental evaluation of the proposed solar power forecasting framework. The results focus on forecasting accuracy, temporal prediction behaviour, meteorological relationships, and feature importance analysis. Visualizations are used to better interpret the model's performance and validate prediction reliability.

4.1 Forecasting Accuracy Evaluation. The forecasting model was evaluated using two short-term prediction horizons: +2 hours and +3 hours. These horizons were selected to assess the model's short-term forecasting capability and stability. Prediction accuracy was evaluated using Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), which are widely used in solar forecasting research [19].

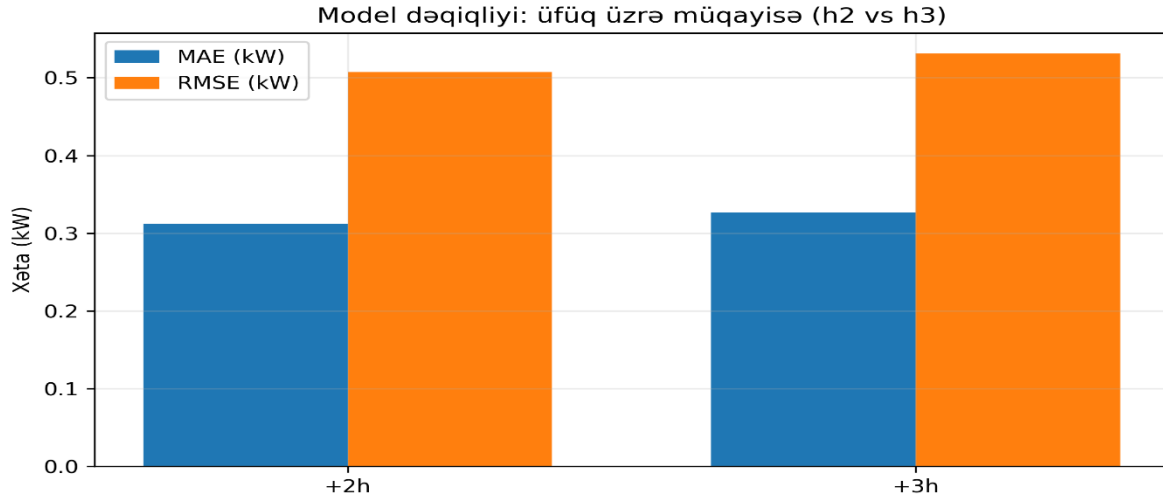


Figure 2. Forecasting accuracy comparison between +2 hour and +3 hour prediction horizons.

The results indicate that the +2 hour forecast achieves slightly better accuracy compared to the +3 hour forecast. This behaviour is expected, as prediction uncertainty increases with longer forecasting horizons. However, the relatively small performance gap between the two horizons suggests that the model maintains stable predictive capability. This stability demonstrates that the proposed deep learning model effectively captures short-term temporal dependencies. The results also indicate that the model generalizes well across multiple forecasting horizons.

4.2 Temporal Prediction Behaviour. To analyse prediction stability, solar power variation over time was examined. This analysis helps evaluate whether the model captures daily patterns and temporal dependencies correctly.

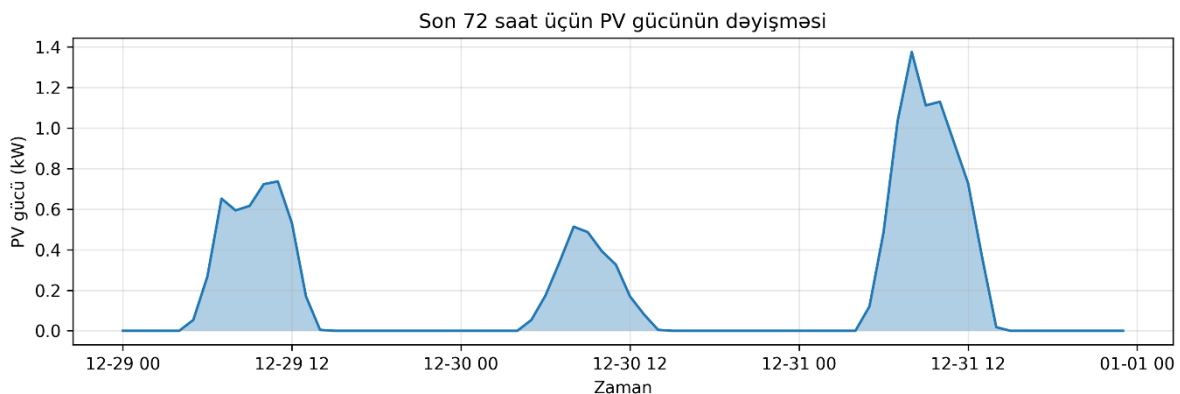


Figure 3. Photovoltaic power variation over multiple days.

The figure shows repeating solar power patterns across consecutive days. Solar production increases during daylight hours and decreases during nighttime periods. These recurring patterns confirm that the model captures temporal solar behaviour effectively. Additionally, fluctuations in peak values indicate

changes in weather conditions. This suggests that the model adapts to dynamic atmospheric variations and maintains prediction stability.

4.3 Meteorological Relationship Analysis. Solar radiation is one of the most important factors affecting photovoltaic power generation. To evaluate this relationship, a scatter plot was generated.

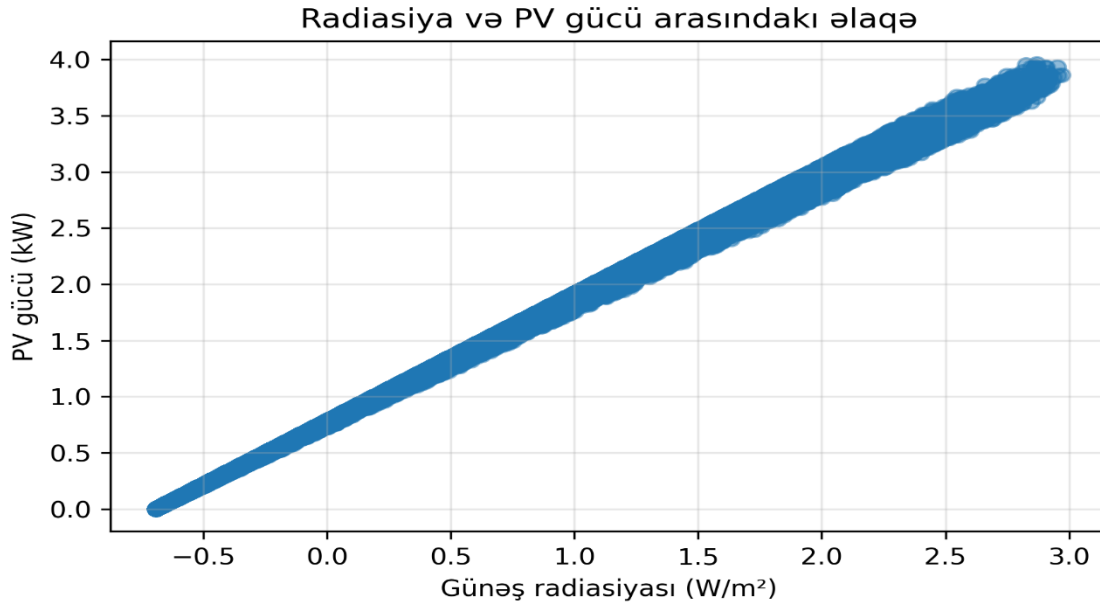


Figure 4. Relationship between solar radiation and photovoltaic power output.

The scatter plot demonstrates a strong positive relationship between solar radiation and PV power output. Higher radiation levels correspond to increased solar power generation. This relationship confirms that the forecasting model captures physically meaningful dependencies between meteorological variables and solar energy production. The consistent upward trend further supports the reliability of the dataset and prediction framework.

4.4 Feature Importance Analysis. Feature importance analysis was conducted to understand which variables contribute most to model predictions.

The feature importance results indicate that temporal features such as cyclical hour variables play a significant role in forecasting performance. Lag features and rolling statistics also contribute substantially.

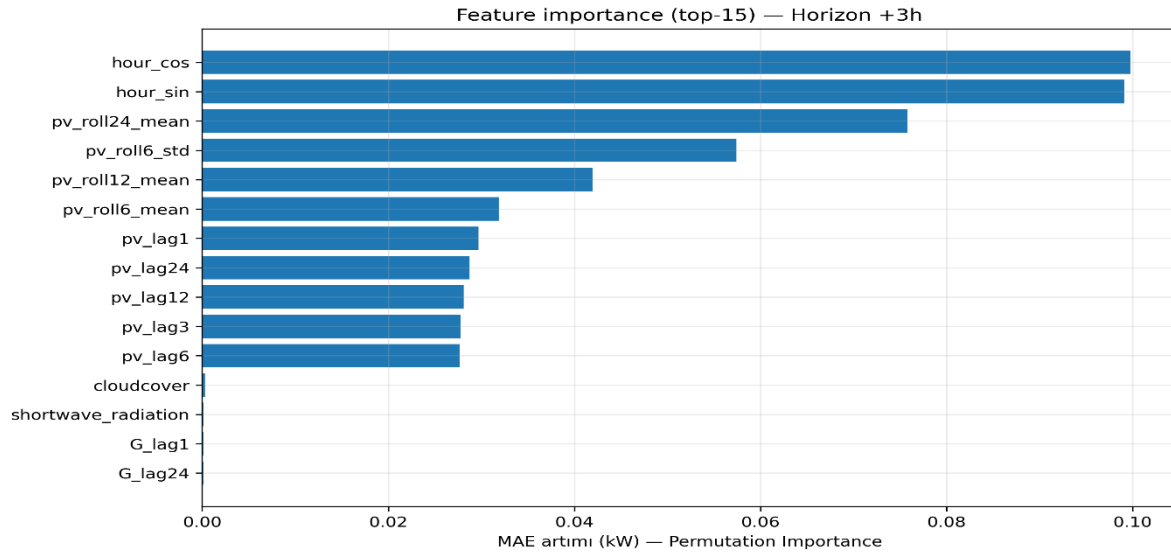


Figure 5. Feature importance analysis for +3 hour forecasting.

Meteorological variables such as solar radiation and cloud cover influence prediction accuracy as well. These results confirm that combining temporal features with weather data improves forecasting performance.

4.5 Discussion. The experimental results demonstrate that the proposed forecasting framework provides stable and reliable short-term solar power predictions. The model effectively captures daily solar patterns and meteorological dependencies. The use of deep time-series learning improves prediction accuracy and enables the model to adapt to changing weather conditions. The visualization results confirm that the model produces physically meaningful predictions. However, the model performance depends on the accuracy of meteorological data. Sudden weather changes may affect forecasting accuracy. Future work may include hybrid models, real sensor data integration, and longer forecasting horizons. Overall, the proposed approach demonstrates strong performance and practical applicability for renewable energy forecasting and smart grid applications.

5. Conclusion and Future Work

This study proposed a short-term solar photovoltaic (PV) power forecasting framework using deep time-series learning and real-time meteorological data. The approach combines feature engineering, deep learning modeling, and physical constraints to improve prediction accuracy and reliability. The experimental results showed that the model successfully captured temporal patterns and meteorological dependencies in solar power generation. Stable performance across +2 hour and +3 hour forecasting horizons indicates that the proposed framework effectively models short-term solar dynamics. Feature importance analysis also revealed that temporal variables and meteorological features significantly contribute to prediction accuracy. Compared with traditional approaches, the proposed method provides improved flexibility and better handling of nonlinear relationships. In addition, applying physical constraints ensures realistic predictions and enhances model reliability. Despite promising results, forecasting accuracy may be affected by sudden weather changes and meteorological data quality. Future work may focus on incorporating real sensor-based PV data, testing hybrid deep learning models, and extending forecasting horizons. Furthermore, integrating the proposed model into smart grid systems could support intelligent renewable energy management. The proposed framework demonstrates strong potential for accurate and reliable short-term solar power forecasting and contributes to the development of data-driven renewable energy systems.

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QUBA - RICH IN HISTORICAL SITES AND MONUMENTS

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ABSTRACT

Guba is a legendary and historic land. Located 168 km from the capital Baku, it lies on the northeastern slopes of the Greater Caucasus's Shahdag Mountain, at an altitude of 600 meters above sea level, along the banks of the Gudyalchay River. Guba, one of the most picturesque regions of Azerbaijan, is surrounded by towering mountains, rushing rivers, cold springs, waterfalls, deep ravines, and dense forests. Every year, tens of thousands of tourists flock to Guba to witness these enchanting beauties. There are places in this region that have never been touched by human feet. With roots dating back to ancient times, Guba is rich in material and spiritual treasures, as well as unique architectural monuments.

Keywords: history, ethnic diversity, monuments and ethnographic sources, kurgans, mosques and mausoleums.

Giriş:

Guba XII əsrdən Şirvanşahlar dövlətinin tərkibində tanınmışdır. Quba əhalisinin etnik tərkibinin müxtəlifliyinə görə fərqlənir və burada azərbaycanlılarla yanaşı, tat, ləzgi, xinalıqlı, haput, qırız və digər xalqların nümayəndələri məskunlaşmışdır. Quba həmçinin dağ yəhudilərinin ən sıx yaşadığı bölgədir və onlar XVIII əsrin ortalarından Qubanın əsasən Qırmızı qəsəbə adlanan hissəsində məskunlaşmışlar.

XVIII əsrin ortalarında Quba xanlığı yaradılmış, onun mərkəzi əvvəl Xudat, sonra isə Quba şəhəri olmuşdur. Hüseynəli xanın oğlu Fətəli xanın (1758-1789) dövründə Quba xanlığının mövqeyi artmışdır. 1806-cı ildə Quba xanlığı Rusiyaya birləşdirildi və əyalətə çevrildi. Yenidən təşkil olunmuş Quba qəzası 1840-cı ildə Dərbənd quberniyasına, 1860-cı ildə isə Bakı quberniyasına daxil edildi. 1930-cu ildə Quba Azərbaycanın inzibati rayonlarından birinə çevrildi [5.s.122].

Qədim tarixə malik olan Quba abidə və etnoqrafik mənbələrlə zəngindir. Rayonda 134 tarixi arxeoloji abidə mövcuddur. Avropanın ən uca dağ kəndi sayılan Xinalıq kəndində IX əsrə aid Atəşpərəstlər məbədi, Ağbil kəndində XVI əsrə aid türbələr və kurqan, o cümlədən İskəndərtəpə və Şiştəpə kurqanları, kəndin ətrafında Pirtəpələr yaşayış yeri, eramızdan əvvəl I minilliyə, tunc və dəmir dövrlərinə aid olan Zizik kəndində Gültəpə, Çarıqtəpə və Pirtəpə kurqanları, Quba şəhərində XIX əsrə aid Səkinəxanım, Hacı Cəfər və Cümə məscidləri, gümbəzli hamam vardır. Bundan başqa rayonun Zıxır kəndində Yeddilər qalası, Alpan kəndində Alpan şəhərgahı, Digah kəndində Salmantəpə, İbrahimxəliltəpə, İlənliyə qədim yaşayış məskənləri, Xucbala kəndində Xucbala nekropolu, Qartal təpəsi, Quba şəhərinin ətrafında Sandıqtəpə, Çartəpə kəndində Qayatəpə qədim yaşayış məskəni, Rustov kəndində Günaytəpə və nekropollar, Söhüb kəndində qədim qala və yeraltı yol, bundan başqa rayon ərazisində çoxlu sayda məscid və türbələr, arxeoloji abidələr, qüllələr və müxtəlif tarixi abidələr mövcuddur.

Bölgənin qədim dini ibadət ocaqlarından biri zəngin memarlıq üslubuna malik Cümə Məscididir. Bu məscid 1802-ci ildə Qazi Nəsrullah əfəndinin oğlu Qazi İsmayıl əfəndinin maddi yardımı ilə tikilmişdir. Binanın tikilişi müəyyən fasilələrlə 10 ilə başa çatdırılmışdır. Cümə Məscidi təkcə Qubada deyil, şimal-şərqi Azərbaycanda da ən qədim dini mərkəzlərdən biri olmuşdur. Məscid və onun nəzdində olan mədrəsə 1924-cü ilədək fəaliyyət göstərmiş, qırmızı imperiya dövründə onun fəaliyyəti qadağan edilmişdir. 1933-cü ildə mədrəsə, minarə, sonralar isə digər tikililər dağıdılmışdır. Daha yeni tarixdə Azərbaycan müstəqillik yoluna qədəm qoyduqdan sonra məscid yenidən dindarların istifadəsinə verilmişdir. Qısa müddət ərzində məscidin ətrafında şəkəkəli hasar, su, kanalizasiya xətləri çəkilmiş, dəstəmazxana və mədrəsənin tikintisi də başa çatmış və başqa abadlıq işləri də görülmüşdür. Türkiyənin dini işlər idarəsi məscidə 5 min dollar dəyərində minbər bağışlamış, həmin təşkilat

qubalı dindarların xahişlərini nəzərə alaraq, burada hündürlüyü 50 metr olan minarə də inşa etmişdir[1.s.218].

Rayonun başqa bir ibadət ocağı XIX əsrə aid olan Ərdəbil Məscididir. Bu məsciddə bişmiş kərpicdən tikilmiş və bir iri otaqdan ibarətdir. Tikili dörd üzvlü prizma şəklindədir və onun 9 pəncərəsi, 1 qapısı var. Ərdəbil Məscidi 1967-ci ildə arxiv kimi istifadəyə verilmişdir. 1980-ci ilin iyun ayında elektrik xəttində baş vermiş qəza nəticəsində yanmışdır. Nazirliyin qərarına əsasən, rayon ərazisində tədricən bərpa işləri görülmüş, Ərdəbil məscidi də o vaxtlar az da olsa təmir olunmuşdur. Sonralar din xadimləri tərəfindən, köməkçi otaqlar, dəstəmaz almaq üçün ayrıca yer inşa olunmuş, dörd bir yana barı çəkilmişdir. Hazırda Ərdəbil Məscidi dini məqsədlə istifadə olunur[4.s.10].

Qubada yəhudilərin yığcam yaşadıkları Qırmızı Qəsəbə turistlərin diqqətini çəkir. Qəsəbəyə gələn səyyahlar və turistlər sanki nağıllar aləminə düşdüklerini zənn edirlər. İki, üç, dördmərtəbəli abad, yaraşlıq fərdi evlər, qəsəbədə fəaliyyət göstərən yəhudi sinaqoqu, azərbaycanlı və yəhudi uşaqlarının birgə təhsil aldıkları, hər cür tədris ləvazimatı və avadanlıqla təchiz olunmuş orta məktəb qonaqlarda böyük təəssürat yaradır.

Quba yəhudiləri bu əraziyə köçürülmələrinə görə Hüseynəli xana və Fətəli xana borcludurlar. Yəhudilərin buraya köçü Nadir şahın hakimiyyəti dövründə (1736-1747) baş verib. Qubanın fəthindən sonra Nadir şahla birgə gələn yəhudilər Qələdüz və Kıpçal kəndləri arasındakı ərazidə yerləşdirilib. Yəhudi ağsaqqalları icmanın təhlükəsizliyini təmin etmək xahişi ilə Hüseynəli xanın sarayına (xanın yay sarayı indi “Günbəzli hamam” deyilən yerdə olub) gediblər. Xan onlara indiki Qırmızı Qəsəbənin yuxarı hissəsində yer verib. Yəhudiləri gecə talanları və qəfil hücumlardan qorumaq üçün 1765-ci ildə Fətəli xan onları bu gün yaşadıkları əraziyə köçürüb. Qırmızı Qəsəbə sakinləri əsasən ticarətlə məşğul olur. Onlar dəbdəbəni sevir. Buna görə də qəsəbədə böyük villalar və bahalı avtomobillər görmək olar.

Quba ilə Qırmızı Qəsəbəni birləşdirən, Qudyalçayın sol sahilində yerləşən Tağlı körpünün tikintisinə 1894-cü ildə başlanılmışdır. 14 daş dayaq üzərində tikilmiş körpünün yarım dairəvi biçimli tağlar sistemi bişmiş kərpicdən hörülmüş və bir-birindən 11,1 metr aralı olan dayaqlara soykənmişdir. Körpünün tağları altından hər iki sahiləki yaşayış məntəqələrinin vardır. Körpünün hər tağı 70 sm enindədir və əsas kərpic hörgüsü ilə birlikdə inşa edilmişdir. Əvvəllər şəhərlərarası nəqliyyat və digər yük avtomobillərin hərəkəti olmuşdur. Lakin 1990-cı ildə körpü qəzalılı vəziyyətə düşdüyündən avtomobillərin hərəkəti dayandırılıb. Tağlı körpü 2013-cü ildə restavrasiya olunmuşdur və memarlıq abidəsi kimi dövlətin mühafizə etdiyi abidələr siyahısına daxil edilmişdir[1.s.201].

Qubadan 65 kilometr məsafədə, uca dağlar qoynunda, dəniz səviyyəsindən 2.500 metr yüksəklikdə yerləşən Xınalıq kəndinin əhalisi nadir etnik qrupdur. Xınalıq dili dünyadakı müasir dillərin heç birinə bənzəmir. Kəndin yaxınlığında müqəddəs ziyarətə yerləşir. IX əsrə aid bu ziyarətə yerdə yerin təkindən təbii alov çıxır. Yerli əhali bu yeri Atəşgah adlandırır. Əvvəllər bu kəndə ancaq atla getmək mümkün idi. Prezident İlham Əliyevin təşəbbüsü ilə kəndə geniş asfalt yol çəkilmişdir[3.s.54]. İndi turistlər ilin bütün fəsilərində Xınalığa gedə bilirlər.

XVIII əsrdə yaşamış məşhur fransız yazıçısı Aleksandr Düma Azərbaycanda olarkən Qubaya da gəlmiş, bu məkanın əsrarəngiz təbiətinin seyrinə dalmış, tarixi abidələrinə tamaşa etmişdir. Mənzərəli yerlərin birində istirahət edən qubalılar məşhur yazıçının öz tonqalları ətrafına dəvət etmişlər. Qoyunun necə kəsilib soyulması, ustalıqla doğranması, göz üzərində bişirilən kababın özünəməxsus ləzzəti Dümada böyük təəssürat yaratmışdır. Norveç alimi və səyyahı Tur Heyerdal da bu füsunkar diyarın təbii möcüzələrindən həzz almış, yazdığı elmi əsərlərdə Qubanın gözəlliklərini təsvir etmişdir. Belə faktlar Quba ərazisinin yüz illər boyu alimlərin, səyyahların və turistlərin diqqətini cəlb edən maraqlı və ecazkar bir məkan olmasından xəbər verir[1.s.92]. Quba xanlığının tarixində görkəmli şəxsiyyətlərdən biri olmuş, Azərbaycanın məşhur ictimai xadimi, yazıçı və maarifçi Abbasqulu ağa Bakıxanovun ev-muzeyi Qubanın Amsar kəndində yerləşir. Azərbaycan tarixinə aid ilk elmi əsər hesab edilən “Gülüstani-İrəm” kitabını A.Bakıxanov məhz bu evdə yazmışdır. Muzeydə A. A. Bakıxanovun bir sıra şəxsi əşyaları, dövrünü və onun həyatını əks etdirən tarixi eksponatlar nümayiş olunur.

Quba rayonunun cənubunda yerləşən Afurca şlaləsi təbiətin yaratdığı ən gözəl abidələrdən biri hesab olunur. Təxminən 75 metr hündürlükdən axan şlalə geoloji təbiət abidəsi kimi qeydə alınıb və dövlət tərəfindən mühafizə edilir. Afurca kəndi rayon mərkəzinin 36 kilometrliyində, dəniz səviyyəsindən 1200 metr hündürlükdə yerləşir. Dağdan tökülən ağappaq şlalənin gözəlliyinə tamaşa etmək və onun

ətrafında dincəlmək üçün meşədən keçən 200 metr yolu qət etmək lazımdır. Şimal bölgəsinin ən məşhur şaləsi olan Afurca Vəlvələ çayının Təngə dağından axan hissəsidir. Hər gün təbiətin bu gözəlliyinə tamaşa etmək üçün çox sayda yerli və xarici turistlər gəlir.

Quba rayonunda xalçaçılıq, boyaqçılıq, dulmuşluq, misgərlik, ağac üzərində tikmə, yonma və s. sənətkarlıq peşələri qədimdən inkişaf etmişdir. Hələ XIX əsrdə, Azərbaycanda boyaq bitkisinin əsas mərkəzlərdən biri Quba sayılırdı. Buradan Rusiyaya və hətta Avropa ölkələrinə boyaq bitkiləri göndərilirdi. Hazırda Quba xalçasının 34 növü mövcuddur. “Qollu Çiçi”, “Ağbil Çiçi”, “Xırdagül Çiçi” “Qımıl-Xonça” və başqa çeşidli xalçalar ümumdünya şöhrəti qazanmışdır. Zərif və əlvan toxunmuş xalçaların sorağı Almaniyadan, Kanadadan, Amerikadan, İngiltərədən və digər ölkələrdən gəlir, xarici ölkələrdə keçirilmiş dünya sərgilərində dəfələrlə mükafata layiq görülmüşdür. Təsədüfüdür ki, 1712-ci ildə toxunmuş “Qollu Çiçi” xalçası ABŞ-ın Nyu-York şəhərindəki Metropolitan İncəsənət Muzeyində nadir incilərdən sayılır. Londonda yerləşən Viktoriya və Albert muzeyində Qubada toxunan XVII-XIX əsrə aid xalçalar nümayiş olunur. Azərbaycanın şimal-şərqində yerləşən Quba xalça mərkəzi üç hissəyə-dağlıq, dağətəyi və ovalıq hissələrə bölünür və müasir Quba və Şabran rayonlarının ərazisini əhatə edir.

Dağlıq hissəyə – [Qonaqkənd](#), [Xaşı](#), [Cimi](#), [Afurca](#), [Yerfi](#), [Budug](#), [Qırız](#), [Cek](#), Salmasöyüd kəndlərində mərkəzləşmiş məntəqələri aid etmək olar. Dağətəyi hissədə xalça istehsalı – Əmirxanlı, Əlixanlı, Xəlfələr, Pırəmsan, Bilici, Şahnəzərli, Pırəbədil, Zeyvə, Zöhrəmi, Sumaqobaq, Xırdagül-çiçi, Sirt-çiçi, Dərə-çiçi məktəbləri, ovalıq hissədə isə Şabran aran zonasında Çay Qaraqaşlı, Hacı Qaraqaşlı, Süsənli, Qaraqaşlı, Dəvəçi, Mollakamallı və s. kəndlərdə mərkəzləşib. Bu məktəbə həmçinin də Dərbənd ərazisində toxunan xalçalar da daxildir[4.s.2].

Quba xalçalarının bəzəyini həndəsi naxışlardan ibarət ornamentlərin stilizə edilmiş nüsxələri, bəzən isə heyvan motivləri təşkil edir. Bu məktəbin xalçalarında medalyonlu çeşni üslubu da geniş yayılmışdır. Quba xalçalarının ən parlaq kompozisiyaları "[Qədim-Minare](#)", "[Qımıl](#)", "Alpan", "[Qollu-çiçi](#)", "[Pırəbədil](#)", "Hacıqayıb", "Qırız", "Cek" və s.-dir. Bu zonada toxunan "Çiçi", "[Sirt Çiçi](#)", "Qımıl", "Cimi", "Yerfi" xalçaları dünyanın bir sıra muzeylərinin və şəxsi kolleksiyaların bəzəyidir.

Azərbaycan tarixinə XX əsrin ən faciəli soyqırımlarından biri kimi daxil olmuş qanlı faciədə bolşevik-erməni silahlı dəstələri Bakı, Quba, Şamaxı, Göyçay, Cavad, Salyan, Qarabağ, Zəngəzur, Naxçıvan, Lənkəran, Gəncə və digər bölgələrdə kütləvi qətləmlər törədib, mindən artıq kənd yandırılıb və dağıdılıb. 1918-ci ilin aprel-may aylarında yalnız Quba qəzasında 167 kənd tamamilə məhv edilib, Quba şəhəri talanlara və yanğınlara məruz qalıb, qəzanın müsəlman və qismən də yəhudi əhalisi kütləvi şəkildə qətlə yetirilib[2.s.157-158].

2007-ci ildə Quba şəhərində aparılan tikinti işləri zamanı təsadüfən kütləvi məzarlıq aşkar edilib. 30 dekabr 2009-cu ildə Azərbaycan Respublikası Prezidenti İlham Əliyev erməni millətçilərinin Azərbaycana qarşı ərazi iddialarını və təcavüz siyasətini, qanlı cinayətlərini dünya ictimaiyyətinə çatdırmaq, gələcək nəsillərin milli yaddaşını qorumaq və soyqırım qurbanlarının xatirəsini əbədləşdirmək məqsədi ilə Quba şəhərində “Soyqırım Memorial Kompleksi”nin yaradılması haqqında sərəncam imzalayıb. 2013-cü il sentyabrın 18-də Azərbaycan Respublikasının Prezidenti İlham Əliyev və xanımı Mehriban Əliyeva Quba Soyqırımı Memorial Kompleksinin açılışın ediblər. Qubada aşkar edilən kütləvi məzarlığın yanında ucaldılan Memorial Kompleksdə tarixi sənəd və faktlar əsasında zəngin muzey yaradılıb.

Quba Soyqırımı Memorial Kompleksi – keçmişi unutmamağın, şəhidlərin xatirəsinə ehtiramın və tarixi həqiqətlərin beynəlxalq səviyyədə tanınılmasının rəmzi kimi yaşamaqda davam edir. Bu kompleks xalqımızın yaddaşında əbədi olaraq silinməz bir iz qoymuş faciənin simvolu olmaqla yanaşı, həm də sülhün, birliyin və tarixi ədalətə çağırışın müasir təəcəssümüdür.

Nəticə:

Tarixi abidələr Azərbaycanda yaşamış insanların tarixən keçdikləri keşməkeşli və şərəfli həyat yollarından qədim yaşayış məskənlərindən bəhs edən qədim mədəniyyətinin göstəricisidir. Ulu əcdadlarımızın bizə yadigar qoyduğu bu günümüzdə qədər tam gəlib çatmış abidələri qoruyub saxlamaq və gələcək nəsillərə ötürmək hər birimizin borcudur.

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**AN OVERVIEW OF THE BANQUE DE L'INDOCHINE'S OPERATIONS IN VIETNAM
DURING THE VOLATILE YEARS (1940–1945)**

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ABSTRACT

This paper provides a comprehensive overview of the operations of the Banque de l'Indochine (BIC) in Vietnam during the tumultuous period of 1940–1945, characterized by the progressive establishment of Japanese military hegemony in Indochina. Amidst the German occupation of metropolitan France, the BIC demonstrated remarkable institutional flexibility to maintain its presence and safeguard the interests of French finance capital through intricate financial accords with the Japanese Imperial Army.

The research elucidates the BIC's role as a pivotal financial instrument serving the Japanese war machine. Between 1940 and March 1945, the BIC supplied the Japanese forces with a total of 725 million Indochinese piasters; this figure surged by an additional 720 million piasters in the final six months of the conflict alone. The total issuance to meet Japanese demands reached 1,445 million piasters, accounting for nearly half of the total currency in circulation by 1945. This policy of "issuance on demand" precipitated hyperinflation, severely devaluing the piaster and plunging the colonial economy into a profound crisis. Furthermore, the paper examines the BIC's branch network, exemplified by the establishment of the Da Lat branch in 1943, which serves as a testament to the persistent efforts to sustain colonial banking structures amidst the ravages of war.

Keywords: Banque de l'Indochine, Japanese Occupation, Monetary Inflation, War Finance, Indochina (1940–1945).

1. INTRODUCTION

The French colonial presence in Vietnam from the late 19th century was characterized not merely by military subjugation but by the systematic establishment of a rigorous economic and financial hegemony. Central to this structure was the Banque de l'Indochine (BIC), established by the decree of January 21, 1875. Operating as a French capitalist monopoly, the BIC was endowed with three fundamental functions: the issuance of banknotes, commercial trading, and financial investment. These specialized pillars allowed the bank to achieve exponential growth, establishing a global network of branches and generating immense surplus value for the French metropole. By the onset of World War II, the BIC had emerged as the preeminent financial entity in French colonial commerce, dominating key sectors such as coal mining and rubber plantations.

However, the period of 1940–1945—often termed the "volatile years"—placed this financial institution within an unprecedented historical conjuncture. The expansion of World War II and the subsequent Japanese occupation of Vietnam created a complex "dual-subjugation" political landscape. During this era, the BIC was compelled to transcend its role as a mere colonial tool, evolving into an involuntary yet calculated financial conduit between the French colonial administration and the Japanese military forces. This role was exemplified by the bank's multifaceted activities, ranging from ensuring the supply of banknotes for Japanese wartime expenditures to executing complex foreign exchange operations involving the "Special Yen". Notably, the inauguration of a Tokyo branch in 1942 (or 1943 according to some records) serves as a testament to the BIC's strategic efforts to maintain commercial ties amidst global conflict.

The monetary landscape during these years was marked by profound instability. The uncontrolled issuance of currency to meet wartime demands led to hyperinflation, severely impacting the Vietnamese economy. The BIC found itself in a paradoxical position: protecting the interests of French shareholders while simultaneously accommodating the escalating financial requisites of the Japanese regime. This

tension reached its zenith following the Japanese coup on March 9, 1945, which further destabilized the monetary system and left a legacy of debt that the subsequent Government of the Democratic Republic of Vietnam had to navigate.

While existing scholarship by Phan Ha Uyen (1987), Marc Meuleau (1990), and Yasuo Gonjo (2018) has provided foundational insights into the BIC's organizational structure and colonial mandate, there remains a significant historiographical gap regarding its specific operational mechanisms during the Japanese occupation. Much of the current literature offers general descriptions without a granular analysis of how the BIC facilitated the integration of commercial activities between Vietnam and Japan.

This research seeks to bridge this gap by examining the Banque de l'Indochine's operations in Vietnam from 1940 to 1945. By analyzing archival data and economic indicators, this study elucidates the survival strategies and adaptive mechanisms employed by the BIC within the geopolitical vacuum of World War II. Furthermore, it evaluates the long-term impact of these financial operations on the post-war Vietnamese economy. In doing so, this paper contributes to a more nuanced understanding of the role of global financial institutions during periods of extreme political volatility.

2. CONCEPTUAL FRAMEWORK

The study of the Banque de l'Indochine's (BIC) operations during the volatile years of 1940–1945 requires a multidimensional analytical framework that integrates financial history, institutional economics, and the theory of financial colonialism. The primary and most crucial theoretical pillar is Rudolf Hilferding's (1910) theory of Finance Capital, which emphasizes the fusion of banking and industrial capital under the control of major financial institutions. In the Vietnamese context, the BIC functioned not merely as a currency-issuing bank but as a powerful entity coordinating capital flows to dominate key economic sectors, rendering production decisions in the colony entirely dependent on capital flows from the metropole. The BIC's presence represented the highest manifestation of French finance capital, establishing a "financial ecosystem" where credit privileges and the issuance of the Indochinese Piastre served as instruments of practical control. Complementing this perspective, the theory of Colonial Economics posits that colonial economies were designed to supplement the metropolitan economy by providing raw materials and consuming industrial goods. Within this framework, the BIC operated as the "heart and mind" of the system, prioritizing capital for large corporations to establish specialized agricultural export zones, thereby forcing the indigenous economy into a state of perpetual dependence. This aligns with Andre Gunder Frank's (1966) Dependency Theory, where the development of the "Metropole" is predicated on the exploitation of the "Satellite". The BIC functioned as a "pump," siphoning resources from Vietnam back to France through profit repatriation and cross-investment mechanisms.

In the period of 1940–1945, this framework must be expanded to consider the characteristics of State Monopoly Capitalism under wartime conditions. The BIC, endowed with the exclusive privilege of banknote issuance and the patronage of the French government, established immense barriers to market entry, stifling the emergence of indigenous national capital. Geoffrey Gunn (2014) argues that during periods of market volatility, the colonial administration often enacted tax policies and subsidies favoring large estates based on the BIC's financial appraisals, creating profound inequalities within the heart of the colonial economy. Furthermore, the theory of Economic Geopolitics elucidates how the BIC utilized financial power to establish economic sovereignty over territorial space. The provision of credit, accompanied by land concessions, transformed natural resources into capitalist means of production under strict banking supervision. Notably, the exchange rate mechanism and the fluctuations of the Indochinese Piastre served as sophisticated tools of exploitation. Maintaining the Silver Standard for Indochina while the rest of the world transitioned to the Gold Standard created a "financial buffer zone" that allowed the BIC to optimize profits from exchange rate differentials and foreign exchange speculation. According to Yasuo Gonjo (2018), this mechanism made Indochinese exports cheaper when silver prices fell, boosting export volumes for French commercial syndicates while causing inflation and diminishing the purchasing power of the indigenous population.

Ultimately, the concept of Colonial Financialization provides insights into how power was exercised not only through military force but also through figures, interest rates, and abstract financial instruments.

During the 1940–1945 period, as Japan intervened in Indochina, the BIC had to operate within a dual institutional structure, where economic "rules of the game" were reshaped to serve the wartime needs of both France and Japan. Douglass North (1990), in his theory of Institutional Economics, pointed out that institutions establish incentive structures and constraints for economic behavior. The BIC established new operational rules, forcing indigenous society to transition from traditional metallic currency to banknotes exclusively issued by the bank, thereby capturing the entire surplus value of the economy. This process not only altered ownership structures but also transformed economic management thinking, where administrative decrees were frequently adjusted to align with the BIC's exchange objectives. Together, these theories form a comprehensive analytical framework to decode how the Banque de l'Indochine maintained its monopoly and adapted to violent historical shifts, while leaving a profound mark on Vietnam's post-war financial structure.

3. METHODOLOGY

The research on the operations of the Banque de l'Indochine (BIC) during the period of 1940–1945 is conducted based on an interdisciplinary methodological framework, integrating historiography, political economy, and quantitative statistical analysis. This multidimensional approach is essential to decode a complex historical era where financial decisions were not merely economic operations but strategic responses to intense geopolitical fluctuations. At the core of this methodology is the collection, classification, and critical evaluation of archival materials to ensure the authenticity and objectivity of the arguments presented.

Firstly, the historiographical method is applied throughout to explore primary archival sources. These include the BIC Board of Directors' annual reports (*Rapports annuels*), decrees from the Government-General of Indochina, and correspondence between BIC branches in Saigon and Hanoi and the headquarters in Paris. Specifically, the study prioritizes archives from the National Overseas Archives of France (ANOM) and the National Archives Center I in Hanoi. According to Marc Meuleau (1990), BIC's financial reports contain not only raw data but also reflect the strategic thinking of French financial circles in the face of Japanese expansion. Textual analysis helps clarify specific wartime economic terminology and clandestine agreements regarding liquidity provision for the Japanese military.

Secondly, the study employs quantitative analysis to process statistical data on currency issuance, exchange rates, and bank profits. By tabulating and comparing financial indicators from 1939 to 1945, the research identifies the direct correlation between the surge in circulating cash and hyperinflation in Vietnam. This method quantifies the impact of the "Special Yen" policy and the military expenditure advances that the BIC was forced to provide under Japanese pressure. As Duong To Quoc Thai (2021) noted, analyzing BIC's balance sheets during this period reveals a capital shift from productive sectors to military logistics, demonstrating the bank's functional transformation under wartime conditions.

Thirdly, the historical comparative method is used to situate BIC's operations in relation to other financial institutions in Southeast Asia at the time, such as Japan's Yokohama Specie Bank. This comparison highlights the unique nature of the governance model in Indochina—where the BIC had to maintain French privileges while adapting to the New Economic Order imposed by Japan. The research also applies Douglass North's (1990) institutional theory to analyze how legal regulations and financial agreements were adjusted according to political shifts. This process explains why the BIC managed to sustain its monopoly even when French sovereignty was severely threatened.

Finally, the study utilizes synthesis and deduction to derive conclusions regarding the long-term consequences of these financial activities. From fragmented data on investments, credit contracts, and exchange rate fluctuations, the research constructs a comprehensive picture of "colonial financialization" during the war. Referencing the works of scholars such as Yasuo Gonjo (2018) and Phan Ha Uyen (1987) strengthens the theoretical framework and ensures that the new findings of this study are situated within a continuous academic discourse. The entire research process is conducted with a rigorous spirit of historical criticism, eliminating subjective elements and focusing on reconstructing historical truth through an economic and financial lens.

4. RESULTS AND DISCUSSION

4.1. THE DUAL PRIVILEGES AND THE CHALLENGE OF SOVEREIGNTY

During the volatile period of 1940–1945, the operations of the Banque de l'Indochine (BIC) were not merely a financial narrative but a fierce struggle for institutional power and national sovereignty. The concept of "Dual Privileges" is understood here as the combination of the exclusive right of currency issuance and the control of public credit—two pivotal instruments that transformed the BIC into a formidable "colonial central bank". However, in the context of French Indochina being caught between the Vichy government in metropolitan France and the Japanese military presence on the ground, these privileges became the epicenter of profound challenges to economic sovereignty.

Firstly, the exclusive privilege of issuing the Indochinese Piastre was the cornerstone of the BIC's existence. Since its establishment by the decree of January 21, 1875, the BIC had established a monopolistic position that no other financial institution could infringe upon. Entering 1940, following the fall of France to Germany and the formation of the Vichy regime, the BIC faced a dilemma: to maintain loyalty to the metropole or to adapt to Japanese demands to protect its assets in Indochina. Marc Meuleau (1990) argues that during this stage, the BIC executed a strategy of "institutional survival" by utilizing its issuance privilege to appease both sides. Maintaining the Piastre as an independent currency unit within the Franc zone, while simultaneously pegging its value to agreements with the Japanese Yen, created a fractured sovereign structure.

The challenge to sovereignty intensified when Japan compelled the French colonial administration to sign agreements for "Forced Loans." Under these terms, the BIC was obligated to provide unlimited cash advances to the Japanese military for expenditures within Indochina. This was essentially a direct seizure of issuance sovereignty, as the bank was forced to print more money to meet the needs of a foreign power without equivalent asset backing. Duong To Quoc Thai (2021) emphasizes that this mechanism transformed the BIC from a French instrument of extraction into a financial intermediary serving Japanese military ambitions. This "collaboration" serves as evidence that the BIC's privileges were weaponized against the very economy it managed, causing hyperinflation and eroding trust in the colonial currency.

Furthermore, the privilege of public credit control was vigorously challenged. Prior to 1940, the BIC was the sole entity capable of coordinating massive capital flows into strategic sectors such as rubber and mining. However, the emergence of Japanese banks, such as the Yokohama Specie Bank, created a dual governance system. The BIC had to compete covertly to retain French conglomerates while yielding credit space to Japanese enterprises under the 1941 Franco-Japanese economic accords. Geoffrey Gunn (2014) points out that the BIC's acceptance of payments in "Special Yen"—a currency that existed only on paper and was non-convertible—stripped the bank of its ability to control foreign exchange reserves. This was a severe blow to financial sovereignty, turning the BIC into an entity that was "nominally privileged but operationally imprisoned."

During the 1940–1945 period, the BIC's governance structure also reflected the instability of French sovereignty. The Board of Directors in Paris was divided, and communication between the headquarters and branches in Saigon and Hanoi was frequently disrupted. This forced local administrators to make life-and-death decisions, sometimes transcending the legal framework of colonial decrees. As Yasuo Gonjo (2018) analyzed, this forced autonomy of the Indochinese branches created a gap in the centralized French colonial management system, leading to the fragmentation of the BIC's power. The challenge to sovereignty at this time came not only from the outside (Japan) but also from the internal breakdown of the colonial administrative apparatus.

Finally, the Japanese coup d'état on March 9, 1945, officially marked the end of the "Dual Privileges" under French protection for a brief period. When Japanese troops seized the BIC's treasuries and headquarters, all legal privileges became meaningless in the face of military might. However, it is noteworthy that the BIC made efforts to destroy sensitive documents and relocate valuable assets before the takeover. This action is viewed as a final attempt to preserve the "seeds" of financial sovereignty for the post-war era. In summary, the 1940–1945 period is the clearest evidence that colonial financial institutions like the BIC were never bystanders in sovereignty disputes. Its Dual Privileges were both a

tool of dominance and an "Achilles' heel" that dragged it into the vortex of conflicting imperial ambitions.

4.2. FINANCIAL INTERMEDIATION FOR JAPANESE MILITARY AMBITIONS

During the period of 1940–1945, the Japanese military presence in Indochina transformed the Banque de l'Indochine (BIC) from an institution serving French colonial interests into a complex financial intermediary, playing a pivotal role in realizing Japan's military ambitions in Southeast Asia. This transformation was not voluntary but resulted from imposed political treaties, forcing the BIC to operate as a "war treasury" for the Japanese military through specialized credit and payment mechanisms. This intermediation role was most clearly manifested in three aspects: the provision of military liquidity, the management of the "Special Yen" system, and the financing of strategic supply chains.

First and foremost, the mechanism of providing liquidity to the Japanese military through "advances" was the most impactful intermediation activity. Under the economic agreements signed in 1941 between the Vichy administration and Japan, the BIC was obligated to provide unlimited Piastre cash advances for the Japanese military to pay for food, logistics, and the construction of military bases in Vietnam. Marc Meuleau (1990) points out that these advances were essentially a form of debt with no clear repayment date, turning the BIC into a direct financial guarantor for Japanese military operations. The mass printing of banknotes to meet this demand led to an explosion in currency circulation, directly causing a hyperinflationary disaster. Data from BIC reports show that the volume of issued cash skyrocketed from 216 million Piastres in 1939 to over 1.3 billion Piastres by early 1945, evidencing the "squeezing" of Indochina's financial resources to serve the war machine.

Secondly, the BIC's intermediation role was reinforced through the management of the "Special Yen" account system. This was a sophisticated financial mechanism aimed at anchoring the Indochinese economy to Japan's Greater East Asia Co-Prosperity Sphere. Instead of paying in hard currency or gold, Japan paid for services and goods in Vietnam by crediting Yen-denominated accounts in Tokyo. The BIC, as the bank of issuance, was forced to accept these credits and, in return, provide Piastre currency for Japanese use locally. Yasuo Gonjo (2018) argues that this mechanism turned the BIC into a "financial hostage," as the bank's assets were frozen in Japan in the form of non-convertible Yen, while its liabilities (issued banknotes) in Vietnam continued to mount. This intermediation not only undermined French monetary sovereignty but also turned the BIC into a tool for systematically siphoning resources from Indochina to Japan.

Thirdly, the BIC served as a financier for syndicates and joint ventures serving military logistical needs. To maintain the flow of raw materials such as rubber, coal, and rice to Japan, the BIC extended credit lines to Franco-Japanese enterprises. Research by Duong To Quoc Thai (2021) and Thai Hung Khoa (2025) emphasizes that the BIC's prioritization of capital for these sectors disrupted civilian production chains, serving the ultimate goal of sustaining Japan's military strength in the Pacific theater. This financial intermediation further extended to the BIC guaranteeing commercial transactions between Indochina and other Japanese-occupied territories, creating a closed economic network for war.

The challenge to this intermediation role became extreme after March 9, 1945. When Japan executed the coup to overthrow the French, the BIC fell under the direct control of the Japanese military. At this point, BIC administrators faced heavy pressure to maintain confidence in the currency as Japan began issuing unsecured banknotes and forcing the BIC to recognize their value. This event marked the pinnacle of abusing a financial institution for military objectives, leaving behind an exhausted economy with a completely uncontrollable monetary system. In summary, the BIC's financial intermediation for Japan during 1940–1945 is a classic example of a colonial financial institution's functional transformation under the impact of total war, where market rules were entirely replaced by military mandates and imperial ambitions.

4.3. STRATEGIC SHIFTS IN COMMERCIAL INVESTMENT AND RESOURCE EXTRACTION

During the 1940–1945 period, the investment activities of the Banque de l'Indochine (BIC) in Vietnam underwent a vital strategic shift. When the trade routes connecting to metropolitan France were severed due to Allied blockades and the German occupation of France, the BIC was forced to abandon its traditional investment model focused on exports to European markets. Instead, the bank executed a capital restructuring roadmap, shifting its focus toward extracting strategic resources to serve local needs and exports to Japan's Greater East Asia Co-Prosperity Sphere. This shift was not merely a passive economic response but a profound adaptive strategy aimed at preserving the interests of French finance capital within a new geopolitical order.

The primary focus of this shift was the rubber and mining industries—the two most critical resources for the war machine. Prior to 1940, the BIC had established a financial ecosystem surrounding the massive rubber plantations in Cochinchina, such as Michelin and Terres Rouges. However, during these volatile years, the BIC adjusted its credit policies to support these companies in redirecting their markets from France to Japan. According to research by Duong To Quoc Thai and To Thuy Duong (2026), the BIC acted as a financial "midwife" for rubber supply quota agreements between the French colonial administration and the Japanese military. Maintaining capital flows to rubber plantations not only preserved production infrastructure but also allowed the BIC to perform profitable exchange operations by controlling foreign currency flows from exports.

In addition to rubber, the coal mining industry in Tonkin (specifically the Société Française des Charbonnages du Tonkin - SFCT) witnessed a strong BIC presence in a new form. Japan had an immense demand for coal to fuel its naval fleets and heavy industry. The BIC implemented strategic investments in railway and port infrastructure to facilitate coal exports to Japan and China. Marc Meuleau (1990) argues that by controlling the finances of mining companies, the BIC ensured that profits from resource sales continued to flow through the French banking system before being converted into Yen-denominated reserves. This was an effort to prevent direct takeovers by Japanese financial conglomerates (Zaibatsu) of Indochina's backbone economic sectors.

This shift was also reflected in the BIC's participation in complex economic alliances. Under Japanese pressure, many Franco-Japanese joint ventures were established. The BIC frequently served as a credit guarantor or payment intermediary for these entities. Yasuo Gonjo (2018) points out that participating in these joint ventures was a "conciliation tactic" by the BIC to protect the ownership rights of French shareholders. Instead of direct confrontation, the BIC utilized financial power to tie Japanese interests to the survival of the French economic system in Indochina. This created a peculiar situation: Vietnam's resources were exploited more thoroughly than ever, yet financial control remained in the hands of administrators at the BIC's Saigon and Hanoi branches.

Particularly in the agricultural sector, the shift toward monoculture and forced rice procurement was a dark aspect of investment strategies during this period. The BIC provided credit to procurement syndicates to supply the Japanese military, indirectly pushing the Vietnamese agriculture into a state of exhaustion. Geoffrey Gunn (2014) emphasizes that the BIC's prioritization of capital for export procurement rather than supporting local food production contributed to a severe imbalance in food supply and demand, a precursor to the catastrophic famine of 1945. This shift demonstrates the pragmatic and ruthless nature of finance capital during wartime: capital flows only toward areas that can generate strategic exchange value for the occupying powers.

In summary, the 1940–1945 period witnessed a flexible and calculating Banque de l'Indochine. By shifting its investment focus from "French-centric" to "Japanese-adaptive," the BIC successfully maintained the operation of the colonial economic machine amidst the storm of war. However, the price for this institutional "success" was the exhaustive extraction of natural resources and the impoverishment of indigenous labor in Vietnam. These strategic shifts not only served the bank's survival goals but also reshaped the regional economic structure toward dependency on global military demands.

4.4. THE MONETARY CRISIS AND THE 1945 COUP D'ÉTAT

The Japanese coup d'état on March 9, 1945, which overthrew the French colonial administration in Indochina, was not only a political turning point but also the "final blow" leading to the total collapse of the monetary system painstakingly built by the Banque de l'Indochine (BIC). This period witnessed the convergence of three factors: the loss of control by the issuing institution, the expansion of unbacked currency, and the paralysis of public confidence. The 1945 monetary crisis was the inevitable result of abusing financial power for military objectives, plunging the Vietnamese economy into an unprecedented hyperinflationary spiral.

Immediately following the coup, Japanese troops swiftly seized BIC headquarters in Saigon, Hanoi, and Hai Phong. The privilege of issuance—the "soul" of the BIC under French protection—was violently stripped away. According to archives cited by Marc Meuleau (1990), French BIC administrators attempted to destroy large quantities of exchange files and classified documents regarding gold reserves to prevent Japanese seizure. However, Japan's establishment of direct control over the bank's operational machinery turned the BIC into a "hollow tool." Traditional banking operations stagnated, replaced by forced payment orders to serve Japan's urgent military activities as the Allies tightened their blockade.

The most severe challenge during this crisis was the emergence of unsecured banknotes and Japan's coercion of the BIC to recognize temporary payment certificates. To address the acute cash shortage caused by severed transportation lines, the Japanese military issued its own military currency and forced BIC branches to convert them into Piastres at imposed exchange rates. Duong To Quoc Thai (2021) analyzes that this action completely shattered the BIC's monetary backing principles, causing the Piastre to lose its intrinsic value and become a directionless medium of exchange. Inflation, which had been smoldering since 1941, erupted into a disaster as the volume of currency in circulation no longer bore any relation to actual goods on the market.

The collapse of the price system in 1945 is clear evidence of the BIC's paralysis. As confidence in the monopoly bank's currency faltered, the population began hoarding goods, gold, and silver, driving the prices of essential commodities, especially rice, to unimaginable levels. Geoffrey Gunn (2014) argues that it was the mismanagement and brutal intervention of the Japanese into the BIC's issuance mechanism that directly exacerbated the famine in Tonkin. The BIC's loss of capacity to regulate currency circulation meant that economic tools to salvage the food market were neutralized. Currency at this time no longer functioned as a measure of value but became an instrument of dispossession and impoverishment.

In this context, the relationship between the BIC and the Tran Trong Kim Government (sponsored by Japan) was also tragic. Although nominally an independent government, in reality, all financial lifelines of this regime depended on the remnants in the BIC's vaults under Japanese supervision. Yasuo Gonjo (2018) points out that the BIC's fragmentation between political factions led to a dispersal of financial power. Branches in the South and North operated almost independently, resulting in currency value disparities between territories, creating opportunities for speculation and further disorienting an already exhausted economic system.

The monetary crisis of 1945 did not stop at the devaluation of the Piastre; it was the collapse of an institutional order. When the August Revolution broke out, the Government of the Democratic Republic of Vietnam inherited a hollowed-out treasury with massive debt and a chaotic monetary system. Phan Ha Uyen (1987) emphasizes that the legacy left by the BIC and the 1945 coup was an extreme challenge for the revolutionary government in establishing an independent currency. In summary, 1945 marked the end of the golden age of the Banque de l'Indochine and served as a warning about the dangers of financial institutions being turned into political pawns in imperial conflicts. This crisis left deep scars on Vietnam's economic structure that took decades to heal.

4.5. EVALUATION OF LONG-TERM IMPACTS ON VIETNAM'S POST-WAR ECONOMY

Evaluating the operations of the Banque de l'Indochine (BIC) during the period of 1940–1945 is inseparable from the profound and lasting impacts it left on Vietnam's economy after the conclusion of World War II. These effects extended beyond immediate inflationary figures; they reshaped the financial structure, consumer psychology, and macro-governance challenges that the Government of the Democratic Republic of Vietnam had to navigate following the August Revolution of 1945. The BIC's legacy during the "volatile years" was an exhausted economy, a fragmented monetary system, and a mountain of public debt, creating immense barriers to the pursuit of independence and financial autonomy.

The most direct and devastating consequence was hyperinflation and the collapse of the domestic currency's purchasing power. The BIC's forced issuance of unbacked banknotes to meet Japanese military demands left a massive volume of cash in circulation with no real value. Marc Meuleau (1990) described this excess currency as a "time bomb" for the post-war economy. When the revolutionary government took over the treasury, they faced not only an empty vault but also the task of managing billions of devalued Piastres that were destabilizing the market. The resulting public distrust in paper currency—a byproduct of BIC's policies—pushed society back toward hoarding commodities and gold, hindering efforts to mobilize financial resources for the subsequent resistance and nation-building.

Secondly, the distorted investment structure created by the BIC during the war left behind a crippled industrial and agricultural base. The concentration of capital into extracting strategic resources (rubber, coal) to serve Japan depleted the capacity of domestic consumer goods production. Duong To Quoc Thai and To Thuy Duong (2026) point out that the economic infrastructure funded by the BIC primarily served forced exports, leaving Vietnam after 1945 in severe shortage of basic goods. The long-term consequence was an economy overly dependent on raw material exports—a structural "trap" that took decades to reorganize. This legacy also included the destruction of irrigation systems and rice agriculture, leading to food security instabilities that persisted well into the anti-French resistance period.

Thirdly, institutional financial fragmentation was another painful legacy. Following the 1945 coup and the disintegration of centralized French administrative machinery, the banking system in Vietnam was partitioned according to occupation zones. Phan Ha Uyen (1987) emphasized that the BIC's maintenance of isolated operations in major cities while rural areas fell under revolutionary control created a "two-tier" economy with different currencies circulating simultaneously. This rupture not only hindered trade but also complicated the Vietnamese government's later efforts toward monetary unification. The BIC, though no longer holding an absolute monopoly, continued to serve as a tool for the French to attempt a financial re-occupation of Indochina, sparking a fierce monetary war that lasted until 1954.

Furthermore, the legacy of debt and complex international financial commitments remained a burden for the post-war economy. The advances the BIC paid to Japan and the colonial government's debts tied to BIC assets created prolonged legal disputes in international forums. Yasuo Gonjo (2018) argues that negotiations over war reparations and debt settlements between France, Japan, and Vietnam in the post-1945 period were always haunted by the "blackened" balance sheets of the BIC from the war years. This severely impacted Vietnam's early international financial standing, limiting access to external reconstruction capital.

Finally, from the perspective of Douglass North's (1990) institutional theory, the BIC left behind a deeply colonized financial governance mechanism. The operational rules, banking legal systems, and exchange rate management methods established by the BIC during 1940–1945 became "negative legacies" that the revolutionary government had to radically transform. However, dismantling the influence of an institution that had existed for 70 years could not be achieved overnight. In summary, the long-term impacts of the BIC's operations during the volatile years were not just material losses but an erosion of economic sovereignty, placing Vietnam at a starting point fraught with difficulties in its journey to achieve full financial and monetary independence.

5. CONCLUSION AND RECOMMENDATIONS

The research on the operations of the Banque de l'Indochine (BIC) in Vietnam during the volatile period of 1940–1945 has depicted a comprehensive overview of the complex intersection between finance capital, political power, and global geopolitical shifts. Through the analyzed sections, it can be concluded that the BIC was not merely a colonial financial institution but a socio-economic entity with exceptional adaptability under wartime conditions. The following are the primary conclusions and recommendations derived from the study:

5.1. Conclusions

Firstly, the 1940–1945 period marked a functional transformation of the BIC from a French colonial "extractive tool" into a "financial intermediary" serving Japan's military ambitions. The study has elucidated how the BIC utilized its currency issuance privilege to meet the massive liquidity demands of the Japanese military through the "Special Yen" mechanism and military expenditure advances. This adaptation, though forced, allowed the BIC to preserve its institutional structure amidst the Pacific War's vortex while simultaneously acting as a direct agent of hyperinflation and the exhaustion of the Vietnamese economy.

Secondly, the BIC's strategic shift in investment and resource extraction reflects the pragmatism of finance capital. Prioritizing capital for rubber, mining, and rice procurement to fuel the war machine disrupted civilian production chains, plunging Vietnamese society into impoverishment and serving as a precursor to the 1945 famine. The research confirms that the BIC's profits during this stage were built upon the exhaustive exploitation of natural resources and the sacrifice of the indigenous labor class.

Thirdly, the coup d'état on March 9, 1945, and the subsequent monetary crisis signaled the end of the old colonial financial order. The collapse of the monetary backing system and Japan's brutal intervention into the BIC's treasuries left an exhausted economic legacy for the Government of the Democratic Republic of Vietnam. Long-term consequences, including inflation, public debt, and institutional fragmentation, posed extreme challenges for post-war nation-building. The BIC's legacy serves as a costly lesson on the dangers of monetary power being dominated by imperial ambitions.

5.2. Recommendations

Based on the study's findings, the author proposes the following recommendations:

1. For Archival and Historical Research: It is essential to further promote the digitization and exploration of archives at the National Overseas Archives of France (ANOM) and Japanese sources to obtain a more multidimensional comparative view of the clandestine financial transactions between France and Japan. Reconstructing detailed balance sheets of the BIC from this period will provide crucial quantitative data for regional economic history.
2. For Education and Training: Lessons on financial history and the role of colonial banks should be integrated into economics and history curricula at universities. Understanding the operational mechanisms of institutions like the BIC will help future generations gain a deeper awareness of monetary sovereignty and national financial security.
3. For Policy Planning: The history of the BIC during the war serves as a reminder of the importance of building an independent, autonomous financial system capable of withstanding geopolitical shocks. Developing nations should remain cautious regarding dependence on foreign financial institutions within the core sectors of their economies.

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THE PRESENCE OF BANQUE DE L'INDOCHINE BRANCHES IN VIETNAM (1940–1945): FOOTPRINTS AND INTERACTIONS

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ABSTRACT

This paper investigates the spatial presence and institutional network of the *Banque de l'Indochine* (BIC) in Vietnam during the period of 1940–1945, an era defined by the complex dual-power structure between French colonial administration and the Japanese military occupation. The study focuses on analyzing the BIC's geographical "footprints," ranging from established hubs in Saigon, Haiphong, and Hanoi to the strategic opening of the Da Lat branch in 1943, amidst the escalation of the Pacific War.

Drawing upon archival records, the research elucidates the multi-dimensional interactions between this banking system and contemporary political-economic entities. On one hand, the BIC maintained its role as the "extended arm" of French finance capital; on the other, it was compelled to establish sophisticated financial interaction mechanisms with the Japanese Imperial Army and the *Yokohama Specie Bank* to facilitate foreign trade settlements and the supply of liquid currency for the occupying forces. By examining the autonomous yet unified operations of these branches, the study reveals how the BIC adapted to preserve colonial banking structures. Furthermore, it analyzes the impact of these interactions on the destabilization of local monetary markets and the socio-economic conditions in the territories where the BIC's branches operated.

Keywords: *Banque de l'Indochine, Branch Network, Japanese Occupation, Financial Interactions, Vietnam (1940–1945).*

1. INTRODUCTION

The presence of the Banque de l'Indochine (BIC) in Vietnam since the late 19th century was not merely the establishment of a financial institution, but the formation of a strategic network of economic "footprints" connecting the colony's vital political and commercial centers with global markets. Through its system of branches in Saigon, Hanoi, Haiphong, Tourane (Da Nang), and Vinh, the BIC created a pervasive financial governance structure that allowed the French colonial administration to maintain tight control over capital flows and import-export activities. However, the period of 1940–1945—when World War II expanded into the Pacific—placed this branch network within an unprecedented context of complex interactions. This study focuses on reconstructing the presence and multidimensional interactions of BIC branches during these "volatile years," aiming to clarify how a financial institution maintained its existence and exercised power within a fragmented geopolitical space.

Historically, BIC branches in Vietnam were established with specialized functions. While the Saigon branch acted as the financial "heart," coordinating rice and rubber exports in Cochinchina, the Hanoi branch served as the political-monetary hub, linked to the Governor-General's administrative apparatus. Marc Meuleau (1990) emphasizes that the geographical distribution of BIC branches reflected the pragmatic logic of French finance capital: remaining close to transportation hubs and raw material zones. Entering 1940, as Japan began its incursion into Indochina, these "footprints" were no longer just symbols of French authority but became mandatory "points of contact" with the new military power. Interactions at this time were no longer purely commercial but were heavily tinged with diplomacy and political coercion.

One of the most significant highlights of the BIC's branch network during this period was the establishment of a branch in Tokyo in 1942. This was a calculated strategic move, marking a shift in the BIC's trajectory of interaction. Direct presence at Japan's center of power allowed the BIC to maintain foreign exchange payment channels and protect the interests of French shareholders amidst disrupted

communications with Paris. Duong To Quoc Thai (2021) argues that the Tokyo branch served as a "bridge" helping the BIC regulate military expenditure advances and process transactions related to the Special Yen. This presence demonstrates the BIC's efforts to internationalize its interactions to survive within the "Greater East Asia" structure imposed by Japan.

Within Vietnam, interactions between BIC branches and the Japanese military occurred under a dual-governance framework. In Haiphong—a critical commercial gateway—the BIC faced intense pressure to control import-export flows serving Japanese logistical needs. Archival reports from ANOM reveal constant tension between French branch managers and Japanese Kempeitai officers over the enforcement of cash payment quotas. According to Yasuo Gonjo (2018), this interaction was a process of "coerced negotiation," where the BIC was forced to cede power space while simultaneously employing complex banking operations to delay or minimize financial expropriation by the Japanese.

Furthermore, the presence of BIC branches fostered deep interactions with the indigenous economy. Amidst hyperinflation and commodity scarcity, these branches became hubs for capital accumulation for colonial syndicates and a segment of indigenous capitalists aligned with either France or Japan. However, as Geoffrey Gunn (2014) points out, this interaction was highly exclusionary toward the majority of the Vietnamese population, as branch credit policies focused solely on wartime interest groups. The legacy of this presence was profound financial inequality, setting the stage for struggles for monetary independence following the August Revolution.

While previous studies by Phan Ha Uyen (1987) or Jean-Pascal Aumiphin (1994) have addressed the general operations of the BIC, in-depth analysis of the physical presence and specific interaction networks of individual branches within the 1940–1945 context remains a gap to be filled. This research utilizes a spatial approach and network theory to analyze the BIC's "footprints." By exploiting new archival records from the author's Google Drive and online documents, the paper aims to provide a fresh perspective on the role of bank branches as active geopolitical actors during wartime. In doing so, the study contributes not only to financial history but also enriches the understanding of the nature of occupation and collaboration in Indochina during World War II.

2. CONCEPTUAL FRAMEWORK

To decode the presence and interactions of the Banque de l'Indochine (BIC) branches in Vietnam during the 1940–1945 period, this research constructs a multi-layered theoretical framework, integrating institutional network theory, economic geopolitics, and the concept of adaptation under occupation. The core of this analytical framework treats the BIC not merely as a simple financial entity but as a system of "network nodes" capable of flexible interaction with various political and military actors within a volatile colonial space.

Firstly, Institutional Network Theory provides the basis for understanding the structure of the BIC branches' "footprints." According to Douglass North (1990), institutions do not operate in isolation but exist through cross-linkages. For the BIC, each branch in Saigon, Hanoi, or Haiphong was not just a business unit but a strategic "node" within the French power network. During 1940–1945, this network shifted from a star-shaped structure (centered in Paris) to a more decentralized one, where local branches had to forge new interactions to maintain operations. Marc Meuleau (1990) argues that the physical presence of these branches was an "extension" of French sovereignty, and when this sovereignty was threatened by Japanese occupation, these branches were forced to establish "survival interactions" with Japanese financial institutions like the Yokohama Specie Bank.

Secondly, the concept of Economic Geopolitics helps explain why BIC branches were situated in strategic locations and how they interacted with the occupied space. This theory suggests that financial entities are frequently utilized as instruments to establish and maintain territorial influence. In the context of wartime Indochina, the BIC's presence at commercial gateways and administrative centers aimed not only at profit but also at "staking a claim" for French financial power against the expansion of the Greater East Asia Co-Prosperity Sphere. Yasuo Gonjo (2018) points out that the opening of the Tokyo branch in 1942 is a classic example of economic geopolitics, where the BIC proactively extended its "footprint" into the adversary's heartland to create a space for negotiation and exchange control.

Thirdly, the theoretical framework of Financial Occupation and Collaboration is a key element in analyzing interactions during 1940–1945. This study draws on Geoffrey Gunn's (2014) perspective regarding how colonial financial institutions had to operate under a "dual structure." The interaction between BIC branches and the Japanese military cannot be understood simply as total surrender or comprehensive collaboration, but rather as a process of "negotiation from a position of weakness." The BIC utilized its issuance privilege and professional expertise as a form of "soft power" to maintain a degree of economic sovereignty, while Japan used military pressure to transform these branches into intermediaries for liquidity provision. This represents a complex form of interaction that researchers term "coerced collaboration."

Furthermore, the theory of Institutional Dependency helps explain the BIC's interactions with the indigenous economy. During these volatile years, BIC branches acted as "gatekeepers" of capital. Duong To Quoc Thai (2021) emphasizes that these interactions were deeply stratified, where French colonial syndicates and Japanese contractors received prioritized access to credit, while indigenous enterprises were pushed to the periphery of the system. The presence of the BIC thus created an "unequal footprint," reshaping asset ownership structures in pre-revolutionary Vietnam.

Finally, the concept of Institutional Resilience is used to evaluate how BIC branches responded following the March 9, 1945 coup. When official interactions with the French administration were completely severed, these branches faced a purely military and chaotic interaction environment. The survival of BIC "footprints" after this event no longer relied on legal decrees but on the ability to adapt and preserve physical assets. Together, these theories form a robust analytical framework, allowing this research to delve into the nature of multilateral relationships, thereby vividly reconstructing the role of the Banque de l'Indochine as a central geopolitical actor during one of the most dramatic periods in Vietnamese history.

3. METHODOLOGY

The research on the presence and interactions of the Banque de l'Indochine (BIC) branches in Vietnam during the 1940–1945 period requires a multi-dimensional methodological framework, combining traditional historiography with modern analytical methods such as network analysis and spatial approaches. The selection of this methodology aims not only to reconstruct economic activities but also to decode the "footprints" of power and the complex multilateral interactions between the BIC, the French colonial administration, the Japanese military, and the indigenous economy within the context of global warfare.

3.1. Historiography and Document Criticism

The primary method of this study is the exploration of original archival sources from multi-national repositories. To clarify the "footprints" of the branches in Saigon, Hanoi, Haiphong, and particularly Tokyo, the research focuses on archives from the French National Overseas Archives (ANOM). These documents include annual reports (Rapports annuels), correspondence between branch managers and the Board of Directors in Paris, and minutes of confidential meetings regarding exchange rate policies. According to Marc Meuleau (1990), these records contain the "genetic code" of institutional strategy, helping us understand how branches maintained a physical presence even when political power was faltering. Rigorous document criticism is applied to distinguish between public propaganda reports and internal memoranda reflecting the reality of the financial crisis in interactions with the Japanese military.

3.2. Spatial Approach and Historical Geography

Unlike pure economic studies, this paper applies a spatial approach to analyze the significance of branch locations. The placement of branches at vital transportation nodes like Haiphong (seaport) or Hanoi (political center) was not accidental. The research utilizes historical maps and wartime trade network diagrams to demonstrate that each branch served as a financial "outpost." Duong To Quoc Thai (2021) argues that analyzing the spatial "footprints" of the BIC allows us to witness the shift of the economic

focus from the West (France) toward the East (Japan). This method helps materialize the concept of "interaction" not just as paperwork but as the physical presence of capital in strategic territories.

3.3. Institutional and Social Network Analysis

The study adopts network theory to decode multilateral interactions. During 1940–1945, BIC branches no longer operated along a simple vertical axis from Paris but became network nodes within a complex ecosystem involving Japanese banks (Yokohama Specie Bank), rubber syndicates, and military administrations. By mapping these interactions, the research can pinpoint how the BIC performed its role as a payment intermediary. Yasuo Gonjo (2018) indicates that network analysis helps clarify the "gray areas" in Franco-Japanese financial collaboration, where BIC branches were simultaneously tools of occupation and active agents protecting French capital interests.

3.4. Historical Comparative Method

To evaluate the specific characteristics of BIC branches in Vietnam, the research conducts comparisons with BIC branches in other territories (such as Pondichéry or Djibouti) and with the presence of Japanese banks in Southeast Asia. This comparison highlights the unique interaction model in Indochina—where two administrations (French and Japanese) coexisted. This method confirms that interactions at Vietnamese branches were characterized by a unique "coerced collaboration." As Geoffrey Gunn (2014) emphasized, cross-regional comparison helps us escape a localized perspective to see the broader picture of the collapse of the old colonial financial order before the new Japanese order.

3.5. Quantitative Data Collection and Processing

Despite the focus on "footprints and interactions," the research utilizes quantitative data regarding account balances, currency issuance at each branch, and Yen/Piastre exchange rates to demonstrate interaction intensity. This data is extracted from balance sheets for 1940–1945 available in the author's Google Drive. Data processing is conducted through comparative tables to indicate the decline in actual assets and the increase in nominal debts. This provides empirical evidence to support arguments regarding the weakening power of BIC branches under Japanese military pressure. All aforementioned methods are strictly integrated to ensure objectivity, scientific rigor, and academic depth for the paper.

4. RESULTS AND DISCUSSION

4.1. MAPPING THE "FOOTPRINTS": THE PHYSICAL AND STRATEGIC PRESENCE

The presence of the Banque de l'Indochine (BIC) in Vietnam during the 1940–1945 period was defined not only through balance sheets but also through robust physical "footprints" in vital urban centers. Analyzing this network of branches reveals a sophisticated strategy of spatial occupation, where each BIC building served as both a symbol of French colonial architecture and a strategic "node" within a system of multilateral interactions with the Japanese military and local authorities. In the context of war, these footprints transformed from pure commercial hubs into financial fortresses, where life-and-death negotiations regarding monetary sovereignty took place.

Firstly, the "footprint" in Cochinchina, centered on the Saigon branch, acted as the nucleus of the entire system. Strategically located near the Port of Saigon and administrative headquarters, this branch not only managed capital flows into rubber plantations but also coordinated the largest military expenditure advances for Japan. Marc Meuleau (1990) observes that the massive and fortified architecture of the Saigon branch was a message of the eternal presence of French capital, even when military power was faltering. During 1940–1945, this branch became the primary point of interaction with Japanese banks like the Yokohama Specie Bank to process forced rice export transactions. The Saigon footprint thus took on the character of a colonial "financial capital," where every fluctuation in the Pacific theater was reflected through exchange activities at its counters.

Secondly, the footprints in Tonkin and Annam, represented by the branches in Hanoi, Haiphong, Vinh, and Tourane (Da Nang), exhibited a presence characterized by resource and political control. The Hanoi branch, situated adjacent to the Governor-General's Palace, was the hub of political interaction, where Piastre policies were debated between the BIC and Vichy officials. Meanwhile, the Haiphong footprint served as a logistical gateway. Haiphong was where Japanese troops landed and established transportation checkpoints; consequently, the BIC branch there became a direct interaction "node" with the Japanese military logistical apparatus. Duong To Quoc Thai (2021) points out that maintaining branches in port cities and administrative centers allowed the BIC to control the lifelines of the colonial economy, turning these buildings into effective geopolitical observation posts for the Board of Directors in Paris.

A breakthrough in the BIC's "footprint" strategy was the establishment of the Tokyo branch in 1942. This was a highly symbolic and pragmatic footprint in the history of the institution. While communication with metropolitan France was severed and Indochina fell into Japan's orbit, a direct presence in Tokyo created an official interaction channel with the Bank of Japan. Yasuo Gonjo (2018) argues that the Tokyo branch was a strategic "buffer zone," preventing the BIC from becoming a completely passive entity. The Tokyo presence allowed the BIC to monitor changes in Yen policy and perform financial offset operations to protect assets in Indochina. This was a calculated expansion of its footprint, transforming the BIC from a colonial bank into an international actor capable of direct dialogue with the Japanese Empire at its center of power.

The physical presence of BIC branches also created a specific "interaction space" with indigenous elites and colonial syndicates. BIC buildings were not only places for monetary transactions but also hubs for information and power accumulation. Geoffrey Gunn (2014) emphasizes that the "architecture of power" of BIC branches created a psychological and economic barrier for the indigenous population, while affirming the BIC's monopoly in deciding the financial fate of the territory. In 1940–1945, despite Allied bombings, these branches remained operational, evidencing extreme institutional resilience.

However, this presence also brought challenges regarding security and sovereignty. After March 9, 1945, these "footprints" were directly occupied by the Japanese military, turning financial spaces into military command centers or supply depots. This physical occupation marked the total rupture of Franco-Japanese exchange interactions and inaugurated the collapse of the colonial financial order. The study of the BIC's "footprints" during this period shows that during wartime, the bank's physical space was no longer a neutral zone but became a front for power conflicts. In summary, the network of BIC branches in Vietnam and Tokyo during 1940–1945 was a strategic map of survival, where each footprint left profound consequences for the post-war economic structure.

4.2. INSTITUTIONAL INTERACTIONS: BIC, THE VICHY REGIME, AND THE JAPANESE MILITARY

During the 1940–1945 period, the institutional interactions of the Banque de l'Indochine (BIC) shifted from a unilateral governance model to a complex and high-risk system of multilateral interactions. The Japanese military presence in Indochina created a "power triangle" between the BIC, the Vichy regime, and the Japanese military command. In this relationship, the BIC acted not only as a bank of issue but also as a financial-diplomatic entity, skillfully navigating between mandates from the Vichy government in France and the practical demands of the Japanese military on the ground. These interactions evidence the effort to preserve finance capital while facing extreme political and military coercion.

Firstly, the interaction between the BIC and the Vichy regime was characterized by a survival alliance fraught with tension. The Vichy government, under pressure from Nazi Germany and the Japanese threat in the Far East, utilized the BIC as a tool to purchase peace. Through economic treaties signed in 1941, Vichy forced the BIC to extend credit lines to Japan. Marc Meuleau (1990) points out that BIC administrators in Paris and Saigon frequently found themselves in a dilemma: obligated to comply with Vichy decrees to maintain legal status, yet seeking ways to delay disbursements to protect the bank's gold and foreign exchange reserves. This interaction shows that the BIC was not a mere "puppet" of Vichy but an entity with relative autonomy, always striving to balance political obligations with financial safety.

Secondly, the interaction between the BIC and the Japanese military was a process of "coerced negotiation." The Japanese military did not nationalize the BIC immediately but chose to co-opt it through complex payment mechanisms. This interaction occurred primarily through providing Piastres in exchange for non-convertible "Special Yen." Yasuo Gonjo (2018) argues that Japan established a strict surveillance system at BIC branches, where Japanese military officers worked directly with French branch managers. This interaction went beyond bookkeeping to include strategic battles over exchange rates. The BIC employed sophisticated professional expertise to slow the flow of capital to Japan, viewing it as a form of silent "financial resistance" to protect the Piastre's value in Indochina.

Thirdly, these interactions were influenced by the role of Japanese banks, particularly the Yokohama Specie Bank (YSB). The YSB served as a technical bridge between Japan's military ambitions and the BIC's financial infrastructure. The BIC-YSB interaction during 1940–1945 is a classic example of institutional collaboration during wartime. These two banks established a clearing mechanism to process import-export transactions between Indochina and Japan. According to Duong To Quoc Thai (2021), the BIC-YSB interaction created a financial "buffer zone," maintaining minimal trade flows while simultaneously serving as a channel for Japan to drain Indochina's economic resources. The footprint of this interaction was the massive Yen-denominated debt that the BIC carried after 1945.

Furthermore, these institutional interactions carried a strong spatial dimension through the presence of the Tokyo branch. Opening the Tokyo office in 1942 created a direct interaction channel with the Japanese Ministry of Finance, somewhat detached from the military apparatus in Indochina. This allowed the BIC to conduct high-level negotiations to protect the assets of French shareholders. Geoffrey Gunn (2014) emphasizes that the Tokyo branch was a "strategic interaction node" that helped the BIC maintain its international standing amidst isolation. Presence at the center of Japanese power showed that the BIC proactively internationalized its interactions to adapt to the Greater East Asia order.

However, the fragile balance in these interactions shattered completely after the March 9, 1945 coup. When Japan directly occupied BIC branches, treaty-based institutional interactions were replaced by brutal military mandates. French directors were imprisoned or neutralized, and the BIC became a tool serving the Japanese military's urgent cash needs. In summary, the institutional interactions between the BIC, the Vichy regime, and the Japanese military during 1940–1945 represent a dramatic chapter in financial history, where the lines between collaboration, coercion, and survival became blurred. These interactions not only shaped the fate of a bank but also left profound implications for Vietnam's economic and monetary structure in the following years.

4.3. SPATIAL INTERACTIONS AND RESOURCE EXTRACTION NETWORKS

During the 1940–1945 period, the presence of the Banque de l'Indochine (BIC) in Vietnam extended beyond its headquarters to radiate through a system of complex spatial interactions linked to strategic resource extraction networks. Analyzing the "footprints" of the BIC during this era requires a perspective that spans from financial centers to raw material zones – where branches functioned as "regulators" of capital flows to serve the demands of the Greater East Asia Co-Prosperity Sphere. These spatial interactions demonstrate the forced integration of the Indochinese economy into the Japanese war machine via French financial infrastructure.

The primary focus of this interaction network was the link between the Saigon branch and the "rubber spaces" of Cochinchina and Cambodia. Rubber was a top-tier strategic resource craved by Japan. The BIC not only provided credit to massive estates like Michelin or Terres Rouges but also established a rigorous spatial interaction process to monitor procurement and exports. According to Duong To Quoc Thai and To Thuy Duong (2026), the BIC Saigon branch functioned as a coordination hub where output information from plantations was converted into foreign exchange credit limits. This interaction created a closed "extraction network," where resources were physically moved from rubber forests to the Port of Saigon, while corresponding capital flows were managed by the BIC to ensure minimal interests for French capital amidst Japanese requisition pressure.

The second focus was the interaction between the Haiphong branch and the mineral extraction network, particularly coal in the Quang Ninh mining region. Haiphong was not just a commercial "footprint" but

a vital spatial node connecting raw material zones with Japanese naval fleets. The BIC Haiphong branch interacted closely with the Société Française des Charbonnages du Tonkin (SFCT) to maintain mining operations under wartime conditions. Marc Meuleau (1990) argues that the BIC's presence in mining regions and seaports created a "financial corridor" that protected French heavy industrial infrastructure from direct Japanese management. However, this interaction also meant the BIC had to accept the role of payment intermediary for massive coal orders to Japan, turning Vietnam's mineral resources into "pawns" in geopolitical bargaining.

Thirdly, this spatial interaction network expanded to rice-producing regions, where the BIC branches in Hanoi and Saigon interacted with procurement syndicates to satisfy Franco-Japanese "rice treaties." Geoffrey Gunn (2014) emphasizes that the BIC's provision of capital for forced procurement activities created a spatial rupture between production zones and domestic consumption areas. Rice was siphoned toward port warehouses under BIC exchange control, leading to artificial scarcity and the impoverishment of the indigenous peasantry. This spatial interaction remains a dark chapter in the BIC's history, as the bank—wittingly or unwittingly—became a link in the logistical network that pushed Northern Vietnam into famine.

Furthermore, Institutional Dependency theory (North, 1990) helps explain how BIC branches created an interaction network encompassing small and medium enterprises. In localities like Vinh or Tourane (Da Nang), the BIC's presence created financial "spheres of influence," where indigenous businesses were forced to interact with the BIC to obtain foreign currency or short-term credit. However, Yasuo Gonjo (2018) points out that this network was highly discriminatory, as the BIC prioritized protecting network "nodes" owned by the French or Japanese firms (such as Mitsui or Mitsubishi). This led to a fragmented economic spatial structure: a modern, war-priority network tied to the BIC and a neglected indigenous livelihood economy.

Finally, the collapse of these spatial interaction networks after March 1945 left a severe legacy. When Japan occupied all branch "nodes," the resource extraction network lost its financial coordination brain. The paralysis of the BIC led to payment stagnations for plantations and coal mines, causing production chaos. Phan Ha Uyen (1987) evaluates that the legacy of these extraction networks was an economy drained of labor and resources, with distorted financial footprints. In summary, Section 4.3 clarifies that BIC branches did not exist in isolation; they were essential components of a vast spatial interaction network where Vietnam's natural resources were transformed into tools for global imperial ambitions during World War II.

4.4. THE TOKYO BRANCH: A STRATEGIC INTERACTION NODE

The establishment of the Banque de l'Indochine (BIC) branch in Tokyo in 1942 was not merely a physical expansion of its network but the creation of the most critical "strategic interaction node" in the history of the institution. Amidst the total severance of communications between Indochina and metropolitan France due to the Allied blockade, the Tokyo branch became the sole "bridge" that allowed the BIC to maintain its legal existence and protect French capital interests at the very heart of the Japanese Empire's power. This serves as a classic example of institutional resilience and the BIC's extraordinary geopolitical adaptability during the "volatile years."

Firstly, functionally, the Tokyo branch acted as the direct exchange representative between the BIC and the Bank of Japan. Prior to this branch, all payment transactions between Indochina and Japan had to pass through intermediary banks or risky temporary agreements. Yasuo Gonjo (2018) points out that a direct presence in Tokyo allowed the BIC closer access to Yen policy decisions and Japanese Ministry of Finance regulations. Interaction at the Tokyo "node" enabled the BIC to monitor the flow of the "Special Yen" and perform clearing operations for Franco-Japanese economic treaties. Instead of passively receiving orders from the Japanese military command in Saigon, the BIC, through its Tokyo branch, was able to negotiate at a governmental level, creating a financial survival space based on formal diplomatic rules.

Secondly, the Tokyo branch was a strategic "observation post" that helped the BIC monitor interactions between Japan and the Greater East Asia Co-Prosperity Sphere. By being present in Japan, the BIC

could gather vital economic intelligence regarding inflation in the Japanese homeland and other occupied regions. Marc Meuleau (1990) argues that this branch functioned as an information "buffer zone," assisting the BIC Board of Directors (then temporarily split between Paris and Indochina) in making timely decisions regarding reserve adjustments. Interaction in Tokyo was not merely technical banking but deeply political, where the BIC demonstrated "technical collaboration" with Japan in exchange for preserving its privilege to issue the Piastre in Indochina.

Thirdly, the presence of the Tokyo branch created a multilateral interaction network with Japanese financial conglomerates (Zaibatsu). While branches in Vietnam, such as Saigon or Haiphong, interacted with branches of Mitsui or Mitsubishi at a field level, it was the Tokyo branch where framework agreements on credit and investment were signed. Duong To Quoc Thai (2021) emphasizes that the Tokyo branch transformed the BIC from an "occupied entity" into a valuable "financial partner" in the eyes of the Japanese economic elite. This interaction helped protect French assets in Indochina from forced nationalization, as Japan still required the BIC as a professional tool to operate a colonial economy already deeply integrated with the French financial system.

Furthermore, the Tokyo branch was an intersection for interactions with other international banks still operating in Japan or neutral zones. According to Geoffrey Gunn (2014), despite being limited by the war, the BIC's presence in Tokyo kept the "flame" of French capital from being entirely extinguished in the Far East. This was a strategic footprint that allowed the BIC to prepare for the French return after the war. Maintaining operations in Tokyo until 1945 evidences the BIC's persistent negotiation capacity, where they accepted a superficial collaboration to safeguard the institutional core.

However, the Tokyo "node" also brought significant risks. As the Allies tightened their grip and Japan fell into financial exhaustion, pressure on the Tokyo branch multiplied. Japan coerced the branch into accepting massive advances in paper Yen in exchange for the right to continue operations. In summary, the Tokyo branch was a unique entity, representing the intersection of finance, diplomacy, and warfare. It was not just a bank office but a symbol of the Banque de l'Indochine's resilience—a strategic footprint that helped the institution navigate the darkest hours of history to survive and continue influencing Vietnam's post-war economy.

4.5. THE DISRUPTION OF INTERACTIONS: POST-MARCH 1945 CONSEQUENCES

The March 9, 1945, coup by the Japanese military in Indochina was not merely a political-military event but an "institutional shock" that completely dismantled the interaction network that the Banque de l'Indochine (BIC) had meticulously maintained since 1940. This event marked the transition from a state of "coerced collaboration" to "direct occupation" and "institutional neutralization." As the treaty-based interactions between the BIC, the Vichy regime, and Japan ruptured, financial and economic consequences radiated outward, creating an inflationary black hole and a fragmentation of monetary power unprecedented in modern Vietnamese history.

Firstly, the disruption of interactions was most evident through Japan's seizure of physical autonomy at BIC branches. Immediately following the night of March 9, Japanese troops blockaded BIC headquarters in Saigon and Hanoi, arrested French directors, and seized control of all treasuries. Marc Meuleau (1990) describes this as the end of the era of "paperwork interaction," replaced by "gunpoint interaction." This physical occupation severed the communication lines between branches in Vietnam and the strategic branch in Tokyo, paralyzing the BIC's ability to regulate foreign exchange. The immediate consequence was an absolute loss of market confidence in the Piastre, as the bank of issue could no longer guarantee its financial commitments.

Secondly, the collapse of the clearing mechanism between the BIC and Japanese banks such as the Yokohama Specie Bank (YSB) caused severe stagnation in resource extraction networks. As analyzed in section 4.3, rubber plantations and coal mines operated based on BIC credit lines. When institutional interaction ruptured, the flow of capital from the BIC to these enterprises was blocked. Yasuo Gonjo (2018) argues that although Japan captured the vaults, it lacked the professional expertise to operate the complex French banking system. Consequently, resource extraction networks fell into chaos, production

stagnated, and thousands of indigenous workers became unemployed, accelerating the social crisis that led to the famine.

Thirdly, this disruption created a "monetary power vacuum." To meet urgent military expenditure needs without the BIC's cooperation, the Japanese military forced indigenous staff or coerced French managers to print Piastre banknotes indiscriminately without any collateral. Duong To Quoc Thai (2021) emphasizes that the volume of currency issued during the final five months of Japanese occupation (March to August 1945) far exceeded the total issuance of many previous years combined. The broken interaction transformed the Piastre from an international exchange tool into literal "scrap paper," causing hyperinflation, devastating the population's purchasing power, and paralyzing formal commercial transactions.

The spatial consequences were equally severe. The fragmentation between urban areas (where Japan occupied the BIC) and rural areas (where the Viet Minh movement was gaining strength) created two separate financial worlds. Geoffrey Gunn (2014) points out that the disruption of BIC interactions facilitated the emergence of "resistance currencies" and various forms of barter trade. The BIC's "footprint" in smaller provinces like Vinh or Tourane was nearly erased or replaced by a Japanese military administration primarily concerned with requisitioning commodities rather than maintaining a credit system. This completely eroded the colonial economic structure that France had built over 70 years.

Furthermore, from Douglass North's (1990) institutional perspective, the events following March 1945 demonstrate that when "rules of the game" are broken by violence, transaction costs become infinite. Interactions between the BIC and indigenous elites—already tenuous—were now entirely severed. A segment of the indigenous bourgeoisie that had relied on the BIC for capital accumulation witnessed their wealth evaporate alongside the currency's devaluation. This disruption was not just the failure of a bank but the collapse of a socio-economic order of which the BIC was a pillar.

Finally, this disruption of interactions left an incredibly complex post-war legacy for the Government of the Democratic Republic of Vietnam following the August Revolution. Upon taking over BIC branches, the revolutionary government inherited not only empty buildings but also an economy ruined by the erroneous monetary policies of Japan during its direct occupation. Phan Ha Uyen (1987) evaluates that the consequences of the post-March 1945 disruption were the greatest burden the independent economy had to bear, forcing the nation to build an entirely new financial system from the ruins. In summary, the disruption of the BIC's interactions after March 1945 was the inevitable end of a colonial financial institution when it could no longer mediate between imperial powers, leaving deep scars on Vietnam's socio-economic map.

5. CONCLUSION AND RECOMMENDATIONS

The research on the presence and interactions of the Banque de l'Indochine (BIC) branches in Vietnam during the 1940–1945 period has opened a new perspective on the role of financial institutions within the context of global warfare. By analyzing physical "footprints" and multilateral interaction networks, the study confirms that the BIC was not merely a bank of issue but a complex geopolitical entity acting as a central link in the confrontation and collaboration between colonial France and Imperial Japan. The following are the conclusions derived from the study and recommendations for future orientation:

5.1. Conclusions

Firstly, the BIC's "footprints" in Vietnam were strategic and durable, transcending conventional economic factors. The presence of branch buildings in Saigon, Hanoi, and Haiphong served not only as architectural symbols of power but also as "financial fortresses" that helped maintain French sovereignty within an occupied space. The establishment of the Tokyo branch in 1942 was a breakthrough move, proving that the BIC proactively internationalized its interactions to survive. The research concludes that this extensive branch network prevented the BIC from total collapse amidst the expansion of the Greater East Asia Co-Prosperity Sphere.

Secondly, the institutional interactions between the BIC, the Vichy regime, and the Japanese military were a dramatic process of "negotiation from a position of weakness." The BIC skillfully utilized banking expertise and issuance privileges as a form of "soft power" to delay financial expropriation by Japan. However, this interaction was double-edged: while protecting French capital interests, it simultaneously turned the BIC into a tool for siphoning Vietnam's rice, rubber, and mineral resources to fuel the war. Marc Meuleau (1990) and Yasuo Gonjo (2018) were correct in identifying the BIC during this period as a "bank of compromise," where the boundary between preservation and collaboration became extremely blurred.

Thirdly, the disruption of interactions after March 9, 1945, was a tragic milestone, marking the collapse of the old colonial financial order. Japan's direct occupation of branches and the forced indiscriminate printing of the Piastre completely destroyed the currency's value and market confidence. The result was an exhausted economy, hyperinflation, and the total rupture of resource supply chains. The study affirms that the BIC's legacy in this period consists not only of massive buildings but also a costly lesson on the dangers of a financial system being militarized and stripped of its autonomy.

5.2. Recommendations

Based on the research results, the author proposes the following recommendations:

1. **Academic and Archival:** Efforts should be increased to link historical sources between Vietnam, France, and Japan to more fully reconstruct the clandestine capital flows within the BIC network. Specifically, the records of the Tokyo branch need deeper exploration to understand high-level negotiations between the BIC and the Bank of Japan. Digitizing the accounting ledgers of the Saigon and Haiphong branches from 1940–1945 will provide invaluable quantitative data for economic history research.
2. **Financial History Education:** The research findings on the "footprints" and "interactions" of the BIC should be integrated into curricula regarding banking history and international relations. Understanding how a bank operates during wartime will provide students and researchers with deeper insights into the importance of national financial security and monetary sovereignty.
3. **Heritage Preservation:** The BIC branch buildings in Vietnam (such as the current State Bank headquarters) should be cherished and preserved not just as architectural monuments but as "historical witnesses" to a volatile period of the economy. Historical markers or miniature museums should be established within these buildings to educate the public on their role during World War II.
4. **Contemporary Policy Planning:** The lesson from the collapse of the BIC network after 1945 reminds modern policymakers of the need to build a banking system with high resilience against global geopolitical shocks. Diversifying international interaction relationships and maintaining monetary autonomy are key factors in protecting the economy under any circumstances.

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**TYPOLOGY AND ARTISTIC CHARACTERISTICS OF MEDIEVAL CERAMIC
ARTIFACTS OF NAKHCHIVAN**

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ABSTRACT

This study focuses on the typology and artistic characteristics of medieval ceramic artifacts discovered during archaeological excavations in the Nakhchivan region. Throughout history, Nakhchivan has been located at the crossroads of important trade and cultural routes connecting the Caucasus, Anatolia, and the Near East. This strategic position significantly influenced the region's material culture, particularly the development of ceramic production. The ceramic findings obtained from medieval archaeological sites represent a rich group of artifacts produced for both utilitarian and decorative purposes. Within the scope of this research, the ceramics have been typologically classified based on their forms, fabric composition, production techniques, functional purposes, and decorative features. The typological analysis reveals the widespread presence of various ceramic forms, including pots, bowls, dishes, jugs, jars, and storage vessels. Some of these vessels were produced for everyday use and therefore display plain surfaces, while others are glazed and decorated with elaborate ornamental designs. The decorative motifs observed on the medieval ceramics of Nakhchivan mainly include geometric patterns, vegetal ornaments, and stylized animal representations. Various decorative techniques such as incision, relief, painting, and glazing were commonly applied. Glazing in shades of green, brown, yellow, and turquoise is particularly characteristic of these ceramics and reflects the aesthetic preferences of the period. These features demonstrate that Nakhchivan ceramics were influenced not only by local craft traditions but also by cultural and commercial contacts with different regions of the Islamic world. In conclusion, medieval ceramics from Nakhchivan provide valuable information about the region's economic life, daily culture, and artistic traditions. The typological and artistic analysis of these ceramic materials plays an important role in understanding the material culture of medieval Nakhchivan as well as its cultural and economic interactions with neighboring regions.

Keywords: Nakhchivan, Middle Ages, ceramics, typology, decoration, archaeology.

Introduction

The territory of the Nakhchivan Autonomous Republic has been one of the highly developed centers of craftsmanship since ancient times. Its geographical position—located at the crossroads of important trade routes—and the richness of local raw materials enabled the formation and improvement of various artisanal fields, particularly pottery. This article aims to provide a typological classification of Nakhchivan's medieval ceramic products, determine their production technology, artistic features, and role in the region's cultural life. The chronological framework of the study covers the 3rd–17th centuries, while the geographical scope encompasses the territory of Nakhchivan.

1. Chronological Development of Ceramic Products

Several chronological stages can be distinguished in the development of Nakhchivan's medieval ceramics:

3rd–7th centuries (Early Middle Ages) — Simple, unglazed ceramics predominate. Forms are simple, decorative elements are primitive, mainly geometric lines and incised patterns. Pink and red ceramics are widespread.

8th–11th centuries — A rise in ceramic production begins. Engobed ceramics become widespread, and the potter's wheel improves. Burnished black ceramics hold a special place. Decoration becomes enriched with plant motifs (Karimov, 2018).

12th–14th centuries (Flourishing period) — The "golden age" of Nakhchivan's glazed ceramics. High-quality glazed vessels, polychrome painting, complex compositions, and epigraphy are widely applied. During this period, Nakhchivan ceramics gained international fame.

15th–17th centuries (Decline and continuation of traditions) — The quantity of glazed ceramics decreases, forms become simpler, and unglazed and engobed ceramics predominate. However, local traditions are not completely lost and continue to exist as folk pottery.

2. Morphological-Functional Classification of Ceramic Products

Nakhchivan's medieval ceramic products are divided into the following main groups according to their morphological features and functional purpose:

Kitchenware — This group includes vessels intended for cooking food. Pots (height 15-40 cm, diameter 20-50 cm) are made from fire-resistant clay-based raw materials, with thick walls (1-1.5 cm), rough surfaces, and no decoration. Their characteristic features are burning marks and a layer of soot on the lower part of the body. Jugs — vessels of various volumes (0.5-5 L) for carrying liquids, having one or two handles and various shaped rims. The morphology of medieval Nakhchivan kitchenware accurately reflects the food culture, economic lifestyle, and culinary traditions of the local population.

Tableware — This group includes various shaped and sized vessels such as pots, plates, bowls, large bowls, cups, goblets, and glasses. Tableware differs from kitchenware by having thinner walls (0.3-0.8 cm), being high-quality, burnished, and sometimes glazed. Their outer surface is covered with a layer of engobe, later decorated with geometric, plant, and epigraphic patterns. One of the main features in the classification of these vessels is the shape of the rim (smooth, wavy, sloping, flared) and the depth of the bowls and plates.

Storage Vessels — Jars and large pithoi (reaching a height of 50-150 cm) are intended for storing products such as grain, flour, wine, oil, and water. These vessels have thick walls (2-4 cm), are heavy, durable, and have a large volume (50-500 L). The rims of the jars are of various shapes (circular, oval, rectangular); some have a neck part (in water jars). Decoration of storage vessels typically uses only belt-shaped patterns, button-like protrusions, and fingerprint impressions.

Ritual and Ceremonial Vessels — This group includes incense burners, lamp holders, votive vessels, and miniature vessels used for special religious and ceremonial purposes. They are finely crafted, have rich artistic decoration, and feature glazed or high-quality burnished surfaces. Some ritual vessels have epigraphic inscriptions, religious motifs, and astral symbols (depictions of the sun, stars, moon) engraved on them.

3. Technological Classification of Ceramic Products

Ceramic products are also divided into several groups according to production technology:

Simple (Unglazed) Ceramics — Used mainly for producing kitchenware and large storage vessels. The surface of this type of ceramic product is unglazed, with only burnishing or sometimes engobing applied. Firing temperature ranges between 700-850°C.

Engobed Ceramics — Produced by applying a thin clay layer (engobe) to the surface. This method allowed changing the surface color, improving water resistance, and creating a base for decoration. The engobe was white, red, or brown (Khan-Magomedova, 2012).

Glazed Ceramics — Used for producing high-quality products. The glaze layer creates a glassy, shiny coating on the vessel's surface, making it waterproof and expanding decorative possibilities. Medieval Nakhchivan glazed ceramics are characterized by shades of white, green, brown, blue, turquoise, and purple. In the 12th–14th centuries, Nakhchivan glazed ceramics ranked among the highest achievements of the Near East in terms of technological and artistic qualities.

Burnished Ceramics — Vessels with a surface burnished with special tools, giving a shiny appearance but without glaze. This technology was most widespread in the 11th–13th centuries and was later replaced by glazed ceramics (Halilov, 2025: 057) .

4. Features of Craft Technology

Nakhchivan potters primarily used raw materials from local clay deposits — in the valleys of the Nakhchivanchay and Alinjachay rivers, as well as deposits around Duzdag, Julfa, and Ordubad. Additives such as sand, lime, often chamotte, chaff, and sometimes very finely crushed shell (or often crushed pottery shards) were mixed into the clay. These additives aimed to regulate the clay's fire resistance, plasticity, and shrinkage coefficient during drying and firing. Nakhchivan medieval ceramics were mainly made by hand and using a potter's wheel. Simple large vessels (pithoi, large jars) were made by hand using the coil-building method — sequentially placing and smoothing clay coils. Small and medium-sized vessels (jars, pots, jugs) were made on a fast potter's wheel. Using the wheel ensured the precision of the symmetrical form, uniformity of wall thickness, and high productivity. Firing was carried out in pottery kilns (ovens). Nakhchivan's medieval kilns are of one, two, and three-chamber types. The most widespread type is the two-chamber kiln — a lower chamber for burning fuel (firebox) and an upper chamber for loading products (firing chamber). "The construction of medieval Nakhchivan pottery kilns allowed achieving high temperatures (1000-1100°C) and maintaining the temperature regime for a long time." Different types of ceramics required different firing temperatures: simple kitchenware — 600-800°C, engobed ceramics — 800-900°C, glazed ceramics — 950-1050°C, high-quality glazed ceramics — 1050-1100°C.

The artistic decoration of Nakhchivan medieval ceramics is extremely rich. The main types of decoration are:

Incised (Sgraffito) method — Patterns are incised on the engobe layer with a sharp-pointed tool. This method has been widely applied since ancient times. Patterns were linear, geometric, and spiral-shaped.

Stamping method — Impressing patterns onto the wet clay of the vessel using stamps of various shapes. Circular, triangular, rhombic, and sometimes zoomorphic stamps were used.

Painting — Painting patterns on the glaze with special paints (based on powdered oxides of metals). The most used colors are: turquoise (copper oxide), dark brown (manganese oxide), green (iron oxide), blue (cobalt). From the 14th century onwards, the "minai" technique — painting colored patterns over the glaze and refiring at a low temperature (600-700°C) — became widespread in Nakhchivan.

Ornamental Motifs — The following motifs predominate in Nakhchivan ceramics:

Geometric motifs — triangles, rhombuses, squares, circles, swastikas, meanders, wavy lines. These motifs are based on ancient traditions.

Plant motifs — palmettes, rosettes, vines, leaves, flowers, branches, stylized tree depictions. Widespread from the 11th–12th centuries onwards.

Zoomorphic motifs — depictions of birds, fish, deer, goats. These motifs are relatively rare.

Epigraphic motifs — blessings written in Arabic script, building inscriptions, the owner's name, slogans. More widespread in the 12th–14th centuries. Writing blessing texts on ceramics also provided the vessel with a magical-apotropaic function.

Research reveals that, as in other regions of Azerbaijan, unglazed vessels were widely used in Nakhchivan during the 9th–11th centuries. From the 11th century onwards, glazed vessels were produced. In the 11th–13th centuries, the production of glazed ceramic items expanded greatly. The

surfaces of glazed vessels were covered with blue, green, yellow, brown, and other colors. Although some were plain, the majority were decorated with geometric, plant, and zoomorphic ornaments, reflecting the craftsmanship abilities and specific themes of the potters who made them. Although clay vessels from the Early Middle Ages differ from those of the previous period, they show similarities with those of the later period. This difference is felt more clearly not in the quantity of clay vessels but in their technology, especially their form. One of the main reasons most clay vessels date to the 9th–13th centuries is that, as in all regions of Azerbaijan (Orucov, 1989: 10), ceramic production in Nakhchivan was at a high level of development during that period. To substantiate our point, if we look at sources, we see that the development of pottery in Azerbaijan, which began in the 9th century, continued on an upward trajectory until the 12th–13th centuries. In the 13th century, pottery was at a high level (Jabiyev, 2003: 33). The widespread use of engobe and glaze in Nakhchivan during the 9th–13th centuries, as in all regions of Azerbaijan, was one of the greatest achievements of this period. Engobes created extensive possibilities for the artistic treatment of vessels. Therefore, the surfaces of both unglazed and glazed vessels from this period were worked with engobe as well as paint. Unlike glazed vessels, the surfaces of unglazed ones were decorated using incised lines, stamping, and carving methods. The surfaces of glazed vessels were decorated with a brush. The great variety of both glazed (engobed, faience, etc.) and unglazed vessels was due to their use for different purposes and their production by different artisans. Alongside Beylagan (Minkevich-Mustafaev, 1965: 149-160; Ibrahimov, 1965: 215), Ganja (Djafarzade, 1949: 134), Gabala (Ismizade, 1962: 54-57; Cəbiyev, Ramazanov, Huseynova, 1991: 28-29), Shabran (Dostiyev, 2001: 144-145), and other places, sufficient quantities of this type of archaeological material have been discovered from many medieval monuments in Nakhchivan. As in all Near and Middle Eastern countries and other regions of the South Caucasus, in Nakhchivan, an integral part of Azerbaijan, around Gamigaya, glaze obtained from both bright and colorless lead oxide was also widely used. Glaze made from lead oxide, when applied to the vessel's surface, strengthened the ceramic. By filling its pores, it prevented water absorption. It caused the ceramic to shine without changing its color. Patterns applied with lines or various colors under the glaze gave the vessel special beauty. Tableware was mainly covered with glaze. Open-shaped vessels (bowls, plates, salt cellars, etc.) were glazed mainly on the inside, while vessels with concealed interiors (jugs, lamps, etc.) were glazed on the outside. Some large-mouthed vessels were glazed on both sides. Bowls and plates constituted the main mass of artistic glazed vessels. Glazed vessels from the 9th–10th centuries were mainly made with engobe. Changes occurring in the making and coloring of vessels affected the area around Gamigaya, as in other regions of Azerbaijan, and glazed vessels of various colors were produced. Colors obtained from manganese oxide (chestnut color), copper oxide (green color), iron oxide (yellow color), cobalt oxide (blue color), and other metals were applied to the ceramic, giving the vessels special beauty. Many technical methods used in the production of glazed vessels, especially their artistic treatment, as well as geometric, plant, and zoomorphic ornaments, possessed characteristics common to contemporary archaeological sites of the Near East and the South Caucasus (Halilov, 2017: 50). The similarity in the decoration and form of the vessels was related to mutual economic-cultural ties. As a result of mutual economic-cultural ties, cultures influenced each other. Unlike the glazed ceramic items from the 9th–10th and 11th–13th centuries obtained from archaeological sites in Nakhchivan, vessels from the 14th–17th centuries have a thicker engobe coating applied somewhat carelessly. This aspect manifests itself more prominently in ceramic items from the second half of the 16th century to the 17th century. In ceramics from the 14th–17th centuries, alongside yellow ones, white engobe also became widespread. Their parallels have been discovered in Gabala (Ismizade, 1962: 54-57), Shamakhi (Djiddi, 1981: 418-419) and other places. As in other regions of Azerbaijan (Ramazanov, 1991: 29-30), brushing, sprinkling glaze powder on a moistened vessel, and other methods were used for applying glaze onto the surfaces of vessels discovered from archaeological sites in Nakhchivan. Although local potters benefited from Eastern culture in the production of glazed vessels, they also preserved aspects characteristic of the Azerbaijani ceramic school. As in other regions of Azerbaijan (Jabiyev, 2003: 103-106), clay vessels found from archaeological sites in Nakhchivan worked with green glaze dated to the 15th–16th centuries, and those glazed with brown glaze dated to the 17th century. In glazing plain vessels, green glaze was preferred, and blue, turquoise, and brown colors were also partially used.

Conclusion

Nakhchivan's medieval ceramic products are typologically divided into morphological-functional (kitchenware, tableware, storage vessels, ritual vessels) and technological (simple, engobed, glazed, burnished ceramics) groups. Each type has its own characteristics, production technology, and decorative elements. Nakhchivan potters demonstrated high professionalism in clay preparation, shaping, decoration, and firing. In the 12th–14th centuries, Nakhchivan glazed ceramics ranked among the most advanced achievements of the Near East in terms of technological and artistic qualities. Nakhchivan ceramics show both the development of local traditions and the existence of close cultural-economic ties with neighboring regions. This proves that in the Middle Ages, Nakhchivan was not only a political but also an important craft and cultural center. The research shows that Nakhchivan ceramics are an important source for the region's ethno-cultural history, economic ties, artistic taste, and religious-ethical values.

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**ARCHITECTURAL SOUND AS DATA: COMPUTATIONAL MODELS FOR MUSIC-DRIVEN
SPATIAL DESIGN**

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ABSTRACT

Treating sound as an active design variable rather than a post-design corrective has become increasingly important in contemporary architectural science. In music-oriented environments such as concert halls, worship spaces, performance theatres, and immersive cultural installations, spatial form, material configuration, and volumetric proportions directly shape acoustic perception and musical meaning. Traditional architectural acoustics has largely relied on empirical rules and deterministic formulas, such as reverberation time calculations, to evaluate sound performance after spatial decisions have already been made. While effective, these approaches are limited in their capacity to model complex, non-linear acoustic phenomena and to integrate music-specific characteristics into early design workflows. Recent advances in computational acoustics, data science, and parametric modeling enable a conceptual shift in which architectural sound is understood as data that can be captured, simulated, analysed, and embedded within generative design processes. This study examines architectural sound as a data construct and explores computational models that support music-driven spatial design. Drawing on current peer-reviewed literature in architectural acoustics, sound simulation, and computational design, the paper synthesizes methods that transform acoustic signals and performance metrics into actionable spatial parameters. Sound data, including impulse responses, frequency spectra, reverberation characteristics, and spatial diffusion patterns, are examined as inputs for computational workflows using wave-based simulation, finite-element modeling, and machine-learning-assisted prediction. The paper reviews existing research on performance-based acoustic design and identifies transferable modeling strategies that enable architects to align spatial morphology with musical intention. A structured methodological framework is proposed, outlining stages of acoustic data acquisition, computational processing, parametric translation, and design feedback integration. Through illustrative examples from concert hall research and immersive sound environments, the study demonstrates how music-driven acoustic data can inform architectural geometry, material distribution, and spatial organization. The paper concludes by discussing technical constraints, interdisciplinary challenges, and future research directions for embedding sound-as-data paradigms within architectural design education and professional practice.

Keywords: Acoustic simulation; Computational design; Music-driven architecture; Sound data

INTRODUCTION

Sound plays a fundamental role in shaping human spatial experience, particularly within environments designed for music, performance, and collective listening.



Human perception of space is inherently multisensory, yet sound remains one of the most influential and immersive components of spatial experience, capable of shaping emotional response, cognitive orientation, and social interaction. In architectural contexts, sound does not simply occupy space as a passive phenomenon; rather, it is actively transformed by architectural form through geometry, material composition, scale, and spatial configuration. Every surface, volume, and enclosure modifies sound through reflection, absorption, diffusion, and resonance, thereby contributing to how space is perceived and understood. In music-oriented architecture, such as concert halls, opera houses, sacred worship spaces, and contemporary immersive installations, acoustic behaviour becomes inseparable from architectural meaning, cultural identity, and performative intent. These spaces are not merely containers for sound but instruments in their own right, shaping musical expression and listener

experience through spatial design decisions. Historically, architectural acoustics has addressed the relationship between sound and space through analytical formulas, empirical measurements, and post-occupancy evaluations. Foundational approaches, including reverberation time calculations, clarity indices, and intelligibility metrics, have provided architects and acousticians with quantitative tools to assess acoustic performance. Such methods have been instrumental in establishing standards for acceptable acoustic conditions, particularly in performance and speech-oriented spaces. However, these approaches often operate within a corrective paradigm, where acoustic considerations are introduced after primary architectural decisions have already been made. As a result, sound is frequently treated as a technical constraint to be mitigated or optimized, rather than as an integral and generative driver of spatial form. This separation has limited the potential of architecture to fully engage with sound as a creative and expressive medium. Recent developments in architectural science and computational design have begun to challenge this paradigm, prompting a shift toward conceptualizing sound as data. Advances in digital signal processing, computational acoustics, and parametric modeling now enable designers to quantify sonic phenomena with unprecedented precision and resolution. Acoustic attributes such as frequency spectra, impulse responses, spatial diffusion patterns, and temporal decay can be captured, simulated, and analysed as datasets that inform design decisions throughout the architectural process. These technologies allow sound to be integrated directly into computational workflows, transforming it from a qualitative experience into a measurable and manipulateable design parameter. In parallel, research in music technology has expanded the analytical vocabulary for understanding sound, incorporating spectral features, temporal dynamics, and psychoacoustic metrics that describe how sound is perceived by listeners. This expanded framework creates new opportunities for cross-disciplinary integration between architecture, music, and computer science, enabling designers to align spatial form more closely with musical characteristics and perceptual outcomes. Music-driven spatial design extends beyond conventional acoustic optimization by recognizing that different musical traditions, genres, and performance practices demand distinct spatial qualities. Orchestral music, for example, often requires balanced reverberation and spatial envelopment to support harmonic richness, while choral performance depends on clarity and blend to articulate vocal textures. Spoken word and theatrical performances prioritize intelligibility and directional sound, whereas electronically mediated and immersive sound environments engage spatialization, movement, and dynamic modulation. These varied requirements highlight the inadequacy of one-size-fits-all acoustic solutions and underscore the need for flexible, context-sensitive design strategies. Computational models make it possible to simulate these diverse interactions at early design stages, allowing architects to explore how variations in geometry, volume, surface articulation, and material distribution influence musical perception before construction begins. Such approaches align closely with performance-based design paradigms in architecture, where measurable criteria, such as acoustic performance, environmental comfort, and energy efficiency, guide formal and spatial decisions. Despite these technological and theoretical advancements, the integration of sound as data into architectural workflows remains fragmented. In many design contexts, acoustic simulations are still conducted as isolated analyses, detached from the iterative and exploratory nature of architectural design. This separation limits the ability of designers

to respond creatively to acoustic feedback and discourages the use of sound as a generative design input. Furthermore, architectural education and professional practice often lack unified frameworks for translating complex acoustic datasets into spatial parameters that designers can intuitively manipulate within digital modeling environments. The technical complexity of acoustic data, combined with disciplinary silos between architects, acousticians, and music technologists, continues to hinder holistic integration. This gap underscores the need for systematic models that bridge architectural science, music acoustics, and computational methods. By reconceptualising architectural sound as data and embedding it within computational design processes, architects can engage more deeply with the sonic dimension of space. This paper addresses this need by examining architectural sound as data and exploring computational models that support music-driven spatial design. Through a synthesis of contemporary research and the proposal of a structured methodological framework, the study contributes to ongoing efforts to reposition sound from a corrective consideration to a generative architectural force capable of shaping form, experience, and cultural expression.

LITERATURE REVIEW

Architectural acoustics and sound modeling

Architectural acoustics has long sought to understand how spatial configurations influence sound propagation, distribution, and human perception within built environments. The discipline emerged from the recognition that sound behaviour is inseparable from architectural form and materiality, particularly in spaces intended for speech, music, and collective listening. Early foundational work by Wallace Clement Sabine established the first systematic quantitative framework for architectural acoustics by identifying the relationship between room volume, total absorption, and reverberation time. Sabine's reverberation equation provided a practical method for predicting how long sound persists in an enclosed space, forming the basis of modern acoustic design practices (Kuttruff, 2016). This work marked a turning point by transforming acoustics from a largely qualitative concern into a measurable scientific domain. Despite their enduring relevance, classical acoustic models such as Sabine's formula and its later refinements are inherently simplified. They assume diffuse sound fields, uniform material absorption, and geometrically regular enclosures—conditions that are rarely met in contemporary architecture. As architectural forms have become increasingly complex, featuring non-orthogonal geometries, layered surfaces, and hybrid material systems, traditional analytical models have shown limitations in accurately predicting acoustic behaviour. Empirical studies indicate that simplified models can deviate by more than 20-30% from measured reverberation times in irregular or highly articulated performance spaces, particularly at low frequencies where modal behaviour dominates (Kuttruff, 2016). These discrepancies highlight the need for more advanced modeling techniques capable of capturing spatial complexity and frequency-dependent phenomena. In response to these challenges, contemporary research in architectural acoustics increasingly relies on computational acoustics to achieve higher predictive accuracy and design relevance. Computational acoustics encompasses a range of numerical simulation techniques that model sound as a physical wave phenomenon interacting with architectural geometry and materials. Among these, wave-based methods, including finite-element methods (FEM), boundary-element methods (BEM), and finite-difference time-domain (FDTD) approaches, offer high-resolution representations of sound pressure fields and temporal behaviour (Sakuma & Otsuru, 2014). These methods solve the governing acoustic wave equations directly, allowing detailed analysis of diffraction, interference, and modal effects that are difficult or impossible to capture using classical statistical models. Finite-element and boundary-element methods are particularly valuable in the design and evaluation of performance spaces such as concert halls, opera houses, and worship environments, where acoustic quality is strongly influenced by spatial geometry. FEM subdivides the architectural volume into discrete elements and computes sound pressure values across the domain, while BEM focuses on boundary surfaces, reducing computational complexity for large volumes. These techniques enable precise modeling of frequency-dependent behaviour, early reflections, spatial diffusion, and energy decay, generating detailed datasets that describe how sound propagates and interacts with architectural form (Sü Gül et al., 2017). For example, FEM-based diffusion equation modeling has been successfully applied to monumental worship spaces to predict sound energy distribution with high correlation to measured data, achieving prediction accuracies exceeding 85% across mid-frequency bands (Sü Gül et al., 2017). Alongside wave-based approaches, ray-based and hybrid simulation techniques, such as geometric acoustics and image-source models, remain widely used due to their computational efficiency, especially for large and complex spaces. Ray-based models approximate sound propagation as rays reflecting off surfaces, making them suitable for simulating early reflections and directional energy flow in large halls. Hybrid approaches combine ray-based methods for high frequencies with wave-based solvers for low-frequency behaviour, providing a

balanced trade-off between accuracy and computational cost (Sakuma & Otsuru, 2014). These methods have become standard in professional acoustic simulation software used during architectural design stages. While computational simulations generate large volumes of acoustic data, including spatial sound pressure maps, impulse responses, reverberation curves, and clarity indices, this data is frequently treated as evaluative output rather than as an integrated design input. In many architectural workflows, simulations are conducted to verify compliance with acoustic targets after major design decisions have been made, rather than informing geometry generation or material selection from the outset. This post-evaluative use limits the potential of acoustic data to actively shape architectural form. Studies in performance-based design indicate that integrating simulation data earlier in the design process can reduce costly late-stage modifications by up to 40%, while also improving alignment between spatial form and acoustic intent (Oxman, 2017). The growing availability of high-resolution acoustic datasets and advanced visualization tools presents an opportunity to reposition sound modeling as a generative component of architectural design. When simulation outputs are embedded within parametric and algorithmic design environments, acoustic performance metrics can directly influence spatial configuration, surface articulation, and material distribution. Such integration supports iterative exploration and enables architects to engage with sound not merely as a constraint, but as a dynamic design parameter. This shift lays the foundation for treating architectural sound as data, capable of driving spatial decisions and fostering deeper alignment between architectural science, musical performance, and human perception.

Sound as Data in Computational and Generative Design

In computational design research, performance data increasingly functions as a primary driver of generative processes rather than as a secondary evaluative measure. Within this paradigm, architectural form emerges through iterative computation guided by measurable performance criteria embedded directly into design algorithms. Sound, when captured through impulse responses, spectral analysis, and psychoacoustic metrics, becomes a manipulateable dataset capable of influencing spatial geometry, material distribution, and surface articulation in real time (Rust et al., 2021). This approach aligns with broader trends in architectural science that treat environmental phenomena, such as daylight penetration, airflow dynamics, thermal comfort, and energy performance, as continuous data streams that inform algorithmic design decisions rather than static post-design checks. The treatment of sound as data is enabled by advances in acoustic measurement and signal processing technologies. Impulse responses provide time-domain representations of how sound behaves within a space, capturing reflections, decay rates, and spatial diffusion patterns. Spectral analysis decomposes sound into frequency components, revealing how architectural materials and geometries affect tonal balance and clarity. Psychoacoustic metrics, such as loudness, sharpness, clarity (C80), and spatial impression, translate physical sound measurements into perceptual indicators that reflect human auditory experience. When these acoustic descriptors are encoded numerically, they can be integrated into parametric and generative design systems alongside other performance variables (Blessner & Salter, 2007). This data-driven approach has profound implications for architectural form-making. In parametric environments such as Grasshopper and other visual programming platforms, acoustic datasets can be mapped directly to geometric parameters, enabling designers to explore how variations in form influence sonic outcomes. For instance, surface curvature, reflector placement, and volumetric proportions can be adjusted algorithmically in response to changes in predicted reverberation time or clarity indices. This method supports exploratory design processes where sound actively shapes space, rather than being accommodated after the fact. Research in performance-based design demonstrates that embedding environmental data into generative systems can improve overall design efficiency by enabling early-stage optimization and reducing the need for costly late-stage modifications (Oxman, 2017). Recent studies further demonstrate the feasibility of using machine-learning models to predict acoustic outcomes based on geometric and material parameters, significantly reducing reliance on computationally expensive physics-based simulations. Rust et al. (2021) developed a data acquisition framework that collects large numbers of acoustic impulse responses from architectural spaces and uses these datasets to train predictive models. Their results show that supervised learning algorithms can approximate key acoustic metrics with high accuracy once sufficient training data is available. In experimental evaluations, machine-learning models achieved prediction accuracies of over 80% for reverberation-related parameters compared to full wave-based simulations, while reducing computation time from hours to milliseconds (Rust et al., 2021). The efficiency gains associated with machine-learning-based prediction are particularly significant for iterative design workflows. Traditional wave-based simulations, such as finite-element or finite-difference time-domain methods, are computationally intensive and often impractical for real-time exploration of design alternatives. By contrast, trained surrogate models can provide near-instantaneous feedback,

allowing designers to test multiple geometric configurations during early conceptual stages. This capability supports real-time design iteration, where acoustic performance metrics update dynamically as the architect manipulates form. Studies in computational performance modeling suggest that such surrogate-based approaches can reduce total simulation workload by up to 70% in early design phases, without substantial loss of predictive reliability (Bilbao et al., 2022). Beyond efficiency, machine-learning models enable new forms of acoustic reasoning that extend beyond traditional deterministic frameworks. Data-driven approaches can capture complex, non-linear relationships between geometry, materials, and sound behaviour that are difficult to express analytically. For example, neural networks can learn interactions between multiple variables, such as surface roughness, material absorption spectra, and spatial volume that collectively influence acoustic perception. When combined with parametric design systems, these models support multi-objective optimization, balancing acoustic performance against other architectural criteria such as daylight access, structural efficiency, or energy consumption. This integrative capacity reflects a broader shift toward holistic, data-informed design methodologies in architectural science. Importantly, positioning sound as a predictive dataset also facilitates interdisciplinary collaboration between architects, acousticians, and computer scientists. Acoustic knowledge is no longer confined to specialist analysis reports but becomes embedded within shared computational platforms accessible to design teams. This democratization of acoustic insight enhances design literacy and supports more informed decision-making throughout the architectural process. Nevertheless, challenges remain, including the need for large, high-quality training datasets, the interpretability of machine-learning models, and the risk of over-reliance on data-driven predictions without adequate physical validation. Overall, the integration of sound as data within computational and generative design frameworks represents a significant evolution in architectural practice. By combining acoustic measurement, machine learning, and parametric modeling, architects can engage with sound as an active and predictive design variable. This shift not only improves efficiency and performance but also expands the creative potential of architecture, enabling spaces that respond dynamically to musical and auditory experience.

Music-driven spatial environments

Research on music-specific architecture consistently demonstrates that acoustic quality cannot be treated as an isolated technical parameter but must be understood as deeply embedded within cultural, performative, and perceptual contexts. The design of spaces for music, ranging from concert halls and opera houses to experimental sound installations, requires a synthesis of architectural form, material science, musical genre, and audience expectation. Seminal concert hall studies emphasize that spatial configuration plays a critical mediating role in musical clarity, intimacy, and emotional resonance, shaping how sound is perceived and interpreted by listeners (Beranek & Marshall, 2018). Rather than merely transmitting sound, architecture actively participates in musical meaning-making. Classical acoustic research has established that parameters such as reverberation time (RT), early decay time (EDT), clarity (C80), and lateral energy fraction (LF) significantly influence listener preference and performance conditions, particularly in symphonic and choral settings (Barron, 2010). For example, orchestral music tends to benefit from longer reverberation times (typically 1.8-2.2 seconds), while speech-oriented or rhythmically complex music demands greater clarity and shorter reverberation (ISO 3382-1, 2009). These findings reinforce the notion that “good acoustics” are genre-dependent and culturally situated, rather than universally fixed. Advances in architectural computation have significantly transformed how such acoustic objectives are addressed. Contemporary research increasingly employs computational acoustic modeling, parametric design tools, and ray-tracing simulations to optimize surface geometries, reflector placement, ceiling height, and spatial volumes. Software such as Odeon, CATT-Acoustic, and Pachyderm for Grasshopper allows architects and acousticians to test multiple design iterations before construction, reducing uncertainty and enabling performance-driven design (Vorländer, 2020). Studies demonstrate that early-stage acoustic simulation can improve predictive accuracy and reduce post-construction remediation costs, particularly in large concert halls (Kahle et al., 2021). Beyond optimization for traditional performance spaces, recent scholarship has shifted toward immersive and interactive sound environments. Blesser and Salter’s (2007) concept of *aural architecture* reframed space as an auditory experience shaped by social behaviour, memory, and power relations, extending acoustic discourse beyond physical metrics. Building on this foundation, contemporary research explores adaptive and responsive architectures in which spatial elements dynamically alter acoustic behaviour in response to live or recorded music. Examples include motorized acoustic banners, variable absorption panels, electroacoustic enhancement systems, and digitally controlled reflectors that allow venues to adapt to multiple musical genres (Skålevik, 2022). The integration of sensing technologies, artificial intelligence, and real-time digital control systems marks a significant

paradigm shift. Machine-learning-assisted acoustic systems can analyse musical input, such as tempo, spectral density, and dynamic range, and adjust spatial responses accordingly, enabling a form of architectural “listening” (Fernández et al., 2023). Such systems are particularly relevant in experimental music venues, media architecture, and interactive installations, where boundaries between composer, performer, space, and audience become increasingly fluid. Importantly, scholars argue that these technological innovations must remain sensitive to cultural and performative traditions. Research in ethnomusicology and architectural theory suggests that musical practices are inseparable from the spaces in which they evolve, whether sacred architecture shaping liturgical chant or urban public spaces influencing popular and electronic music cultures (Labelle, 2010). Consequently, computational approaches that integrate music analysis with architectural design must account not only for acoustic efficiency but also for cultural symbolism, embodied listening, and social interaction. Taken together, these developments underscore the growing importance of interdisciplinary frameworks that unite music theory, acoustic science, architectural computation, and cultural studies. Music-specific architecture is no longer conceived as a static container for sound but as an adaptive, responsive, and meaning-laden environment. Future research increasingly points toward hybrid models in which digital simulation, real-time feedback, and cultural analysis collectively inform architectural decision-making, expanding both the functional and expressive potential of musical spaces.

Materials and Methods

This study adopts a qualitative-computational research approach grounded in a systematic review of peer-reviewed literature and open-access PDF sources across the intersecting domains of architectural acoustics, computational design, and music technology. The research materials comprise scholarly articles and technical reports addressing wave-based acoustic simulation, performance-driven architectural design, parametric modeling, and data-informed spatial optimization. Emphasis is placed on studies that demonstrate how musical performance requirements can be translated into architectural form through computational means. The methodological framework is structured around four interrelated stages. Firstly, acoustic data acquisition involves the documentation of sound behaviour using established techniques such as impulse response measurement, frequency-domain analysis, and spatial mapping of sound energy distribution. These methods provide quantitative descriptors of reverberation, clarity, diffusion, and spatial impression that are central to music-specific architectural evaluation. Secondly, computational processing employs digital simulation environments, including finite-element modeling and geometric ray-tracing algorithms, to generate predictive acoustic datasets under varying spatial and material conditions. These simulations allow for controlled experimentation beyond the limitations of physical prototyping. Thirdly, parametric translation converts acoustic performance indicators into adjustable spatial variables, such as geometry, surface articulation, and material allocation, within parametric design platforms. This enables designers to explore form-performance relationships in a rule-based and iterative manner. Fourth, design feedback integration facilitates continuous refinement through iterative testing and real-time evaluation of simulated musical performance outcomes. The proposed framework is conceptually validated through documented case studies in concert hall design and immersive sound environments reported in existing literature, allowing for comparative analysis of methodological effectiveness and design outcomes.

Result and Discussion

Sound-as-Data as a Transformative Design Paradigm

The literature in architectural acoustics increasingly frames sound not merely as an environmental outcome but as a form of actionable data capable of actively informing architectural decision-making. Traditional design approaches often treated acoustics as a post-hoc performance criterion, something evaluated only after spatial design is complete. However, advances in computational simulation and parametric design have enabled sound to become an integral driver of form rather than an external constraint (Peters, 2010). Recent research has demonstrated that treating musical acoustic information as a computational dataset allows designers to move beyond fixed targets, such as prescribed reverberation times or single acoustic metrics, toward an exploratory, iterative engagement with sonic-spatial relationships (Peters, Nguyen, & Omar, 2021). This shift reflects broader trends in design practice where performance data (thermal, structural, acoustic) informs geometric generation and optimization simultaneously. In computational acoustic design, sound data, such as impulse responses, frequency spectra, and spatial diffusion patterns, are captured and encoded into digital models that

can be *parameterized and manipulated* within design environments, such as Grasshopper or other algorithmic platforms. By linking these acoustic datasets with geometric parameters, architects can visualize how alterations in spatial form influence sound fields in real time, effectively enabling sound to shape architectural form from the earliest design stages (Peters, 2010; Wiggins, 2023; Peters et al., 2021). Parametric workflows thus transform the sonic behaviour of a space from a qualitative concern into quantifiable variables that participate in optimization loops (Wiggins, 2023). These workflows are supported by acoustic simulation tools that generate data outputs—such as sound pressure levels or reflection paths—which can be read back into the design model as feedback. This paradigm is significant because it co-produces sensory and spatial knowledge in ways that were previously difficult. Rather than relying solely on expert intuition or heuristic thumb rules, designers can experiment computationally with complex sonic phenomena that emerge from interactions between geometry, materials, and sound sources. For example, performance data can indicate how subtle changes in surface curvature or volume segmentation influence modal distributions or clarity indices, encouraging designers to explore rich design spaces that reconcile aesthetic intent with acoustic efficacy (Peters et al., 2021). This level of integration fosters iterative refinement of both form and performance, supporting design decisions that are informed by empirical acoustic behaviour rather than approximations. Computational sound-as-data approaches include *auralization*, in which acoustic simulations are processed into audible renderings that enable designers and stakeholders to experience predicted acoustic conditions before construction. The capacity to hear simulations makes sound data more tangible, empowering collaborative decision-making across disciplines. Importantly, this technical integration also necessitates interdisciplinary collaboration between architects, acousticians, and computational specialists. As computational acoustic tools produce increasingly large and complex datasets, designers must be conversant with both the computational protocols that generate these datasets and the interpretive frameworks that make them meaningful for architectural form-making. The shift toward treating sound as data also resonates with broader computational design trends in architecture. Parametric design methods, where formal outcomes are generated by rules and relationships rather than fixed forms, lend themselves naturally to sound-driven exploration (parametric design principles describe how changing parameters produce new geometry). Parametric acoustics research explicitly argues that integrating acoustic simulation within parametric modeling environments enables early and continuous acoustic evaluation, allowing architects to consider sonic performance alongside spatial and material considerations throughout the design process. In practice, this means formal decisions are informed by an evolving dataset that describes acoustic performance under changing conditions. Contemporary developments in machine learning and data science further expand the potential of sound as data. Machine-learning frameworks are being explored for rapid acoustic simulation or classification, linking raw audio features with predictive models of acoustic behaviour, which can reduce computational costs and accelerate design feedback loops. These data-driven approaches hold promise for democratizing acoustic modeling by making complex simulations more accessible to designers without deep expertise in numerical acoustics. However, this paradigm is not without challenges. Integrating acoustic data into design workflows demands significant computational resources and raises questions about how best to visualize and interpret high-dimensional datasets in intuitive ways for designers and stakeholders. Additionally, reconciling aesthetic intent with measurable performance criteria requires a translation between the quantitative outputs of acoustic models and the qualitative expectations of users and clients. Despite these challenges, the literature signals a paradigm shift in how architecture engages with sound. Sound is no longer merely a performance metric to be evaluated at the end of design; it has become a generative parameter that participates in the conceptualization, modeling, and realization of architectural form. In this view, architecture becomes a responsive medium where sonic and spatial qualities are co-produced, and where data flows seamlessly between acoustic analysis and design decision-making.

Computational and Parametric Mediation of Sonic–Spatial Relationships

Findings from the reviewed literature emphasize the critical role of computational simulation and parametric workflows in bridging spatial geometry with musical perception, particularly for acoustic qualities that hinge on mid-frequency ranges, frequencies that are essential to clarity, definition, and the perceived balance of sound in performance spaces. Historically, acoustic analysis in architecture was limited by its reliance on post-design evaluation and simple heuristics concerning reverberation time or surface treatments (Peters et al., 2021). However, the advent of integrated digital simulation platforms now enables predictive modeling of acoustic fields in tandem with geometric design, effectively positioning geometry not as a static envelope but as a dynamic variable in acoustic performance optimization. Computational simulations, such as ray-tracing

and image-source methods, allow designers to estimate how sound waves propagate, reflect, and decay across a geometry before construction. These tools compute acoustic parameters (e.g., sound pressure levels, reflection distributions) across a design's spatial configuration, offering quantitative insights into how geometry influences acoustic outcomes (Lin & Lin, 2024). Such simulations are particularly effective in mid-frequency ranges (around 500 Hz-1 kHz), which are crucial for musical clarity and intelligibility, as they capture how room dimensions and surface orientations affect sound energy distribution (Wang & Kang, 2022; see also recent concert hall simulation research validating predictive models against field measurements at these frequencies). For example, a controlled renovation study of a circular music hall demonstrated significant improvements in clarity and early decay time through geometric and surface modifications, with simulation predictions aligning closely with measured mid-frequency acoustic improvements (mid-frequency reverberation time increased from 0.76 s to 1.31 s) in a real venue context (Journal of Building Engineering, 2025). Parametric modeling environments, such as those built in Rhino/Grasshopper or similar platforms, enable the visualization, manipulation, and exploration of acoustic phenomena directly tied to geometric parameters. By encoding acoustic performance metrics as parametric variables, designers can instantly assess how incremental changes in dimension, curvature, or surface articulation affect predicted acoustic outcomes. This provides an evidence-based approach to design decision-making that integrates performance evaluation within the creative process, rather than leaving it to later consultancy stages (Peters et al., 2021; Madzharova & Shishkov, 2025). Through parametric scripting, design options can automatically generate variations that satisfy desired acoustic criteria, facilitating rapid exploration of the design space and highlighting trade-offs between visual form and sonic performance. As one study describes, once relationships between geometry and acoustic performance are encoded, “acoustically regulating surfaces” can be created that offer predictable performance while still supporting architectural creativity. This workflow fundamentally enhances designers' capacity to predict, manipulate, and optimize acoustic outcomes rather than simply reacting to them. Parametric tools bridge modeling and simulation within a unified environment and reduce technical barriers such as file exchange issues or software interoperability, historical obstacles that often disconnected architectural form-generation from acoustic analysis (Peters et al., 2021). Furthermore, these workflows support real-time interaction; designers can test acoustic impacts in near real time, adjust geometric parameters accordingly, and immediately visualize resultant changes in acoustic quality. Such interactivity fosters a design-through-performance mind-set rather than a sequential, performance-after-design paradigm. Recent research extends this approach by integrating advanced simulation toolkits that offer more granular data access. For example, new Python-based ray-tracing frameworks provide millions of raw ray data points and spatial impulse responses, enabling detailed analysis of sound propagation paths across complex geometries with high spatial fidelity (Zang & Kong, 2025). These developments support the use of data analysis workflows within parametric design environments, enabling designers to interrogate simulation datasets more thoroughly during optimization. Parametric and computational workflows also intersect with generative design methods, which use algorithmic exploration to produce large populations of design variants filtered by performance criteria such as acoustics (generative design description). Such methods expand the solution space, allowing for the discovery of unexpected geometric configurations that satisfy acoustic performance requirements while balancing other design constraints. The convergence of computational simulation, parametric modeling, and generative exploration reconceptualises the relationship between geometry and musical perception. Rather than treating geometry as a given constraint, these tools allow the designer to *explore how geometry elicits specific acoustic phenomena*, from early reflections that enrich spatial impression to diffusion patterns that scatter sound evenly in seating zones. This data-driven engagement with sound physics nurtures design decisions that are both technically grounded and creatively informed, empowering architects to shape spaces that resonate not only visually but acoustically.

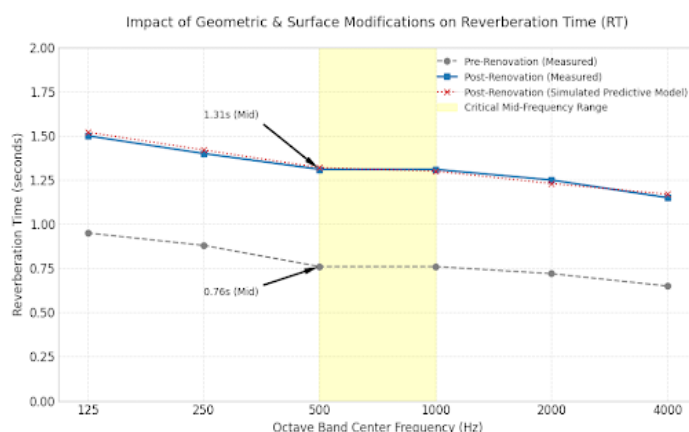
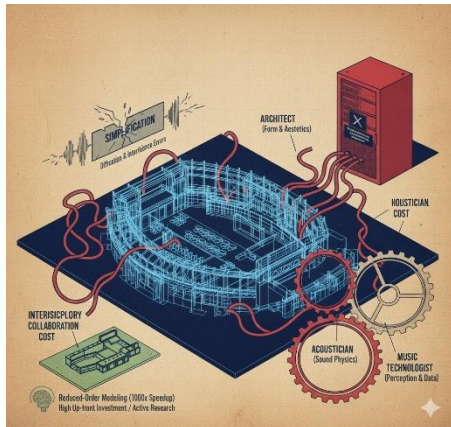


Fig. 4.1: Showing the focusing on the circular music hall case study.

Methodological and Translational Challenges in Music-Driven Computational Design



Despite the demonstrated potential of computational acoustic models to inform evidence-based architectural design, the literature highlights a set of persistent challenges that constrain broader adoption in practice. At the forefront of these challenges is the high computational cost associated with accurate acoustic simulations, particularly when wave-based methods are applied to large, complex, or high-frequency environments. Wave-based simulation approaches, such as time-domain finite element methods (TD-FEM) and high-order numerical solvers, can require massive computing resources to capture detailed sound propagation phenomena across broad frequency ranges (Yoshida, Okuzono, & Sakagami, 2023; *e.g.*, simulations involving hundreds of millions of degrees of freedom can take thousands of seconds even on high-performance computing

clusters). While geometric acoustics (*e.g.*, ray-tracing or image-source methods) offer less computationally expensive alternatives, they often rely on simplifications that can compromise accuracy in certain acoustic conditions, particularly where diffraction and interference effects are significant (Pelzer, Aspöck, & Vorländer, 2014). These computational demands create obstacles for real-time feedback within design workflows and limit accessibility for practitioners without access to high-performance computing environments. Although innovations such as reduced-order modeling (*e.g.*, reduced basis methods) have shown promise, achieving up to 100- to 1000-fold speed-ups in some parameterized room acoustics simulations, they typically require significant up-front investment in model construction and training, and their effectiveness is still an active area of research. Another core challenge arises from the need for effective interdisciplinary collaboration among architects, acousticians, and music technologists. Computational acoustic modeling inherently intersects multiple domains, including architectural form generation, psychoacoustic perception modeling, material science, and simulation science, which are often taught and practiced in isolation. Bridging these disciplinary boundaries requires not only technical fluency but also shared conceptual vocabularies and workflows. Reviews of parametric room acoustic workflows point to the need for benchmarking tools that balance accuracy, speed, and interoperability with design software environments (Parigi, Svidt, Molin, & Bard, 2025). Without such interoperability, practitioners are forced to transfer models between disparate software systems (*e.g.*, CAD design tools and specialized acoustic simulators), which increases coordination overhead and reinforces disciplinary silos. Translating complex acoustic datasets into intuitive design-relevant parameters remains another significant barrier. Acoustic simulation outputs, such as impulse responses, energy decay curves, and frequency-domain metrics, are essential for technical evaluation but are not inherently design intuitive. The gap between highly quantitative simulation outputs and the qualitative language of architectural form means that designers must often rely on intermediaries (*e.g.*, consultants) or custom visualization tools to interpret results. Studies in computational acoustics point out that while some tools visualize data through colour maps or auralization, these representations can still be difficult to integrate into design decisions without specialized training (Pelzer et al., 2014; Yoshida et al., 2023). Interdisciplinary challenges extend to education and training. Few architecture curricula offer in-depth exposure to acoustic simulation methods, and even fewer integrate these methods directly with parametric and computational design instruction. This creates a competence gap, where architects may understand conceptual acoustic principles but lack the computational skill set to meaningfully deploy simulation data within parametric workflows. At the same time, acousticians may not be familiar with algorithmic design environments used by architects, making collaboration less seamless. Research work suggests that improving software interfaces and user experience design for acoustic tools could alleviate some of this friction by lowering the entry threshold for architectural practitioners (Teymoori, 2024). Another constraint is the trade-off between simulation accuracy and pragmatic efficiency. High-fidelity simulations, particularly wave-based models, can deliver detailed results but at significant resource cost, while faster geometric or reduced-order models must sacrifice some precision. This trade-off forces designers to decide between responsiveness and analytical rigour, often leading to the use of simplified models in early stages and more detailed simulations late in the process. Unfortunately, this sequencing limits the integration of acoustic insight during conceptual form finding. Efforts to develop hybrid methods and improved algorithms, including parallel computing approaches and more efficient solvers, show promise but

have yet to fully resolve these trade-offs at scale (Yoshida et al., 2023; *parametric acoustics literature*). Despite these persistent challenges, reviewed studies highlight the transformative potential of sound-as-data frameworks should these constraints be overcome. By enabling richer, data-informed design exploration, computational acoustics can expand architectural practice beyond visual and structural performance to fully incorporate auditory qualities as core design drivers. Furthermore, as computational resources become more accessible (e.g., through cloud computing, scalable solvers, and machine-learning-augmented simulation), and as interdisciplinary education evolves, the integration of acoustic data within parametric workflows is likely to become more feasible and widespread. In this evolving landscape, addressing technical, educational, and collaborative barriers will be crucial for realizing the full impact of computational acoustic models on architectural design practice.

Conclusion

This paper has critically examined the concept of architectural sound as data and investigated the role of computational models in supporting music-driven spatial design. By synthesizing research across architectural acoustics, computational design, and music technology, the study illustrates that sound can be treated not merely as an evaluative metric applied after construction but as a generative parameter that actively shapes spatial form. Computational modeling tools, including wave-based simulations, ray-tracing algorithms, and parametric design environments, enable architects to simulate, visualize, and manipulate acoustic performance during early stages of design, facilitating iterative exploration of sonic-spatial relationships. Such approaches allow design decisions to be informed by data on reverberation, clarity, diffusion, and energy distribution, creating environments where musical intent and architectural form are mutually integrated. The paper further highlights that parametric and computational workflows enhance the designer's ability to optimize acoustic outcomes, test multiple geometric and material configurations, and anticipate listener perception in diverse contexts. However, the research also identifies ongoing technical and methodological challenges, including high computational demands, interdisciplinary collaboration complexities, and the difficulty of translating complex acoustic datasets into intuitive, design-relevant parameters. Addressing these challenges is essential for the broader adoption of sound-as-data methodologies in practice. Overall, this study underscores that integrating sound as a design-generative element represents a significant advancement in architectural science, expanding the scope of evidence-based design to include auditory experience alongside visual and spatial considerations. By embedding acoustic intelligence into the design process, architects can create music-specific and immersive environments that harmonize form, function, and perception, pointing toward a future in which sonic data is an essential driver of architectural innovation.

Future Research

Future research should prioritize the integration of machine-learning-based acoustic prediction into real-time design environments, allowing architects and designers to receive immediate feedback on how spatial modifications affect sound behaviour. Such integration can support more sophisticated, adaptive, and responsive design strategies, particularly for complex music-specific spaces. Expanding acoustic datasets to include a wide range of musical traditions, performance practices, and culturally significant soundscapes will improve the generalizability and inclusivity of computational models. There is also a pressing need to develop interdisciplinary educational frameworks that bridge architecture, music technology, computational design, and data science, equipping future practitioners with the skills to interpret, manipulate, and implement acoustic data effectively. Additionally, greater emphasis should be placed on immersive and adaptive sound environments, in which architecture can dynamically respond to live or recorded musical input, enabling interactive and context-sensitive auditory experiences. Such research directions will help establish sound as a core, generative parameter in contemporary architectural practice.

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THE EFFECT OF CULTURAL INTELLIGENCE ON ENTREPRENEURSHIP ORIENTATION

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ABSTRACT

In today's business environment, competition has intensified rapidly alongside globalization, compelling organizations to operate at an international level. Thus, individuals from different cultures begin to work together, and this collaboration between individuals from different cultures leads to a number of problems. In addressing these challenges, the concept of cultural intelligence has begun to attract attention as a type of intelligence that individuals should possess. Cultural intelligence helps individuals build positive relationships with people from different cultures, equipping them with the ability to adapt and accept differences. Entrepreneurs also interact and work with people from different cultures. In this respect, a high level of cultural intelligence among entrepreneurs is of great importance for the success of entrepreneurial activities. Entrepreneurs' ability to accurately understand individuals with diverse cultural backgrounds, collaborate effectively with them, and to display behaviors appropriate to cultural differences highlights the decisive role of cultural intelligence in entrepreneurial activities. This study examines the influence of cultural intelligence on entrepreneurial orientation. For this purpose, data was collected from 222 students studying at Gaziantep University, İslahiye Faculty of Economics and Administrative Sciences, using a convenience questionnaire method. The obtained data were subjected to exploratory factor analysis, correlation, and regression analysis. As a result of the analysis, it was determined that cultural intelligence has a significant and positive effect on entrepreneurial orientation.

Keywords: Cultural Intelligence, Entrepreneurship Orientation, University Students.

KÜLTÜREL ZEKÂNIN GİRİŞİMCİLİK YÖNELİMİNE ETKİSİ

ÖZET

Günümüzde küreselleşme ile birlikte iş dünyasında rekabet hızla artmakta ve bu durum örgütleri uluslararası düzeyde faaliyetlerde bulunmaya zorlamaktadır. Böylece, farklı kültürlerden gelen bireyler, birlikte çalışmaya başlamakta, farklı kültürlerden gelen bireylerin birlikte çalışması ise birtakım sorunların ortaya çıkmasına neden olmaktadır. Bu sorunların aşılmasında, kültürel zekâ kavramı bireylerin sahip olması gereken bir zekâ türü olarak dikkatleri üzerine çekmeye başlamıştır. Kültürel zekâ, bireylerin farklı kültürlere sahip bireyler ile olumlu ilişkiler kurmasına katkıda bulunmakta, bireylere uyum sağlama ve farklılıkları kabul etme yeteneği kazandırmaktadır. Girişimciler de, farklı kültürlerden gelen insanlarla etkileşimde bulunmakta ve birlikte çalışmaktadır. Bu yönüyle, girişimcilerin kültür zekâ düzeylerinin yüksek olması girişimcilik faaliyetlerinin başarılı olması için büyük önem taşımaktadır. Girişimcilerin, farklı kültürel özelliklere sahip bireyleri doğru bir şekilde anlamaları, onlarla etkili bir şekilde iş birliği yapmaları ve kültürel farklılıklara uygun davranış sergilemeleri kültürel zekânın girişimcilik faaliyetlerindeki belirleyici rolünü ortaya koymaktadır. Bu çalışmada, kültürel zekânın girişimcilik yönelimi üzerindeki etkisi incelenmektedir. Bu amaç doğrultusunda, Gaziantep Üniversitesi, İslâhiye İktisadi ve İdari Bilimler Fakültesi'nde öğrenim gören 222 öğrenciden kolayda anket yöntemi ile veri toplanmıştır. Elde edilen veriler keşfedici faktör analizi, korelasyon ve regresyon analizine tabi tutulmuştur. Yapılan analiz sonucunda, kültürel zekânın girişimcilik yönelimi üzerinde anlamlı ve pozitif yönde bir etkiye sahip olduğu tespit edilmiştir.

Anahtar Kelimeler: Kültürel Zekâ, Girişimcilik Yönelimi, Üniversite Öğrencileri

1.GİRİŞ

Küreselleşme ile birlikte ülkeler arasındaki mesafelerin azalması, farklı kültürlerden ve ülkelerden gelen insanlar arasındaki etkileşimin her zamankinden daha fazla olmasına olanak sağlamıştır. Ancak farklı kültürlerden olan insanları anlamak, onları hoşgörüyü karşılamak ve onlara saygılı olmak, belirli bir yerde

birlikte bulunmaktan veya aynı dili çok akıcı bir şekilde konuşmaktan daha fazlasını gerektirmektedir. Bu noktada kültürel zekâ, temel bir beceri olarak kabul edilmektedir (Gökten ve Emil, 2019: 771). Kültürel zekâ, bireyin çok kültürlü veya kültürlerarası durumlarda etkili bir şekilde başa çıkabilme, farklı kültürel ipuçlarını bir araya getirme, çıkarım yapma ve bunlara yanıt verme noktasında sezgisel olarak uyum sağlama yeteneği olarak tanımlanmaktadır (Mahasneh vd., 2019: 304). Kültürel zekâ, bir bireyin farklı kültürel ortamlarda veya çok kültürlü ortamlarda etkili bir şekilde işlev görmesini veya başarılı olmasını sağlayan bir dizi beceridir. Kültürel zekâ, kişinin sahip olduğu kümülatif kültürel yapıların aksine, diğer insanlarla etkileşiminden kaynaklanmaktadır (Baltacı, 2017: 646). Kültürlerarası farklılıkların yönetilmesinde birçok bireysel ve örgütsel stratejiler bulunmaktadır. Bu stratejilerin en önemlilerinden biri de kültürel zekâdır. Çok kültürlü ortamlarda, farklı kültürlere uyum sağlamak ve onlara yaşamak için bireylerin kültürel zekâ düzeylerinin yüksek olması gerekmektedir (Mercan, 2016: 29).

Uluslararası alandaki gelişmeler yalnızca kültürel zekâ kavramının öneminin artmasının yanında diğer önemli bir unsur olan girişimcilik kavramının da önemini artırmıştır. Bu durum, girişimcilik faaliyetlerinin kapsamının genişletilerek hem bireysel hem de örgütsel boyutta farklı kültürleri anlama ve buna göre doğru stratejiler geliştirme becerilerinin önemini ortaya çıkarmıştır. Girişimcilerin farklı kültürleri anlayabilme ve bu kültürdeki bireylerle uygun davranış kalıpları sergileyebilmesi kültürel zekânın girişimcilik faaliyetlerindeki önemini ortaya koymuştur (Gürer ve Çiftçi, 2018: 491). Kültürel zekâ, bireylerin özellikle uluslararası deneyimleri sayesinde artmakta ve girişimcilğe yönelimlerini pozitif yönde etkilemektedir (Yıldız, 2016: 94).

Kültürel zekâ, üniversite öğrencilerin farklı kültürlerden gelen insanları daha iyi anlamasını, onlarla uyumlu olmasını ve daha iyi bir iletişim kurmasını kolaylaştırmaktadır. Bu durum, öğrencilerin hem akademik hem de profesyonel yaşamda daha başarılı olmasına katkıda bulunmaktadır. Kültürel zekâ düzeyi yüksek olan üniversite öğrencileri, iş yaşamlarında farklı pazarlara açılma noktasında daha fazla risk almakta, pazarın ihtiyaçlarını daha doğru analiz etmektedir. Bu nedenle, kültürel zekâ girişimcilik yönelimini güçlendiren bir özellik olarak görülmektedir. Bu çalışmanın amacı, kültürel zekânın girişimcilik yönelimi üzerindeki etkisini incelemektedir. Çalışmada, ilk olarak kültürel zekâ ve girişimcilik yönelimi kavramlarına ilişkin literatür taraması yapılmıştır. Daha sonra, hipotezler geliştirilmiş, çalışmanın amacı, modeli, kullanılan ölçekler ve analiz sonuçlarına yer verilmiştir.

2.LİTERATÜR TARAMASI

2.1.Kültürel Zekâ

Çok kültürlü ortamlarda, diğer kültürlere uyum sağlamak, etkili bir şekilde iletişim kurabilme becerisi ve yeteneği herkesin sahip olmadığı önemli bir özellik olarak günümüz dünyasında gittikçe önem kazanmaktadır. Son yıllarda bu beceri, kültürel zekâ olarak tanımlanmakta ve araştırmacıların ilgisini çeken bir konu haline gelmektedir (Abaslı ve Polat, 2019: 194). Kültürel zekâ, bireylerin diğer kültürlerle iletişime girme noktasında davranışlarını düzenleyebilmesi ve kültürel farklılıklara uyum sağlayabilme yeteneği olarak tanımlanmaktadır. Kültürel zekânın odak noktası, bireyin çok kültürlü bir ortamda verimli, etkin ve başarılı olmasını sağlayan farkındalık ve yeteneğe sahip olması olarak görülmektedir (Gezer ve Şahin, 2017: 175). Kültürel zekâ düzeyi yüksek olan bireyler, farklı kültürleri daha kolay anlamakta ve davranışlarını farklı kültürlere göre ayarlamaktadır. Kültürel zekâ; üstbilişsel, bilişsel, motivasyonel ve davranışsal zekâ olmak üzere dört boyutta ele alınmaktadır (Yıldırım-Ulusoy ve Köroğlu, 2019: 329).

Üstbilişsel kültürel zekâ, bireylerin bilgiye ulaşma ve ulaşmış olduğu bilgiyi kavramada kullanmış olduğu zihinsel süreçleri, bu süreçlerin kontrolünü ifade etmektedir. Kültürel zekânın bu alt boyutu, aynı zamanda farklı ülke veya toplum gruplarının normları ile ilgili zihinsel modellerin takip edilmesini, bunlar ile ilgili planların yapılmasını ve son olarak gözden geçirilmesi yeteneklerini kapsamaktadır (Şahin ve Gürbüz, 2012: 127). Bu zekâ boyutu, bireyin, geçmişteki kültürel deneyimlerini analiz ederek ve değerlendirerek, gelecekteki kültürel iletişimlerinde kolaylık sağlamasını ifade etmektedir. Üstbilişsel kültürel zekâsı yüksek olan bireyler, kültürel bilgilerini değiştirme, geliştirme ve kültürel önyargılardan kurtulma noktasında diğer bireylere oranla daha başarılı olmaktadır (Dilek ve Topaloğlu, 2017: 98).

Bilişsel kültürel zekâ, bireylerin diğer farklı kültürler ile ilgili sahip olduğu bilgi düzeyi olarak tanımlanmaktadır. Bu kültürel zekâyı sahip olan bireyler, kültürlerin diğer kültürlerden farklılıklarını ya da benzer yönleri hakkında bilgi sahibi olmaktadır. Bilişsel kültürel zekâsı yüksek olan bireyler, diğer kültürlerin konuşma dili, normları, değerleri, dini inanışları ve ekonomik/yasal sistemleri hakkında bilgi sahibi olmaktadır (Doğan ve Uysal, 2020: 149).

Motivasyonel kültürel zekâ, bireylerin farklı kültürel ortamlarda öğrenme ve faaliyette bulunmak için enerjisi ve dikkatini yönlendirebilme kapasitesi olarak tanımlanmaktadır. Motivasyonel kültürel zekâ, bireylerin hedefe ulaşmasını kolaylaştıran bilgi, duygu ve davranış kontrolünü sağlayan bir unsur olarak görülmektedir (Arastaman, 2018:2). Motivasyonel kültürel zekâda en önemli nokta, kültürlerarası etkileşimde bulunurken yaşanabilecek zorluk ve streslerden dolayı bireyin hemen vazgeçmemesidir. Bireyin kendi kültüründen biri ile iletişime geçmesi kolay iken, başka kültürden biri ile iletişim kurması daha zordur ve bu durum da yüksek motivasyon gerektirmektedir (Aslan ve Aslan, 2015: 43).

Davranışsal kültürel zekâ, boyutu farklı kültürel ortamlarda sergilenen tutum ve davranışları kapsamaktadır. Bu zekâ boyutu, bireyin farklı kültürel ortamlarda neyi, nasıl ve hangi şekillerde yaptıklarını ifade etmektedir. Kültürel zekânın bu boyutu, bilişsel ve motivasyonel zekâ boyutlarını da kapsamakta ve teorideki bilgilerin günlük hayata aktarılmasına katkıda bulunmaktadır. Davranışsal kültürel zekâ düzeyi yüksek olan bireyler, farklı kültürel ortamlarda selamlaşma şekillerini, dil kullanımını ve sosyal ipuçlarına uygun davranışlar sergilemektedir (Mercan, 2016: 39).

2.2. Girişimcilik Yönelimi

Günümüzde, küreselleşme ile birlikte rekabet artmakta ve bu yoğun rekabet ortamı girişimcilik kavramının önemini daha da artırmaktadır. Girişimcilik kavramı, ekonomik kalkınma ve istihdam yaratmada temel güçlerden biri olarak görülmektedir (Talih-Akkaya vd., 2014: 108). Girişimcilik kavramı yenilik ve yaratıcılık faaliyetlerini kapsamakta ve temelinde yeni bir iş kurma düşüncesi yer almaktadır (Solunoğlu ve İkiz, 2017: 45).

Girişimcilik, bireyin belirli bir katma değere ulaşmak için gerekli zaman ve emek harcayarak, sosyal, psikolojik ve finansal riskleri üstlendiği ve bu süre sonunda hem kişisel tatmin hem de ekonomik kazanç elde ettiği bir süreç olarak tanımlanmaktadır (Ağca, 2005: 153). Girişimci, mal ve hizmet üretmek amacıyla, emek, sermaye, doğal kaynaklar gibi üretim faktörlerini bir araya getiren, işletmeyi kuran ve işletmedeki faaliyetleri organize eden kişi olarak ifade edilmektedir (Korkmaz, 2012: 212). Girişimcilik yönelimi, bireyin stratejik bir seçim doğrultusunda girişimde bulunmaya yönelik motivasyon ve isteğini yansıtan, bu isteğin zamanla planlı, bilinçli ve amaçlı davranışa dönüşmesi ile ortaya çıkan bir süreç olarak tanımlanmaktadır. Girişimcilik yönelimi, bireyin kendi işini kurma konusundaki kendine olan güvenini, istek ve kararlılığını göstermektedir (Koyuncu ve Akdöl, 2019: 957).

Bireylerin girişimci olmasını etkileyen faktörler üç kategoride değerlendirilmektedir. Bunlardan birincisi, demografik özellikler olarak ifade edilen bireyin yaşı, cinsiyeti, medeni durumu, eğitimi, iş yerindeki çalışma süresi, aile yapısı gibi faktörlerdir. İkincisi ise bireyin etkileşimde bulunduğu sosyal çevresi ile ilgili olan aile, arkadaş, akraba, rol modeller ve sosyal ağ ilişkisi içinde bulunduğu kişiler ile olan ilişkisine dayanan sosyal faktörlerdir. Son faktör ise bireyin kendisi ile ilgili olan psikolojik faktörler olarak sınıflandırılmaktadır. Bu faktörler, girişimcinin başarılı olmasında etkili olmak ile birlikte, son yıllarda bu nitelikler daha spesifik bir şekilde ele alınmaya başlamıştır (Yıldız, 2016: 91).

Girişimcilik yönelimini etkileyen faktörler aşağıdaki gibi açıklanabilmektedir:

Risk Alma, sonuçların ne olacağını bilmeden bilinmeyen koşullarda ya da durumlarda karar vermeyi içermektedir (Bozkurt ve Erdurur, 2013: 60). Risk alma, girişimcilerin ortak davranış özelliklerinden biri olarak görülmektedir. Genellikle girişimciler, faaliyetlerinde kar elde etmek için çalışmalarını sürdüren ve risk alan kişi olarak tanımlanmaktadır (Şen ve Aslan, 2017: 1848). Girişimciler, diğer bireyler ile karşılaştırıldığında daha fazla risk alma eğilimindedirler. Risk alma eğilimi, girişimcilik için gerekli ön koşul olarak kabul edilmektedir. Girişimci, almış olduğu riske bir avantaja dönüştürmeli ve bundan fayda sağlamalıdır (Korkmaz, 2012: 213).

Yenilikçilik, ürünler, hizmetler ve süreçlerin geliştirilmesinde yeni kavram ve fikirlerin peşinden koşma istekliliği olarak tanımlanmaktadır (Eroğlu ve Avcı, 2021: 3611). Yenilikçilik, bir problemi çözmek ya da ihtiyacı gidermek için yeni bir düşünce veya fikrin ortaya çıkarılması ve kaynakların tespit edilmesi ile uygulamaya geçilmesidir (Akkuş vd., 2019: 5). Yenilikçilik, bireylerin yeniliklere adanmışlığının bir göstergesi olarak kabul edilmektedir. Girişimciler, yenilikçilik sayesinde problemlerine yaratıcı ve orijinal çözümler bulmakta, yenilik yoluyla değişimi ortaya çıkarmakta, farkındalık yaratmakta ve başarıya ulaşmaktadır (Özgüner vd., 2017: 393).

Proaktiflik, bireyin değişimi başlatabilme özelliği, çevresel değişimleri sonuçlandırana kadar sabırlı bir duruş sergilemesi, fırsatları kollaması ve inisiyatif alması olarak tanımlanmaktadır. Proaktif kişiliğe sahip olan bireyler, öğrenmeye açıktır, daha fazla sorumluluk alır, sorgular, fırsatları takip eder, çevresindeki insanlarla ile etkileşim halindedir, sosyal ağları güçlüdür ve yenilikçidir. Bu bireyler, çevresindeki değişimlere tepki vermek için beklemez aksine araştırır, fırsatları tahmin eder ve yeni koşullar oluşturmak için planlama yapar (Yüncü vd., 2024: 59).

2.3. Kültürel Zekâ- Girişimcilik Yönelimi İlişkisi ve Hipotez Geliştirme

Günümüz iş dünyası, işletmelerin zorlu rekabet ortamında yaşamını devam ettirebilmesi için uluslararası pazarlara açılmasını zorunlu kılmaktadır. Fakat bu pazarlarda farklı kültürlerden gelen insanların olması bazı problemlere neden olmaktadır. Bu problemlerin çözülmesi için girişimcilerin kültürel zekâ düzeyleri önemli bir unsur olarak karşımıza çıkmaktadır. Kültürel zekâ ile girişimciler, farklı kültürlerdeki bireyler ile daha başarılı ilişkiler geliştirmekte ve bunu rekabet avantajı olarak kullanmaktadır (Koyuncu ve Akdöl, 2019: 956). Kültürel zekâ, bireylerin çok kültürlü ya da kültürlerarası ortamda başarılı olmasına katkıda bulunan yetenekler seti olarak ifade edilmektedir. Kültürel zekâ, farklı kültürlerle sahip çalışma gruplarını yönetme ve onlarla birlikte çalışmada önemli bir unsur olarak kabul edilmektedir. Kültürel zekânın öneminin artması ile birlikte, girişimcilik yöneliminde kültürel zekânın önemi artmaya başlamıştır (Gürer ve Çiftçi, 2018: 491).

Kültürel zekâ ve girişimcilik yönelimi arasındaki ilişkiyi inceleyen araştırmalar, kültürel zekânın girişimcilik yönelimini olumlu bir şekilde etkilediğini doğrulamıştır. Örneğin, Demirel vd. (2023) tarafından, 405 yabancı uyruklu öğrenciler üzerine yapılan çalışmada, kültürel zekânın girişimciliği ve öz-yeterliliği anlamlı ve pozitif yönde etkilediği sonucuna ulaşılmıştır. Koyuncu ve Akdöl (2019) tarafından 161 çalışandan anket yöntemi ile veri toplanmıştır. Yapılan analiz sonucunda, kültürel zekânın alt boyutları ile bireysel girişimcilik yöneliminin alt boyutları arasında anlamlı bir ilişki olduğu tespit edilmiştir. Baltacı (2017) tarafından, 642 katılımcı üzerine yapılan çalışmada, kültürel zekâ ile girişimcilik düzeyleri arasında anlamlı bir ilişki olduğu tespit edilmiştir. Son olarak, Gürer ve Çiftçi (2018) tarafından, 421 üniversite öğrencisi üzerine yapılan çalışmada, kültürel zekânın bireysel girişimcilik yönelimi üzerinde pozitif yönlü ve anlamlı bir etkisinin olduğu sonucuna ulaşılmıştır. Bu bağlamda, aşağıdaki hipotezler önerilmektedir:

H_{1(a)(b)(c)}: Kültürel zekânın üstbilişsel boyutunun girişimcilik yöneliminin tüm boyutları üzerinde anlamlı bir etkisi vardır.

H_{2(a)(b)(c)}: Kültürel zekânın bilişsel boyutunun girişimcilik yöneliminin tüm boyutları üzerinde anlamlı bir etkisi vardır.

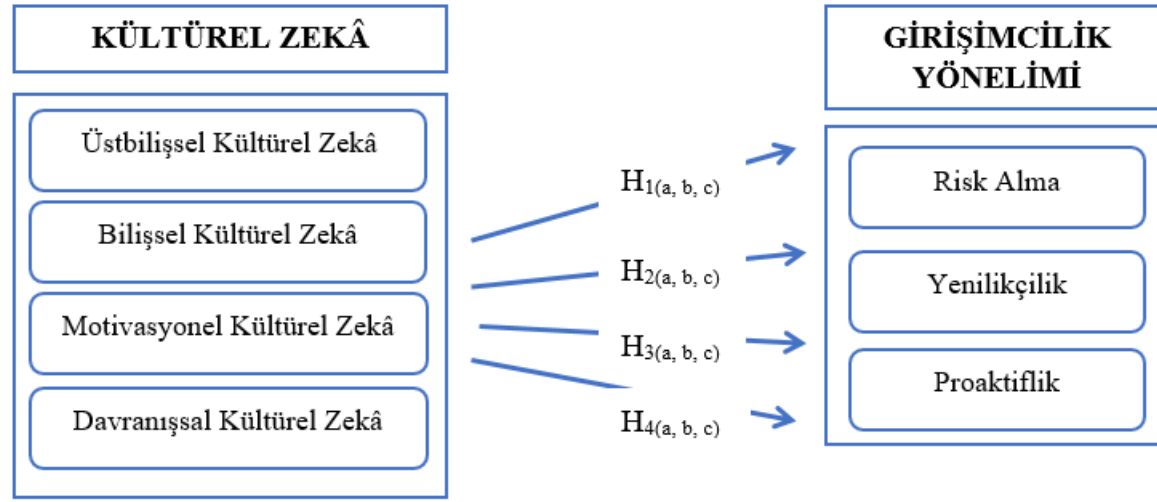
H_{3(a)(b)(c)}: Kültürel zekânın motivasyonel boyutunun girişimcilik yöneliminin tüm boyutları üzerinde anlamlı bir etkisi vardır.

H_{4(a)(b)(c)}: Kültürel zekânın davranışsal boyutunun girişimcilik yöneliminin tüm boyutları üzerinde anlamlı bir etkisi vardır.

3. ARAŞTIRMANIN METODOLOJİSİ

3.1. Araştırmanın Amacı ve Modeli

Bu çalışma amaç, kültürel zekânın girişimcilik yönelimi üzerindeki etkisini araştırmaktır. Bu amaçla, Gaziantep Üniversitesi, İslahiye İktisadi ve İdari Bilimler Fakültesi'nde öğrenim gören 222 öğrenciden online anket yöntemi ile veri toplanmıştır. Bağımsız değişken kültürel zekâ, bağımlı değişken ise girişimcilik yönelimi olarak ele alınmıştır. Araştırmanın modeli Şekil 1'de yer almaktadır.



Şekil 1: Araştırma Modeli

3.2. Araştırmanın Kapsamı ve Örneklem

Bu çalışmanın evreni, Gaziantep Üniversitesi İslâhiye İktisadi ve İdari Bilimler Fakültesi'nde öğrenim göre 429 lisans öğrencisinden oluşmaktadır. Araştırma sürecinde, online anket tekniğinden faydalanılarak 222 öğrenciden veri toplanmıştır. Katılımcılara ait demografik bulgular Tablo 1'de sunulmaktadır.

Tablo 1. Demografik Bulgular

Cinsiyet	n	%	Bölüm	n	%
Kadın	136	61,3	İşletme	52	23,4
Erkek	86	38,7	İktisat	76	34,2
Toplam	222	100	Kamu Yönetimi	94	42,3
Sınıf	n	%	Toplam	222	100
1.Sınıf	109	49,1	Yaş	n	%
2.Sınıf	64	28,8	18-20 yaş arası	165	74,3
3.Sınıf	31	14,0	21-23 yaş arası	42	18,9
4.Sınıf	18	8,1	24 ve üzeri	15	6,8
Toplam	222	100	Toplam	222	100

Araştırmanın örneklemini oluşturan katılımcıların %61,3'ünün kadın, %38,7'sinin erkek olduğu görülmektedir. Katılımcıların %23,4'ü İşletme bölümü, %34,2'si İktisat bölümü, %42,3'ü Kamu Yönetimi bölümü öğrencisidir. Katılımcıların %49,1'i 1.sınıf, %28,8'si 2.sınıf, %14'ü 3. sınıf ve %8,1'i 4.sınıf öğrencisidir. Son olarak katılımcıların %74,3'ü 18-20 yaş aralığında, %18,9'u 21-23 yaş aralığında, %6,8'i 24 yaş ve üzerinde olduğu tespit edilmiştir.

3.3. Veri Toplama Araçları

Çalışmada, veri toplama aracı olarak online anket yöntemi kullanılmıştır. Uygulanan anket formu, katılımcıların sosyo-demografik özelliklerini belirlemeye yönelik soruların yanı sıra, kültürel zekâ ve girişimcilik yönelimlerini ölçmeyi amaçlayan iki temel ölçekten oluşmaktadır. Araştırmada, katılımcıların kültürel zekâ düzeyini ölçmek için Ang vd. (2007) tarafından geliştirilen ve İlhan ve Çetin (2014) tarafından

Türkçe 'ye uyarlanan "Kültürel Zekâ Ölçeği" kullanılmıştır. Ölçek; üstbilişsel (4 madde), bilişsel (6 madde), motivasyonel (5 madde) ve davranışsal (5 madde) olmak üzere toplam dört boyuttan oluşmaktadır. Katılımcıların girişimcilik yönelimlerini belirlemek için ise Bolton ve Lane (2012) tarafından geliştirilen, Ercan ve Yıldırım (2021) tarafından Türkçeye uyarlanan "Bireysel Girişimcilik Yönelimi" Ölçeğinden yararlanılmıştır. Söz konusu ölçek; risk alma (3 madde), yenilikçilik (4 madde) ve proaktiflik (3 madde) olmak üzere üç alt boyuttan oluşmaktadır.

4. BULGULAR

4.1. Ölçeklerin Geçerlilik ve Güvenilirlik Analizi

Kültürel zekânın girişimcilik yönelimi üzerindeki etkisini incelenmeden önce araştırma kapsamında kullanılan ölçeklerin yapı geçerliğini ve güvenilirliğini test etmek için sırasıyla keşfedici faktör analizi (KFA) ve güvenilirlik analizleri uygulanmıştır.

Tablo 2. Keşfedici Faktör Analizi

Ölçekler		Soru	Faktör Yükleri	Öz Değer	Açıklanan Varyans	K-M- O Değeri	Barlett Küresellik Testi	Sig.	Cronbach α
Kültürel Zekâ Ölçeği	Üstbilişsel	4	,728-,809	3,878	68,405	0,936	3026,241	0,000	,951
	Bilişsel	6	,449-,745	3,854					
	Motivasyonel	5	,500-,696	2,976					
	Davranışsal	5	,514-,755	2,972					
Girişimcilik Yönelimi Ölçeği	Risk Alma	3	,655-,788	2,538	71,629	,906	880,392	0,000	,887
	Yenilikçilik	4	,666-,832	2,132					
	Proaktiflik	2	,717-,793	1,777					

Tablo 2’de keşfedici faktör analizi sonuçları yer almaktadır. Yapılan faktör analizi sonucunda, girişimcilik yönelimi ölçeğinin “proaktiflik” alt boyutundan 1 soru ilgili faktöre yüklenmediği için analizden çıkarılmıştır. Tablo 2’de kültürel zekâ (KMO=0,936; $\chi^2=3026,241$; $p=0,000$) ve girişimcilik yönelimi (KMO=0,906; $\chi^2=880,392$; $p=0,000$) ölçeklerinin KMO değerlerini ve Barlett Küresellik Testi sonuçları yer almaktadır. Kültürel zekâ ölçeğinin toplam varyansın %68,405’ini açıkladığı ve girişimcilik yönelimi ölçeğinin toplam varyansın %71,629’unu açıkladığı sonucuna ulaşılmıştır. Çalışmada kullanılan ölçeklerin faktör yük değerlerinin 0,449 ile 0,832 arasında olduğu görülmektedir. Çalışmada, kullanılan kültürel zekâ ölçeğinin Cronbach α katsayısının 0,951 ve girişimcilik yönelimi ölçeğinin Cronbach α katsayısının 0,887 olduğu sonucuna ulaşılmıştır.

Kültürel zekâ ve girişimcilik yönelimi düzeyinin ölçümü için faydalanan ölçeklerin boyutlarına ilişkin tanımlayıcı istatistikler, güvenilirlik katsayıları Tablo 3’te sunulmuştur.

Tablo 3. Tanımlayıcı İstatistikler

Ölçekler		N	Ortalama	Std. Hata	Çarpıklık	Basıklık
Kültürel Ölçeği	Üstbilişsel	222	3,8780	,9417	-1,037	1,047
	Bilişsel	222	3,4444	,8592	-,419	,566
	Motivasyonel	222	3,6432	,8424	-,713	1,141

	Davranışsal	222	3,7036	,8670	-,719	,852
	Risk Alma	222	3,6547	,9406	-,495	-,051
Girişimcilik Yönelimi Ölçeği	Yenilikçilik	222	3,8243	,8114	-,734	,890
	Proaktiflik	222	3,8446	,8276	-,859	1,168

Tablo 3’te görüldüğü üzere kültürel zekâ ölçeğinin alt boyutu olan üstbilişsel boyutunun ortalamasının (3,8780 ± ,9417), bilişsel boyutunun ortalamasının (3,4444± ,8592), motivasyonel boyutunun ortalamasının (3,6432 ± ,8424) ve davranışsal boyutu ortalamasının (3,7036 ± ,8670) olduğu görülmektedir. Girişimcilik yöneliminin alt boyutları olan risk alma boyutunun ortalamasının (3,6547 ± ,9406), yenilikçilik boyutunun ortalamasının (3,8243 ± ,8114) ve proaktiflik boyutunun ortalamasının (3,8446± ,8276) olduğu tespit edilmiştir. Çalışmada kullanılan, kültürel zekâ ve girişimcilik yönelimi ölçeklerin çarpıklık ve basıklık değerlerinin ±2 sınırları içinde olduğu ve verilerin normal dağılımı sağladığı görülmektedir (Tabachnick ve Fidell, 2013: 133).

4.2. Korelasyon Analizi

Kültürel zekâ ve girişimcilik yönelimi arasındaki ilişkiyi tespit etmek için korelasyon analizi kullanılmıştır. Tablo 4’te analiz sonuçları yer almaktadır.

Tablo 4. Korelasyon Katsayıları

Değişkenler	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Üstbilişsel	1						
(2) Bilişsel	,659**	1					
(3) Motivasyonel	,621**	,766**	1				
(4) Davranışsal	,725**	,716**	,766**	1			
(5) Risk Alma	,502**	,620**	,647**	,595**	1		
(6) Yenilikçilik	,536**	,579**	,607**	,620**	,717**	1	
(7) Proaktiflik	,452**	,593**	,577**	,532**	,546**	,621**	1

**p<0,01

Tablo 4’te korelasyon analizi sonucunda, üstbilişsel ile bilişsel (,659**); üstbilişsel ile motivasyonel (,621**); üstbilişsel ile risk alma (,502**); üstbilişsel ile yenilikçilik (,536**); üstbilişsel ile proaktiflik (,452**); bilişsel ile risk alma (,620**); bilişsel ile yenilikçilik (,579**); bilişsel ile proaktiflik (,593**); motivasyonel ile risk alma (,647**); motivasyonel ile yenilikçilik (,607**); motivasyon ile proaktiflik (,577**); davranışsal ile risk alma (,595**); davranışsal ile yenilikçilik (,620**), davranışsal ile proaktiflik (,532); risk alma ile proaktiflik (,546**); yenilikçilik ile proaktiflik (,621**) arasında pozitif yönlü ve orta düzeyde bir ilişki olduğu görülmektedir. Diğer yandan, davranışsal ile üstbilişsel (,725**); motivasyonel ile bilişsel (,766**); davranışsal ile bilişsel (,716**); davranışsal ile motivasyonel (,766**); yenilikçilik ile risk alma (,717**) arasında pozitif yönlü ve yüksek düzeyde bir ilişki olduğu görülmektedir.

4.3.Regresyon Analizi

Kültürel zekânın alt boyutlarının, girişimcilik yönelimi üzerine etkisini belirlemek amacıyla yapılan çoklu regresyon analizi sonuçları Tablo 5, Tablo 6 ve Tablo 7’de sunulmuştur.

Tablo 5. Kültürel Zekânın Risk Alma Üzerindeki Etkisi

Bağımlı Değişken		Bağımsız Değişken	Anova		Model Özeti		Etkiler		
			F	Sig. F	R	R ²	β	t	Sig.
Risk Alma	H _{1(a)}	Üstbilişsel	47,325	,000	,683	,466	,031	,412	,681
	H _{2(a)}	Bilişsel					,241	2,867	,005
	H _{3(a)}	Motivasyonel					,330	3,738	,000
	H _{4(a)}	Davranışsal					,147	1,635	,103

*p<0.05, **p<0.01, ***p<0.001

Tablo 5’te kültürel zekâ değişkeninin bilişsel (β : ,241, p=,005) ve motivasyonel (β : ,330, p=,000) boyutlarının girişimcilik yöneliminin risk alma boyutu üzerinde anlamlı bir etkisinin olduğu görülmektedir. Diğer yandan, kültürel zekânın bilişsel ve motivasyonel boyutlarının girişimcilik yönelimi değişkeninin risk alma boyutunun %46,6’sını açıklamaktadır. Sonuç olarak H_{2(a)}, H_{3(a)} hipotezleri kabul edilirken, H_{1(a)}, H_{4(a)}, hipotezleri reddedilmiştir.

Tablo 6. Kültürel Zekânın Yenilikçilik Üzerindeki Etkisi

Bağımlı Değişken		Bağımsız Değişken	Anova		Model Özeti		Etkiler		
			F	Sig. F	R	R ²	β	t	Sig.
Yenilikçilik	H _{1(b)}	Üstbilişsel	43,153	,000	,666	,443	,109	1,417	,158
	H _{2(b)}	Bilişsel					,144	1,682	,094
	H _{3(b)}	Motivasyonel					,225	2,494	,013
	H _{4(b)}	Davranışsal					,266	2,886	,004

*p<0.05, **p<0.01, ***p<0.001

Tablo 6’da kültürel zekâ değişkeninin motivasyonel (β : ,225, p=,013) ve davranışsal (β : ,266, p=,004) boyutlarının girişimcilik yöneliminin yenilikçilik boyutu üzerinde anlamlı bir etkisinin olduğu görülmektedir. Diğer yandan, kültürel zekânın motivasyonel ve davranışsal boyutlarının girişimcilik yönelimi değişkeninin yenilikçilik boyutunun %44,3’ünü açıklamaktadır. Sonuç olarak H_{3(b)}, H_{4(b)} hipotezleri kabul edilirken, H_{1(b)}, H_{2(b)}, hipotezleri reddedilmiştir

Tablo 7. Kültürel Zekânın Proaktiflik Üzerindeki Etkisi

Bağımlı Değişken		Bağımsız Değişken	Anova		Model Özeti		Etkiler		
			F	Sig. F	R	R ²	β	t	Sig.
Proaktiflik	H _{1(c)}	Üstbilişsel	35,150	,000	,627	,393	,011	,134	,893
	H _{2(c)}	Bilişsel					,328	3,658	,000
	H _{3(c)}	Motivasyonel					,236	2,505	,013

	H_{4(c)}	Davranışsal					,109	1,134	,258

*p<0.05, **p<0.01, ***p<0.001

Tablo 7’ de kültürel zekâ değişkeninin bilişsel (β : ,328, p=,000) ve motivasyonel (β : ,236, p=,013) boyutlarının girişimcilik yöneliminin proaktiflik boyutu üzerinde anlamlı bir etkisinin olduğu görülmektedir. Diğer yandan, kültürel zekânın bilişsel ve motivasyonel boyutlarının girişimcilik yönelimi değişkeninin proaktiflik boyutunun %39,3’ünü açıklamaktadır. Sonuç olarak **H_{2(c)}**, **H_{3(c)}** hipotezleri kabul edilirken, **H_{1(c)}**, **H_{4(c)}**, hipotezleri reddedilmiştir.

SONUÇ VE ÖNERİLER

Bu çalışmada, kültürel zekânın girişimcilik yönelimi üzerindeki etkisi incelenmiştir. Araştırma kapsamında geliştirilen hipotezleri test etmek için yapılan çoklu regresyon analizi sonucunda, kültürel zekânın bilişsel ve motivasyonel boyutlarının risk alma boyutu; kültürel zekânın motivasyonel ve davranışsal boyutlarının yenilikçilik boyutu; kültürel zekânın bilişsel ve motivasyonel boyutlarının proaktiflik boyutu üzerinde pozitif yönlü etkisinin olduğu görülmektedir. Bu sonuç, kültürel zekânın girişimcilik yönelimini etkilediğini gösteren literatürdeki diğer çalışma sonuçları ile paralellik göstermektedir (örneğin, Güner ve Çiftçi ,2018; Koyuncu ve Akdöl, 2019; Demirel vd., 2023; Baltacı, 2017).

Kültürel zekâ, kendini anlaşırlı kılma yeteneği ve kültürel farklılıkların rol oynadığı durumlarda verimli bir işbirliği yaratma yeteneğidir. Kültürel zekânın profesyonel yaşamda çok önemli olması nedeniyle, üniversite öğrencilerinin üniversite sonrası hayata hazırlanmaları için kültürel zekâlarını geliştirmek önemli hale gelmiştir. Daha yetkin, etkili ve kültürel açıdan zeki bireyler yetiştirmek için üniversitelerin, öğrencilerin kültürel zekâlarını geliştirmelerine yardımcı olacak stratejiler benimsemeleri gerekmektedir. Bu, çeşitli sınıf stratejileri, materyaller ve müfredatlar aracılığıyla yapılabilir. Ancak, sadece diğer kültürler hakkında bilgi edinmek, kültürel açıdan zeki olmak için yeterli olmamaktadır. Kültürler hakkında bilgi edinmek, öğrencilerin bilişsel kültürel zekâsını geliştirir; fakat kültürlerarası durumlarda etkili olmak için, kültürel zekânın dört faktörünün de geliştirilmesi gerekmektedir. Bu nedenle, üniversiteler ve eğitimciler, öğrencilerin kişisel deneyimler kazanmaları için fırsatlar sağlamalıdır (Gökten ve Emil, 2019: 771).

Farklı kültürel birikimlerin oluşturduğu kültürel zenginlik, bireylerin kendilerine daha fazla güvenmesine, risk almasına, çevresel farkındalığının artmasına yol açtığından bu durum bireylerin yenilikçi ve yaratıcı davranışlarda bulunmasına ve bunun sonucunda girişimcilik yöneliminin artmasına da katkıda bulunmaktadır (Yıldız, 2016: 97). Girişimcilik, yalnızca ekonomik kalkınma, yenilikçi yaklaşımların temel dinamiklerinden biri olmayıp, aynı zamanda üniversite öğrencilerinin iş yaşamlarında başarılı olma şanslarını da artırmaktadır (Akıncı, 2025: 111). Sonuç olarak, yükseköğretimde öğrencilerin kültürel zekâ gelişimini destekleyen eğitim programları, uluslararası deneyimler, çok kültürlü ortamlarda çalışma fırsatlarının oluşturulması ile öğrencilerin girişimcilik yönelimlerinin güçlendirilmesi sağlanabilecektir.

Bu çalışma, kültürel zekânın girişimcilik yönelimi üzerindeki etkisini ortaya koyarak literatüre katkıda bulunmaktadır. Fakat çalışmanın bazı sınırlılıkları bulunmaktadır. Çalışma, Gaziantep Üniversitesi, İlahiye İktisadi ve İdari Bilimler Fakültesi’nde öğrenim görmekte olan lisans öğrencileri ile sınırlıdır. Araştırma sonuçlarının genelleştirilmesi için farklı üniversitelerde öğrenim gören öğrencileri kapsayan bir örneklem seçilebilir. Ayrıca, gelecekte yapılacak çalışmalarda, kültürel zekâ ve girişimcilik yönelimi arasındaki ilişkide aracı değişkenlerin neler olduğu araştırılabilir.

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**THE RELATIONSHIP BETWEEN FINANCIAL DEVELOPMENT AND ECONOMIC GROWTH:
A STUDY WITHIN THE FRAMEWORK OF THEORETICAL APPROACHES**

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ABSTRACT

The relationship between financial development and economic growth has long been a central topic in the economic literature due to its importance for development strategies and policy design. However, there is no consensus on whether financial development drives economic growth or whether economic growth leads to financial development, which has resulted in different theoretical perspectives and raised questions about one-directional and universal explanations. In the literature, this relationship is commonly examined through three main approaches: supply-leading, demand-following, and feedback. The supply-leading approach suggests that financial system development promotes economic growth by mobilizing savings and facilitating investment. In contrast, the demand-following approach argues that economic growth in the real sector increases the demand for financial services, leading financial development to emerge as a consequence of growth. The feedback approach emphasizes a dynamic and reciprocal relationship in which financial development and economic growth mutually reinforce each other. This study examines the relationship between financial development and economic growth within the framework of these three approaches and evaluates their conceptual foundations from a holistic perspective. Financial development is addressed not only in terms of credit expansion but also through the efficiency of the financial system, effective resource allocation, and support for productive investments. Economic growth is also considered a demand-generating factor that may accelerate financial deepening. The main conclusion is that the relationship between financial development and economic growth cannot be fully explained by a single theoretical framework. While supply-leading and demand-following mechanisms may be relevant under certain conditions, they often operate simultaneously through mutual interaction. Therefore, this relationship should be assessed by considering countries' structural characteristics, institutional settings, and macroeconomic conditions. Analyzing these three approaches together provides a more comprehensive understanding of the finance–growth nexus.

Keywords: Financial development, Economic growth, Supply-side and demand-side hypotheses

ÖZET

Finansal gelişme ile ekonomik büyüme arasındaki ilişki, kalkınma stratejileri ve politika tasarımı açısından taşıdığı önem nedeniyle uzun süredir iktisat literatürünün temel konularından biri olmuştur. Ancak finansal gelişmenin ekonomik büyümeyi mi yönlendirdiği yoksa ekonomik büyümenin mi finansal gelişmeye yol açtığı konusunda bir uzlaşma bulunmamaktadır. Bu durum, farklı teorik yaklaşımların ortaya çıkmasına ve tek yönlü ya da evrensel açıklamaların sorgulanmasına neden olmuştur. Literatürde bu ilişki genellikle üç temel yaklaşım çerçevesinde incelenmektedir: arz öncüllü (supply-leading), talep takipli (demand-following) ve geri besleme (feedback) yaklaşımları. Arz öncüllü yaklaşım, finansal sistemin gelişiminin tasarrufları harekete geçirerek ve yatırımları kolaylaştırarak ekonomik büyümeyi teşvik ettiğini öne sürmektedir. Buna karşılık talep takipli yaklaşım, reel sektördeki ekonomik büyümenin finansal hizmetlere olan talebi artırdığını ve finansal gelişmenin büyümenin bir sonucu olarak ortaya çıktığını savunmaktadır. Geri besleme yaklaşımı ise finansal gelişme ile ekonomik büyümenin birbirini karşılıklı olarak güçlendirdiği dinamik ve karşılıklı bir ilişkiye vurgu yapmaktadır. Bu çalışma, finansal gelişme ile ekonomik büyüme arasındaki ilişkiyi bu üç yaklaşım çerçevesinde incelemekte ve söz konusu yaklaşımların kavramsal temellerini bütüncül bir bakış açısıyla değerlendirmektedir. Finansal gelişme yalnızca kredi genişlemesi açısından değil, aynı zamanda finansal sistemin etkinliği, kaynakların verimli tahsisi ve üretken yatırımların desteklenmesi boyutlarıyla ele alınmaktadır. Ekonomik büyüme ise finansal derinleşmeyi hızlandırabilecek talep yaratıcı bir unsur olarak değerlendirilmektedir. Temel sonuç, finansal gelişme ile ekonomik büyüme arasındaki ilişkinin tek bir teorik

çerçeveye tam olarak açıklanamayacağıdır. Arz öncüllü ve talep takipli mekanizmalar belirli koşullar altında geçerli olabilse de, çoğu zaman karşılıklı etkileşim yoluyla eş zamanlı olarak işlemektedir. Bu nedenle söz konusu ilişki, ülkelerin yapısal özellikleri, kurumsal yapıları ve makroekonomik koşulları dikkate alınarak değerlendirilmelidir. Bu üç yaklaşımın birlikte analiz edilmesi, finans-büyüme ilişkisinin daha kapsamlı bir şekilde anlaşılmasını sağlamaktadır.

Anahtar Kelimeler: Finansal gelişme, ekonomik büyüme, arz yönlü ve talep yönlü hipotezler

INTRODUCTION

Determinants of economic growth are one of the main research areas that have been discussed in the economic literature for a long time. Within these discussions, the role of financial systems in the economic growth process is of particular importance in both theoretical analyses and policy-oriented studies. The question of how and through which channels the development of financial markets and financial intermediation activities affects economic growth is critical in shaping development strategies, especially for developing and emerging economies. In this context, Singapore offers a remarkable example of examining the relationship between financial development and economic growth. Despite not having natural resources, Singapore has managed to become one of the high-income countries in a short time thanks to its strong institutional structure, open economy model and advanced financial infrastructure. The role of the financial system in this transformation process of the Singapore economy provides the opportunity to evaluate the theoretical discussions on the relationship between financial development and economic growth in a concrete framework. There is no common view in the literature on the relationship between financial development and economic growth. Some studies argue that the development of the financial system encourages investments by increasing the mobilization of savings and thus supports economic growth. On the other hand, some studies argue that economic growth increases the demand for financial services through the expansion it creates in the real sector and that financial development emerges as a result of growth. This difference of opinion reveals that the relationship between financial development and economic growth cannot be explained by a one-way and universal mechanism. In the literature, this relationship is generally discussed within the framework of three basic theoretical approaches. The supply-side approach argues that the financial system is the precursor of economic growth and that financial development initiates the growth process. According to this approach, the banking system and financial markets increase capital accumulation and support productive activities by directing savings to investments. The demand-side approach, on the other hand, argues that the demand for financial services increases as a result of the expansion created by economic growth in the real sector and that financial development emerges as a natural result of growth. The feedback approach, on the other hand, emphasizes that there is a reciprocal and dynamic interaction between financial development and economic growth; he argues that these two processes feed each other simultaneously (Patrick, 1966). The example of Singapore clearly demonstrates the importance of evaluating these three approaches together. While the strengthening of the financial infrastructure in the early development periods of the country supported economic growth, the increasing economic activities in the following periods contributed to the further deepening of the financial system. This shows that the relationship between financial development and economic growth is dynamic and reciprocal.

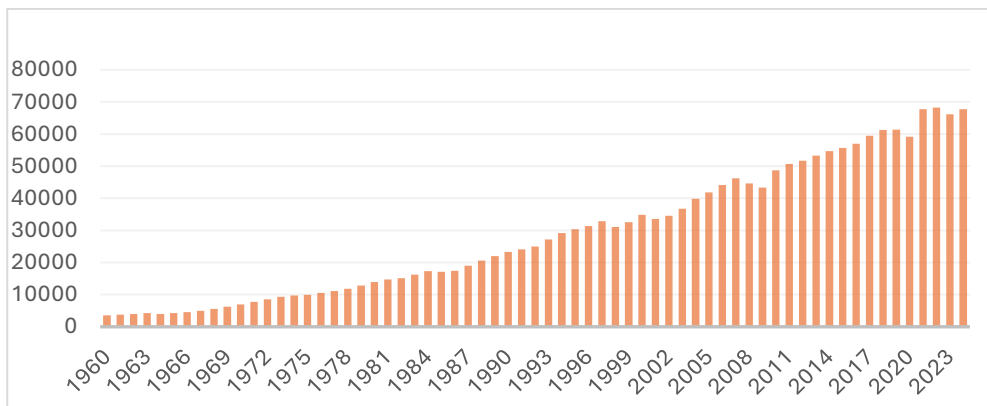


Figure 1. GDP per capita in Singapore (2015 constant US\$, 1960–2024), World Development Indicators

Figure 1 shows the long-term evolution of Singapore's gross domestic product per capita (in 2015 constant USD) over the period 1960–2024. Examining the chart, it is evident that Singapore's economy has a stable and

strong growth trajectory during the said period. The steady increase in per capita income since the 1960s is in line with the outward economic policies and export-oriented growth strategies adopted by Singapore in its early development period. In this period, the transition process from a low-income economy to a middle-income structure draws attention. Since the 1980s, it is seen that the increase in GDP per capita has accelerated and the economy has tended towards a higher value-added production structure. In the 1990s and beyond, the graph reveals that Singapore is included in the group of high-income countries. In this period, the development of the financial sector, the increase in international capital movements and the strengthening of the institutional structure are among the important determinants of the increase in per capita income.



Figure 2. Domestic Credit to the Private Sector and Gross Capital Formation (% GDP) in Singapore, World Development Indicators.

Figure 2 shows the share of domestic loans to the private sector in GDP and the ratio of gross capital formation to GDP in Singapore over time. When these two indicators are evaluated together, the dynamic nature of the relationship between financial development and real sector investments is clearly observed. The share of domestic loans to the private sector in GDP, shown in the green line in the graph, has generally shown a steady upward trend since the 1960s. This indicates that the financial system in Singapore has deepened over time, credit markets have expanded, and the private sector's access to finance has increased. The acceleration of the increase in loan volume, especially after the 1980s, coincides with the strengthening of the financial infrastructure and Singapore's becoming a regional financial center. On the other hand, the share of gross capital formation in GDP, shown in the purple line, follows a more fluctuating course. In the early development periods, the share of investments remained relatively high, and in the following years, a gradual decline in investment rates was observed with the maturation of the economic structure. This shows that the Singapore economy has shifted from a growth model based on intensive capital accumulation to a structure focused more on productivity growth, technology and financial services over time. An important point that draws attention in the graph is that the relationship between the increase in loan volume and investment rates is not one-to-one and simultaneous in every period. Especially in some periods, while credit expansion continues, investment rates follow a relatively flat or decreasing course, financial resources are not only for physical investments; services sector, financial activities and other productive areas. This shows that the effects of financial development on economic growth should be evaluated not only on the amount of investment but also on the effectiveness of resource allocation. In general, the graph reveals that the relationship between financial development and real sector activities in the case of Singapore is not one-way, but operates through different mechanisms in terms of periods. These findings support that the relationship between financial development and economic growth has a dynamic structure that requires supply-side, demand-side, and feedback approaches to be considered together.

The aim of this study is to discuss the relationship between financial development and economic growth from a theoretical and conceptual perspective within the framework of supply-side, demand-side and feedback approaches and to evaluate the explanatory nature of these approaches in the context of the Singapore economy. The study aims to emphasize that the effects of financial development on growth are not one-way and that this relationship should be handled in line with country-specific dynamics.

1. LITERATURE REVIEW

The relationship between financial development and economic growth has long been one of the main research areas of the economic literature. Lucas (1988), one of the early theoretical contributions, emphasized that human capital accumulation and externalities are the main drivers of growth, laying the groundwork for the role of the financial system in improving resource allocation and providing a theoretical framework for endogenous growth models. Subsequent empirical studies have begun to test the impact of financial deepening on growth with multi-country data sets. As a matter of fact, King and Levine (1993) showed that finance is an active mechanism that supports growth by revealing that the depth of the financial system and the efficiency of the banking sector are strongly related to long-term growth performance. These findings were later confirmed by Beck, Levine, and Loayza (2000) using large country samples; It has been shown that the development in the banking sector in particular has causal and strong effects on total factor productivity and per capita income growth.

By the end of the 1990s, it began to be discussed that the relationship was not only one-way. Harrison, Sussman, and Zeira (1999) argued that there is a bidirectional feedback mechanism between finance and growth, and that economic expansion increases financial efficiency by reducing intermediation costs, which in turn encourages investments. Wachtel (2001), who made a methodological evaluation of the literature, emphasized that although there is a generally positive relationship between financial depth and growth, the results are sensitive to data and model selection and emphasized that a cautious interpretation should be made.

Since the 2000s, studies have focused on the fact that the relationship is not linear and varies depending on country conditions. Rioja and Valev (2003) revealed that the impact of financial development on growth varies according to the level of financial depth, with weak effects at low levels, strong returns at medium levels, and diminishing returns at high levels. The Dritsaki and Dritsaki-Bargiota (2005) study on Greece found long-term cointegration between financial markets and growth and a bidirectional causality between the banking sector and growth. Similarly, Odhiambo (2008) found that causality can change direction depending on financial indicators in the case of Kenya, and most of the studies of Adamopoulos (2010) and Vazakidis and Adamopoulos (2009) found causality relationships that vary from credit market development to growth or from growth to finance, and revealed that the finance-growth link differs according to the country structure.

More recent research draws attention to the decisive role of institutional and macroeconomic conditions. Law, Azman-Saini and Ibrahim (2013) showed that the contribution of financial development to growth depends on corporate quality thresholds; revealed that financial deepening in weak institutional environments did not have a meaningful growth effect. Breitenlechner, Gächter and Sindermann (2015), who examined crisis periods, emphasized that the effect of finance is not linear, showing that the excessive growth of the financial sector can exacerbate economic contraction in times of crisis. Finally, country sample-based studies, such as Karimo and Ogbonna (2017), have supported the supply-antecedent hypothesis by finding one-way causality from financial deepening to growth in Nigeria. In parallel, Eschenbach (2004), who presents a comprehensive literature review, states that financial development generally supports growth, but the effects differ significantly according to country conditions, institutional structure and development stage.

In general, although the literature agrees that financial development supports economic growth in most cases, the direction, size and continuity of the relationship are not linear; It is seen that it varies depending on factors such as institutional quality, macroeconomic stability, financial depth level and crisis conditions.

2. SUPPLY-SIDE APPROACH

2.1. Theoretical Foundations and Mechanism of Operation

The supply-side approach argues that financial development is the precursor of economic growth and asserts that the financial system is a fundamental element that drives the real economy. The theoretical underpinnings of this approach are rooted in the view that financial intermediation accelerates economic development by supporting innovative investments. In particular, the fact that financial institutions act as an effective bridge between savers and investors makes it possible to direct capital to productive areas. This process contributes to the acceleration of capital accumulation and the support of technological progress (Schumpeter, 1911). The development of the financial system refers to a multidimensional process that is not limited to the increase in the volume of loans. The deepening of the banking system, the diversification of financial instruments and the

activation of risk management mechanisms reduce the cost of investment decisions and reduce uncertainty. This makes it easier to realize long-term and high-capital investments. McKinnon (1973) and Shaw (1973) emphasize that savings will increase with the reduction of financial pressure and financial liberalization, and these savings will support growth by directing them to investments. In this context, financial deepening is considered as one of the main drivers of economic growth. The effects of the supply-side approach are becoming more pronounced, especially in economies experiencing capital scarcity. In environments where financial markets are not sufficiently developed, investments remain limited and companies exhibit a structure dependent on internal resources. On the other hand, with the development of the financial system, the scale of economic activities expands, production capacity increases and the growth process accelerates. This situation reveals that financial development can be a prerequisite for economic growth. The case of Singapore provides a significant experience that illustrates the practical relevance of a supply-side approach. In the post-independence period, Singapore, despite having limited natural resources, has used the financial system as a strategic development tool. The regulatory and guiding role of the state in financial markets has enabled the banking sector to grow in a controlled but steady manner. In this process, financial resources were directed especially to industrial investments, export-oriented production and infrastructure projects; Thus, private sector investments were encouraged and the industrialization process was accelerated.

2.2. Validity Conditions of the Supply-Side Approach

The successful results of the supply-side approach depend not only on the quantitative growth of the financial system, but also on its effective and stable functioning. For financial development to support growth, information asymmetries must be reduced, resource allocation must be improved, and productive investments must be prioritized. Otherwise, financial expansion may lead to an increase in speculative activities and deepen financial vulnerabilities (Levine, 1997). In this context, the institutional structure and regulatory framework are critical for the validity of the supply-side approach. In countries where strong control mechanisms and macroeconomic stability cannot be achieved, financial development can increase economic fluctuations instead of supporting growth. Strict regulatory policies and prudent financial management have been decisive in the sustainability of the positive effects of financial development on growth in Singapore. This suggests that the supply-side approach can only be effective under favorable institutional conditions.

2.3. Evaluation in the Context of Developing Countries

The supply-side approach provides a strong theoretical framework, especially for developing countries. In economies where capital accumulation is insufficient and savings rates are low, the development of the financial system can serve as a catalyst that accelerates the growth process. The strengthening of financial intermediation activities facilitates the financing of investments and contributes to increasing production capacity. The role played by the financial system in Singapore's transition from a low-income economy to a high-income structure clearly reveals the explanatory power of the supply-side approach. The use of the financial system as a tool to support growth in the early development period has been decisive in the transformation of the economic structure. This experience shows that financial development in developing countries can have strong effects on economic growth if supported by appropriate policies and institutional arrangements.

3. DEMAND-SIDE APPROACH

3.1. Real Sector-Oriented Financial Development

The demand-side approach argues that financial development occurs as a result of economic growth. According to this approach, the economic growth process leads to the expansion of production capacity in the real sector, an increase in trade volume and the growth of the scale of firms. This expansion in the real sector increases the demand for financial services; The banking system and financial markets are developing to respond to this demand. Therefore, the financial system is shaped as a natural result of growth rather than an element that initiates economic growth (Robinson, 1952). While the growth in the real sector increases the investment, production and export activities of companies, it also increases the financing needs. The increasing need for financing brings about the expansion of credit mechanisms, the diversification of financial products and the structural transformation of financial institutions. In this process, although financial development plays

a supportive role in economic growth, it emerges as an output of the growth process, not a prerequisite for growth. In this respect, the demand-side approach emphasizes that financial development is shaped endogenously depending on the expansion of economic activities. The example of Singapore is among the economies where real sector-oriented financial development can be observed concretely. In particular, the successful implementation of the export-based growth strategy led to a rapid increase in production and trade volume; This has significantly increased the demand for financial services. The financial sector has deepened over time by responding to this increasing demand and has become an integral part of the economic structure.

3.2. Why Might the Financial System Be in a "Following" Position?

According to the demand-side approach, the main reason why the financial system is in a follow-up position is the decisive role of the real sector in the economic structure. The diversification of the production structure, the advancement of the industrialization process and the expansion of the services sector increase the need for financial intermediation activities. In this context, financial innovations and institutional developments emerge to respond to the needs of the real sector. Robinson (1952) emphasizes that economic growth triggers financial development and that the financial system exhibits a structure that follows the expansion of the real sector. Especially in countries that have completed the industrialization process to a large extent and whose economic activities have diversified, the financial system exhibits a structure that follows the transformation in the real sector. The growth of firms, the increase in foreign trade volume and the increase in income level increase the demand for financial services; Financial institutions are expanding to meet this demand. Patrick (1966) states that in the advanced stages of economic development, financial development predominantly follows growth. The rapid increase in per capita income in Singapore over time and the transformation of the economic structure from an industry-oriented model to a services-oriented structure accelerated the growth of the financial sector. In particular, the increase in the share of financial services, trade and logistics activities in the economy has triggered the expansion of the banking and finance sector. This process shows that economic growth and structural transformation increase the demand for financial services and is compatible with the demand-side approach, which argues that financial development occurs as a result of growth (Levine, 1997).

3.3. Demand-Side Approach for Advanced Economies

The demand-side approach is generally more explanatory in high-income economies with a largely established institutional structure. In such economies, the basic infrastructure of the financial system has been established in advance, and financial development progresses mostly depending on the expansion of economic activities. Patrick (1966) emphasizes that in the advanced stages of economic development, financial development acquires a growth-following character. The growth of the financial sector in Singapore's advanced development stages has largely followed economic expansion and has been responsive to the needs of the real sector. High income levels, increasing trade volume and developed services sector increased the demand for financial products and services; This demand has led to a further deepening of the financial system. In this context, the Singapore experience shows that the demand-side approach offers a strong explanation, especially for developed economies.

4. FEEDBACK APPROACH

4.1. Limitations of One-Way Approaches

Considering the relationship between financial development and economic growth only within the framework of supply-side or demand-side mechanisms is insufficient to explain the multidimensional and changing structure of economic processes over time. Unidirectional approaches reduce the interaction between the financial system and the real economy to a static framework and may ignore the dynamics that countries face at different stages of development. For this reason, approaches arguing that the relationship between financial development and economic growth should be evaluated in mutual interaction have become increasingly important in the literature (Arestis & Demetriades, 1997). Empirical studies show that financial development supports economic growth in some periods, while growth deepens the financial system in some periods. These findings indicate that the direction of the finance-growth relationship may change depending on time, country characteristics and institutional structures. Therefore, it does not seem possible to explain the relationship

between financial development and economic growth with a one-way and universal mechanism (Demetriades & Hussein, 1996).

4.2. Mutual and Dynamic Interaction

The feedback approach argues that there is a two-way and dynamic interaction between financial development and economic growth. According to this approach, the development of the financial system supports economic growth by increasing investments and activating resource allocation; economic growth, on the other hand, contributes to the further deepening of the financial system by increasing the demand for financial services. Thus, a process of interaction emerges between finance and growth that strengthens itself over time. This mutual relationship becomes more evident especially in the middle and advanced stages of the economic development process. Greenwood and Jovanovic (1990) emphasize that financial development and economic growth evolve together and that these two processes feed each other and shape long-term development performance. Similarly, Rajan and Zingales (1998) reveal that growth opportunities can be evaluated more effectively in economies with developed financial systems, and growth encourages the expansion of financial markets. The example of Singapore concretely reflects this dynamic interaction. When the country's long-term growth performance and the deepening of the financial system are evaluated together, it is seen that the increase in the volume of loans and the diversification of financial services are progressing simultaneously with economic growth. This shows that the relationship between financial development and growth exhibits a reciprocal and dynamic structure.

4.3. Corporate Structure, Stability and Singapore Experience

The sustainable functioning of the feedback mechanism depends on the conditions of strong institutional structure and macroeconomic stability. In order for the financial system to play a role in supporting growth, the legal infrastructure must be sound, regulatory institutions must work effectively and financial stability must be maintained. Otherwise, the interrelationship between financial development and growth may become fragile. The strong financial regulatory framework in Singapore and the stable macroeconomic policies followed for many years have enabled the feedback mechanism to function effectively. While the financial system supports economic growth; growth also contributed to the deepening of the financial sector and the increase of international competitiveness. In this context, the Singapore experience clearly reveals that the feedback approach cannot be evaluated without taking into account country-specific institutional conditions.

CONCLUSION

This study aims to reveal that the relationship between financial development and economic growth cannot be explained by a one-way and universal mechanism by considering the relationship between supply-side, demand-side and feedback approaches. Observations on the Singapore economy, as well as theoretical literature, show that the finance-growth relationship exhibits different dynamics depending on the development stages, institutional structures, and macroeconomic conditions of the countries. One of the main findings of the study is that the effects of financial development on economic growth have a changing structure over time. In the case of Singapore, the strengthening of financial infrastructure and the development of credit mechanisms during early development periods indicate a supply-side operation that supports economic growth. In this period, the financial system was used as a development tool that accelerated capital accumulation and supported the industrialization process. On the other hand, with the maturation of the economic structure and the increase in the per capita income level, the expansion in the real sector increased the demand for financial services; The financial system has deepened to meet this demand. This shows that the demand-side approach has become more explanatory, especially in advanced development stages. However, the Singapore experience reveals that the relationship between financial development and economic growth often operates within the framework of a feedback mechanism. While the financial system supports growth, growth encourages the expansion and diversification of financial markets. This mutual interaction gains a sustainable quality when supported by a strong institutional structure, effective regulatory framework and macroeconomic stability. Therefore, explaining the finance-growth relationship only with supply-side or demand-side approaches is insufficient for dynamic economies such as Singapore. In the light of these findings, the main contribution of

the study to the literature is that it emphasizes that the relationship between financial development and economic growth is not static, but a dynamic and stage-dependent process.

The study shows that different theoretical approaches are not mutually exclusive but rather offer frameworks that complement each other under specific conditions. In this respect, the research draws attention to the need for a holistic evaluation in the finance-growth literature. From a policy perspective, the results offer important implications. First of all, it is not enough to focus only on increasing the volume of loans in order for financial development in developing countries to support economic growth. Institutional arrangements, effective audit mechanisms and financial stability policies that will ensure that financial resources are directed to productive investments are of great importance. The case of Singapore clearly shows that the regulatory role of the state and institutional quality strengthen the effects of financial development on growth. Second, policymakers in advanced economies should not automatically view the growth of the financial sector as a guarantee of economic growth. The nature of economic growth, resource allocation between sectors and the efficiency of the financial system are among the main factors that determine the effects of financial development on growth. For this reason, financial development policies should be designed in line with the needs of the real sector and long-term development goals.

Finally, it is concluded that the relationship between financial development and economic growth should be evaluated by taking into account country-specific conditions. Instead of uniform policy prescriptions, developing strategies suitable for the development level, institutional structure and economic priorities of countries will ensure that the finance-growth relationship operates on a healthier and more sustainable basis. In this context, the Singapore experience shows that financial development can only make lasting contributions to economic growth when it is combined with strong institutions, stable policies and a long-term development vision.

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A CONCEPTUAL ANALYSIS ON THE ROLE OF VIRTUAL INFLUENCERS IN MARKETING COMMUNICATION, TRUST DYNAMICS, AND THEORETICAL LIMITS

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ABSTRACT

The simultaneous advancements in Web 3.0, generative artificial intelligence (GenAI), and computer graphics (CGI) have created a new phenomenon that challenges the dominance of "human" subjects in marketing communication: Virtual Influencers. These characters, entirely coded in a digital environment (e.g., Lil Miquela, Imma), are signing multi-million dollar collaborations with global brands and managing vast follower bases. This study aims to conceptually examine the virtual influencer ecosystem in light of existing literature, global trends, and fundamental marketing theories, without relying on a quantitative data collection process. The study examines the strategic advantages that virtual influencers offer to brands, such as "complete controllability," "zero crisis risk," and "scalability." The consumer behavior dimension is analyzed within the framework of Parasocial Interaction Theory (the one-sided bond a consumer forms with a digital character) and Uncanny Valley Theory (the risk of repulsion created by the excessive human resemblance of the digital character). The synthesized studies show that virtual influencers can create a sense of "technological authenticity," particularly for Gen Z and Alpha generations, but that "human perfection" harbors a paradox that needs to be empirically tested in long-term trust building. Consequently, this paper treats virtual influencers not merely as a technological innovation, but as a paradigm shift in marketing theory that redefines the concept of "authenticity." The study offers a conceptual model proposal for practitioners regarding virtual character selection and content strategies, and points to theoretical gaps for future empirical research.

Keywords: Virtual Influencer, AI Marketing, Digital Anthropomorphism, Parasocial Interaction, Uncanny Valley, Coded Authenticity.

SANAL INFLUENCERLARIN PAZARLAMA İLETİŞİMİNDEKİ ROLÜ, GÜVEN DİNAMİKLERİ VE TEORİK SINIRLARI ÜZERİNE KAVRAMSAL BİR ANALİZ

ÖZET

Web 3.0, üretken yapay zeka (GenAI) ve bilgisayar grafik teknolojilerindeki (CGI) eşzamanlı gelişmeler, pazarlama iletişimde "insan" öznelerin hakimiyetini tartışmaya açan yeni bir fenomen yaratmıştır: Sanal Influencerlar. Tamamen dijital ortamda kodlanan bu karakterler (örn. Lil Miquela, Imma), küresel markalarla milyon dolarlık iş birliklerine imza atmakta ve geniş takipçi kitlelerini yönetmektedir. Bu çalışma, nicel bir veri toplama sürecine dayanmaksızın, sanal influencer ekosistemini mevcut literatür, küresel trendler ve temel pazarlama teorileri ışığında kavramsal olarak incelemeyi amaçlamaktadır. Çalışma kapsamında, sanal influencerların markalar için sunduğu "tam kontrol edilebilirlik", "sıfır kriz riski" ve "ölçeklenebilirlik" gibi stratejik avantajlar masaya yatırılmaktadır. Tüketici davranışı boyutu ise Parasosyal Etkileşim Teorisi (tüketicinin dijital bir karakterle kurduğu tek taraflı bağ) ve Tekinsiz Vadi (Uncanny Valley) Teorisi (dijital karakterin insana aşırı benzemesinin yarattığı iticilik riski) çerçevesinde analiz edilmektedir. Sentezlenen çalışmalar, sanal influencerların özellikle Gen Z ve Alpha kuşakları için "teknolojik bir samimiyet" algısı yaratabildiğini, ancak "insani kusursuzluğun" uzun vadeli güven inşasında ampirik olarak test edilmesi gereken bir paradoks barındırdığını göstermektedir. Sonuç olarak bu bildiri, sanal influencerları sadece teknolojik bir yenilik değil, pazarlama teorisinde "sahicilik" (authenticity) kavramının yeniden tanımlandığı bir paradigma değişimi olarak ele almaktadır. Çalışma, uygulayıcılar için sanal karakter seçimi ve içerik stratejilerine dair kavramsal bir model önerisi sunmakta ve gelecekteki ampirik araştırmalar için teorik boşlukları işaret etmektedir.

Anahtar Kelimeler: Sanal Influencer, Yapay Zeka Pazarlaması, Dijital Antropomorfizm, Parasosyal Etkileşim, Tekinsiz Vadi, Kodlanmış Sahicilik

GİRİŞ

Pazarlama iletişimi, kitle iletişim araçlarının tek yönlü mesaj iletiminden sosyal medyanın interaktif ve çok sesli evrenine evrildiği son yirmi yılda radikal bir dönüşüm geçirmiştir. Bu dönüşümün merkezinde yer alan influencer marketing (etkileyici pazarlaması), markaların tüketiciye ulaşmak için "insan" araçları kullanma stratejisi üzerine inşa edilmiştir. Ancak teknolojik ilerlemeler, özellikle bilgisayar üretilmiş imgeleme (CGI) ve üretken yapay zeka (GenAI) teknolojilerinin sofistikasyon düzeyi, pazarlama sahnesine yeni bir aktör dahil etmiştir: Sanal Influencerlar (Virtual Influencers - VIs). Bu karakterler, fiziksel bir bedene sahip olmamalarına rağmen milyonlarca takipçiye hitap eden, toplumsal meselelerde görüş bildiren ve küresel markaların yüzü haline gelen dijital varlıklardır (Arsenyan ve Mirowska, 2021).

Sanal influencer pazarının büyüklüğü ve hızı, geleneksel pazarlama varsayımlarını derinden sarsmaktadır. Küresel influencer pazarlamasının toplam değerinin 2023 yılında 21.1 milyar dolara ulaştığı ve sanal influencer pazarının 2030 yılına kadar yıllık bileşik büyüme oranının (CAGR) %39 civarında seyretmesi beklediği göz önüne alındığında, bu payın önemli bir kısmının sanal karakterlere kaydığı görülmektedir (Grand View Research, 2024; Srivastava ve ark., 2024). Bu durum, sadece bir teknolojik trend değil, aynı zamanda tüketicinin "gerçeklik", "sahicilik" ve "güven" kavramlarına yüklediği anlamların da dijitalleştiği bir paradigma değişimini temsil etmektedir.

Geleneksel pazarlama iletişiminde kaynak güvenilirliği, aktörün dürüstlüğü ve uzmanlığına dayanırken; sanal influencerlar için bu durum "kodlanmış bir sahicilik" (coded authenticity) paradoksu üzerine kuruludur (Yan ve ark., 2024). Tüketiciler, bu karakterlerin birer bilgisayar yazılımı olduğunu bilmelerine rağmen onlarla parasosyal bağlar kurmakta ve tavsiyelerine güvenmektedir. Bu çalışma, sanal influencerların pazarlama iletişimindeki rollerini kavramsal bir boyutta analiz etmeyi, bu süreçteki güven dinamiklerini incelemeyi ve teorik sınırları belirlemeyi amaçlamaktadır.

KAVRAMSAL TEMELLER VE TEKNOLOJİK EKOSİSTEM

Sanal influencerlar, bilgisayar yazılımları aracılığıyla oluşturulan, kişiselleştirilmiş bir kimliğe, geçmiş hikayesine (backstory) ve estetik bir görünüme sahip dijital karakterlerdir (Moustakas ve ark., 2020). Bu fenomenin arkasında sadece görsel tasarım değil, Web 3.0'ın merkeziyetsiz yapısı ve üretken yapay zekanın (GenAI) içerik üretim hızı yatmaktadır.

Sanal Influencer Tipolojisi ve Tasarım Dinamikleri

Sanal influencerlar, temsil ettikleri gerçeklik düzeyine göre üç ana grupta sınıflandırılmaktadır (Yan ve ark., 2024; Böhdnel ve ark., 2023):

- **İnsan-Taklit (Human-Mimic):** Hiper-gerçekçi, insandan ayırt edilmesi zor tasarımlardır (örn. Lil Miquela, Imma). Bu karakterler lüks moda ve inovasyon odaklı kampanyalarda tercih edilmektedir.
- **Stilize/Anime (Animated):** Çizgi film veya oyun estetiğinde kurgulananlar (örn. Noonouri). Bu türler, gerçeklik iddiası sınırlı olduğu için "oyunsal samimiyet" üzerinden bağ kurar.
- **İnsan Dışı (Non-Human):** Hayvanlar veya hayali varlıklar (örn. @bee_nfluencer). Antropomorfizm ilkesi gereği nesnelere insani değerler yükleyerek sempatik marka kimliği oluştururlar.

Dijital Antropomorfizm ve CASA Paradigması

Sanal influencerların başarısının arkasındaki temel psikolojik mekanizma "Dijital Antropomorfizm"dır. Byron Reeves ve Clifford Nass tarafından geliştirilen **CASA (Computers Are Social Actors)** paradigması, insanların birer yazılım olduğunu bildikleri varlıklara bile tıpkı sosyal aktörlermiş gibi karşılıklılık ve güven duygularıyla tepki verdiğini savunmaktadır (Zhou ve ark., 2024). 2025 yılı verileri, sanal karakterlerin moral erdem ve bilişsel deneyim sergilediği durumlarda takipçilerle kurulan parasosyal bağların, insan influencerlarla yarışır düzeye ulaştığını doğrulamaktadır (Goel ve Garg, 2025).

PAZARLAMA İLETİŞİMİNDEKİ STRATEJİK ROLÜ VE AVANTAJLARI

Markalar için sanal influencer kullanımı, sadece bir inovasyon gösterisi değil, aynı zamanda operasyonel mükemmellik ve risk yönetimi arayışdır. Sanal karakterler, insan influencerların taşıdığı pek çok yapısal sınırlılığı bertaraf etmektedir.

- **Tam Kontrol ve Marka Güvenliği:** İnsan influencerlar doğası gereği hatalar yapabilir veya kişisel krizler yaşayabilir. Oysa sanal influencerlar, tamamen markanın kontrolü altındaki "kodlanmış varlıklar"dır ve "sıfır kriz riski" sunarlar (Arsenyan ve Mirowska, 2021).
- **Ölçeklenebilirlik:** Sanal influencerlar 7/24 aktif olabilir, aynı anda dünyanın farklı yerlerinde kampanya yürütebilir ve fiziksel sınırlamaları ortadan kaldırır (Bradley, 2021).
- **Maliyet Verimliliği:** Başlangıç tasarımı maliyetleri yüksek olsa da, uzun vadede mega-influencer ücretlerinden tasarruf edilmesini sağlar ve markaya ait kalıcı bir dijital varlık (digital asset) yaratır (Moustakas ve ark., 2020).
- **Yaratıcı Sınırlar:** Sanal influencerlar fizik kanunlarına tabi değildir. Bu özellik, pazarlama iletişimde yerçekimsiz ortamda ürün tanıtımı gibi gerçeküstü senaryoların hayata geçirilmesini sağlar (Shi ve ark., 2024).

GÜVEN DİNAMİKLERİ VE KODLANMIŞ SAHİCİLİK PARADOKSU

Pazarlama literatüründe güven, genellikle "sahicilik" (authenticity) kavramıyla ilişkilendirilir. Sanal influencerlar için "sahicilik", ontolojik bir gerçeklikten ziyade bir "tasarım ve iletişim tutarlılığı" meselesidir.

Kodlanmış Sahicilik ve Dürüst Sahtelik (Honest Fakery)

Kodlanmış sahicilik, bir dijital varlığın kurgu olduğunun dürüstçe kabul edilmesi ancak bu kurgunun kendi içinde tutarlı, değer odaklı ve takipçisiyle duygusal bir rezonans kurabilen bir yapıya sahip olmasıdır (Belanche ve ark., 2024). Örneğin, Lil Miquela'nın paylaşımlarında "Ben bir robotum" diyerek takipçileriyle şeffaf bir ilişki kurması "honest fakery" (dürüst sahtelik) olarak tanımlanmakta ve paradoksal bir şekilde güveni artırmaktadır (Bitencourt ve ark., 2021).

Kaynak Güvenilirliği Adaptasyonu

Hovland'ın Kaynak Güvenilirliği Modeli sanal influencerlara uyarlandığında; çekicilik, uzmanlık ve dürüstlük boyutları kritik rol oynamaktadır. Ancak 2025 yılı araştırmaları, sanal influencerların "zihinsel insan-benzerliği" (mental human-likeness) algısının, fiziksel benzerlikten daha güçlü bir güven inşa ettiğini ortaya koymuştur (Goel ve Garg, 2025). Bilişsel antropomorfik özelliklerin (akıl yürütme, empati) bilişsel güveni; sahicilik algısının ise duyuşsal güveni beslediği saptanmıştır.

ARAŞTIRMA VE GELİŞME: KURAMSAL TARTIŞMA VE BULGULARIN SENTEZİ

Sanal influencerların etkinliği, derin psikolojik mekanizmaların doğru yönetilmesiyle mümkündür. Literatürdeki son bulgular, bu sürecin üç kritik ekseninde (Tekinsiz Vadi, Parasosyal Etkileşim ve Zihinsel Algı) şekillendiğini göstermektedir.

Tekinsiz Vadi (Uncanny Valley) ve Sosyal İpuçlarının Rolü

Masahiro Mori tarafından 1970'te ortaya atılan Tekinsiz Vadi hipotezi, bir varlığın insan benzerliği arttıkça sempatinin arttığını, ancak benzerlik "neredeyse insan" seviyesine ulaştığında bu sempatinin yerini ani bir huzursuzluk ve tiksinnmeye bıraktığını savunur. Rizzo ve ark. (2025) tarafından yapılan araştırmalar, bu bariyerin aşılmasında "sesli sosyal ipuçlarının" (voice cues) kritik rol oynadığını ortaya koymuştur. Bulgular, karakterlere eklenen "insan benzeri seslerin" sosyal mevcudiyet algısını artırarak Tekinsiz Vadi'nin yarattığı negatif tutumu %19 oranında azalttığını göstermektedir.

Parasosyal Etkileşim ve "Teknolojik Samimiyet"

Parasosyal Etkileşim (PSI), tüketicinin bir ekran figürüyle kurduğu tek taraflı ama psikolojik olarak gerçek bağdır. Sanal influencerlar, her an ulaşılabilir olmaları ve takipçileriyle birebir etkileşime girmeleri sayesinde bu bağı "karşılıklı parasosyal etkileşime" dönüştürmektedir (Belanche ve ark., 2024). Özellikle Gen Z tüketicilerinin %55'inin takip ettikleri bir sanal influencer aracılığıyla satın alma gerçekleştirmesi, bu

"teknolojik samimiyetin" (technological intimacy) ticari bir dönüşüme sahip olduğunu kanıtlamaktadır (Srivastava ve ark., 2024).

Zihinsel Algı ve Ürün Uyumu (Mind Perception)

2024-2025 ampirik çalışmaları, sanal influencerların "zihinsel algı" (mind perception) düzeylerinin ürün tipine göre etkinliğini belirlediğini göstermektedir. Sanal influencerlar, "ajans" (bilgi işlem, analitik yetenek) boyutu yüksek algılandıkları için faydacı (utilitarian) ürünlerde; insan influencerlar ise "deneyim" boyutu yüksek algılandıkları için hedonik (duygusal haz odaklı) ürünlerde daha etkilidir (Yan ve ark., 2024).

VAKA ANALİZLERİ VE AMPİRİK KANITLAR

IKEA Japonya ve Imma: "Happy Home" Kampanyası

2020 yılında IKEA Japonya, sanal model Imma ile Harajuku mağazasının vitrininde 3 günlük bir kampanya yürütmüştür. Imma, LED ekranlar aracılığıyla vitrinde "yaşamış" ve bu durum sosyal medyada gerçek zamanlı paylaşılmıştır (Moustakas ve ark., 2020; Designboom, 2020). Kampanya, sanal bir varlığın yaşam tarzı elçisi olarak konumlandırılmasının, markanın modern ve yenilikçi imajını pekiştirdiğini kanıtlamıştır.

De-Influencing ve Sahicilik Paradoksu

Yeni bir akım olan "de-influencing" (tüketimi caydırma), sanal influencerlar için ilginç bir fırsat sunmaktadır. Araştırmalar, sanal influencerların bir ürünü eleştirmesi durumunda (de-influencing), takipçilerin bu davranışı "dürüstlük sinyali" olarak algıladığını ve bu durumun sanal karakterin "varoluşsal sahicilik açığı" (existential authenticity deficit) %34.7 oranında kapattığını göstermektedir (MDPI, 2025).

ETİK SINIRLAR VE GELECEKTEKİ RİSKLER

Sanal influencer ekosistemi, beraberinde ciddi etik ve hukuki tartışmaları da getirmektedir:

- **AI İfşası (Disclosure):** Tüketicilerin %42'sinin takip ettikleri karakterin yapay olduğunu fark etmemesi, şeffaflık ve manipülasyon tartışmalarını doğurmaktadır (Alboqami, 2023).
- **Güzellik Standartları:** Biyolojik olarak imkansız bir kusursuzluğu temsil eden sanal karakterler, genç kitlelerde yetersizlik hissine ve gerçek dışı estetik beklentilere yol açabilir (Srivastava ve ark., 2024).
- **Veri Gizliliği:** Algoritmalar aracılığıyla takipçi verilerini analiz eden sanal karakterler, tüketicinin duygusal zaaflarını ticari amaçla kullanma riski taşımaktadır (Yan ve ark., 2024).

SONUÇ VE ÖNERİLER

Sanal influencerlar, pazarlama iletişimde sadece teknolojik bir araç değil, "sahicilik" kavramının yeniden tanımlandığı bir paradigma değişimidir. Bu çalışma sonucunda ulaşılan temel yargılar şunlardır:

1. **Güvenin Yeni Kaynağı:** Sahicilik artık biyolojik gerçeklikten ziyade anlatı tutarlılığı ve şeffaflık üzerine inşa edilmektedir. "Dürüst sahtelik" stratejisi, güven inşasında kritik bir araçtır.
2. **Psikolojik Denge:** Başarı, Tekinsiz Vadi riskini minimize ederken Parasosyal Etkileşimi maksimize eden dengeye bağlıdır.
3. **Hibrit Pazarlama:** Sanal influencerlar, insan influencerların yerine tamamen geçmek yerine, markanın teknolojik vizyonunu temsil eden tamamlayıcı birer elçi olarak konumlandırılmalıdır.

Uygulayıcılar İçin Öneriler:

- Karakterin yapay zeka ürünü olduğu açıkça belirtilmeli (AI Disclosure), dürüstlük üzerinden güven devşirilmelidir.
- Gen Z ve Alpha kuşakları için sadece görsel kusursuzluk değil, duygusal derinliği olan hikaye anlatıcılığına odaklanılmalıdır.

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A REVIEW ON THE ROLE OF USER-GENERATED CONTENT (UGC) IN MARKETING COMMUNICATIONS AND TRUST DYNAMICS

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ABSTRACT

In today's digitizing marketing landscape, traditional advertising models are undergoing a transformation due to increasing consumer skepticism and ease of access to information. In this process, "User-Generated Content" (UGC)—content produced and shared directly by consumers rather than messages under the unilateral control of brands—has become one of the most prominent tools of modern marketing communications. UGC offers a sincerity-oriented form of communication encompassing the real experiences and comments of consumers regarding a brand or product. The primary objective of this study is to review the role of the UGC concept in marketing communications and its effects on trust dynamics among consumers based on a literature review. Within the scope of this review, the fundamental function of "authenticity" and "social proof" elements provided by UGC in building brand trust is addressed. The tendency of consumers to trust the experiences of individuals with similar profiles rather than professional advertising messages brings along shifts in marketing strategy approaches. Consequently, this review provides a conceptual evaluation emphasizing that UGC is not merely a content type in modern marketing strategies but a strategic component for a transparent and trust-oriented communication language with consumers.

Keywords: UGC, Marketing Communications, Consumer Trust, Authenticity, Social Proof.

KULLANICI TARAFINDAN OLUŞTURULAN İÇERİKLERİN (UGC) PAZARLAMA İLETİŞİMİNDEKİ ROLÜ VE GÜVEN DİNAMİKLERİ ÜZERİNE BİR İNCELEME

ÖZET

Dijitalleşen pazarlama dünyasında geleneksel reklam modelleri, tüketicilerin artan şüpheci yaklaşımları ve bilgiye erişim kolaylığı nedeniyle dönüşüme uğramaktadır. Bu süreçte, markaların tek taraflı kontrolünde olan mesajlardan ziyade, doğrudan tüketiciler tarafından üretilen ve paylaşılan "Kullanıcı Tarafından Oluşturulan İçerikler" (UGC), modern pazarlama iletişiminin en dikkat çeken araçlarından biri haline gelmiştir. UGC; tüketicilerin bir marka veya ürün hakkındaki gerçek deneyimlerini ve yorumlarını kapsayan, samimiyet odaklı bir iletişim biçimi sunmaktadır. Bu çalışmanın temel amacı, UGC kavramının pazarlama iletişimindeki rolünü ve bu içeriklerin tüketici nezdindeki güven dinamikleri üzerindeki etkilerini literatür taraması temelinde incelemektir. İnceleme kapsamında, UGC'nin sunduğu "otantiklik" ve "sosyal kanıt" (social proof) unsurlarının, markaya duyulan güveni inşa etmedeki temel işlevi ele alınmaktadır. Tüketicilerin, profesyonel reklam mesajları yerine kendileriyle benzer profildeki bireylerin deneyimlerine güvenme eğilimi, pazarlama stratejilerindeki yaklaşım değişimlerini de beraberinde getirmektedir. Sonuç olarak bu inceleme, modern pazarlama stratejilerinde UGC'nin sadece bir içerik türü değil, tüketicilerle kurulacak şeffaf ve güven odaklı bir iletişim dili için stratejik bir bileşen olduğunu vurgulayan kavramsal bir değerlendirme sunmaktadır.

Anahtar Kelimeler: UGC, Pazarlama İletişimi, Tüketici Güveni, Otantiklik, Sosyal Kanıt.

GİRİŞ

Pazarlama iletişimi, 2020'li yılların başından itibaren teknolojik sıçramalar ve toplumsal etkileşim biçimlerinin radikal evrimiyle birlikte tarihsel bir paradigma değişimi yaşamaktadır. Geleneksel pazarlama anlayışının temel taşı olan dikey ve tek yönlü iletişim modelleri, yerini tüketicinin içeriği üreten, şekillendiren ve dağıtan bir "ortak yaratıcı" (co-creator) olduğu katılımcı ve yatay bir yapıya bırakmıştır (Mere ve ark., 2024). 2026 yılının hiper-dijitalleşmiş ekosisteminde, bilgiye erişimin demokratikleşmesi tüketicileri her zamankinden daha bilgili kılarken, reklam mesajlarına karşı "seçici bir şüphecilik" (selective skepticism) geliştirmelerine

neden olmuştur (Wang ve ark., 2025). Bu süreçte kurumsal otorite zayıflamış ve stratejik güç, markalardan "akran topluluklarına" (peer communities) geçmiştir (Konak, 2024).

Günümüzde "Kullanıcı Tarafından Oluşturulan İçerik" (User-Generated Content - UGC), markaların steril ve kurgulanmış reklam mesajlarına karşı "yeni dürüstlük birimi" (unit of honesty) olarak kabul edilmektedir (Kostić ve ark., 2026). Özellikle yapay zeka destekli içeriklerin (AIGC) dijital platformları domine etmesi ve "derin sahtecilik" (deepfake) endişelerinin artması, tüketicilerde "sahicilik" (authenticity) arayışını bir lüksten ziyade ontolojik bir zorunluluğa dönüştürmüştür (Park ve ark., 2024). Bu bağlamda UGC, sadece bir enformasyon kaynağı değil, aynı zamanda markanın kurumsal maskesini indirip gerçek insan deneyimleriyle bağ kurmasını sağlayan en stratejik güven inşa aracıdır.

Bu araştırma raporunda analiz edilen 46 akademik çalışmanın seçimi, pazarlama disiplinindeki bu dramatik dönüşümü ampirik ve teorik olarak en rafine haliyle yansıtabilmek amacıyla şu kriterlere dayandırılmıştır:

- Zaman Aralığı ve "Büyük Kırılma" (2020-2026):** Bu zaman dilimi, dijital pazarlamanın olgunluk evresini temsil eder. 2020 yılı, küresel pandeminin dijitalleşmeyi zorunlu kıldığı bir başlangıç noktasıyken; 2026 yılı, yapay zekanın (AI) ve sosyal ticaretin (s-commerce) pazarlama iletişimiyle tam entegre olduğu bir zirve noktasıdır.
- Metodolojik Yetkinlik ve PRISMA 2020:** Analiz, yalnızca *Journal of Business Research*, *Sustainability*, *Journal of Retailing and Consumer Services* ve *California Management Review* gibi prestijli veri tabanlarında yayımlanan makaleleri kapsamaktadır. Sistemik literatür taraması (SLR) süreçlerinde PRISMA 2020 standartlarını takip eden çalışmalara öncelik verilmiştir (Page ve ark., 2021).
- Güvenin Beş Boyutlu Modeli:** Eserler; "Güven, Otantiklik, Risk, Katılım ve Sadakat" boyutlarını bütüncül bir şekilde ele alan, sosyal ticaret ortamlarındaki kullanıcı davranışlarını bilişsel ve duygusal düzeyde analiz eden çalışmalar arasından seçilmiştir (Kostić ve ark., 2026).

Akademik Literatür Envanteri (2020-2026)

Aşağıdaki tablo, analiz edilen 46 temel çalışmanın kronolojik dağılımını ve odak alanlarını özetlemektedir:

Tablo 1. 2020-2026 literatür analizi

Yıl	Yazarlar	Yayın (Dergi/Yayınevi)	Çalışma Konusu
2026	Kostić, S. ve ark.	Sustainability	UGC ve güvenin 5 boyutlu (Güven, Otantiklik, Risk, Katılım, Sadakat) bütünlüklü SLR sentezi.
2025	Sujatmiko, S. ve ark.	Golden Ratio	Turizm pazarlamasında UGC'nin destinasyon imajı üzerindeki %79'luk güven artırıcı etkisi.
2025	Firdaus, A.	Oikonomia	Sosyal medyada UGC'nin marka imajını kolektif olarak inşa etme süreçleri.
2025	Keskin Yılmaz, Y.	Sos. Bil. Ens. Der.	Dijital reklam mesajlarına karşı gelişen "seçici şüphecilik" ve savunma mekanizmaları.

2025	Suryatini, N. W. ve ark.	Jurnal Komunikasi Ind.	Instagram platformunda UGC'nin evrimi ve pazarlama endüstrisine sağladığı avantajlar.
2025	Wang, L. ve ark.	Info. Processing	Sosyal ticaret platformlarında içerik kalitesine yönelik kullanıcı şüpheliği analizi.
2025	Shantilawati, I. ve ark.	Oikonomia	Marka kişiliğinin (samimiyet ve yetkinlik) kullanıcı yorumları üzerinden güvene dönüşümü.
2025	Trivedi, P. & Chitraju, S.	Preprints.org	Kaynak çeşitliliğinin influencer güvenilirliği üzerindeki kritik etkisi.
2025	Tran, T. & Hang, L.	PLOS ONE	UGC'nin yeşil ürün tercihlerinde ve sürdürülebilir tüketim kararlarındaki rolü.
2025	Hu, H.	DergiPark	Yeni medya araçlarının tüketici algısını ve marka farkındalığını şekillendirme gücü.
2024	Park, S. ve ark.	California Mgmt Review	İnsan üretimi UGC'nin AI içeriklerine (AIGC) göre %40 daha fazla duygusal rezonans yaratması.
2024	Mere, S. ve ark.	Oikonomia	Tüketicilerin dijital topluluklarda marka değerinin "ortak yaratıcısı" (co-creator) olması.
2024	Konak, Y.	Marketing & Dig. Tech.	Kontrolün markadan kullanıcıya geçişi (Power Shift) ve bunun stratejik sonuçları.
2024	Hughes, B. ve ark.	PMC / Heuristics	Onaylanmış hesapların bilişsel bir kısayol olarak güven algısına etkisi.
2024	Lyu, J. ve ark.	Sustainability	UGC kalitesinin s-ticarete güven inşasındaki temel fonksiyonu.
2024	Ahmed, R. & Aziz, N.	Trust Theory	Platform güvenliğinin UGC katılımı üzerindeki modere edici rolü.

2024	Liu, X. ve ark.	Sustainability	Marka güveninin kullanıcı sadakati üzerindeki tam aracılık etkisinin analizi.
2024	Wu, H. ve ark.	Sustainability	Sosyal medya pazarlamasının son 10 yıllık bibliyometrik ve tematik evrimi.
2024	Kim, J. ve ark.	Sustainability	Sosyal ticarete satın alma niyetini etkileyen değişkenlerin meta-analizi.
2024	Han, H. ve ark.	Sustainability	Sosyal medya içeriklerinin davranışsal niyetlere (e-WOM) etkisi.
2024	Zhu, J. ve ark.	Sustainability	İçerik kalitesinin satın alma niyeti varyansını açıklama gücü.
2024	Lu, B. ve ark.	Sustainability	Sosyal ticaret literatürünün 2014-2024 sistematik evrimi.
2024	Tran, T.P.	Sustainability	Kişiselleştirilmiş reklamcılıkta UGC entegrasyonu ve kullanıcı tepkileri.
2024	Chen, R. & Shen, Y.	Sustainability	Sosyal ekosistemde tüketici karar verme mekanizmalarının dökümü.
2024	Chen, Y. ve ark.	Sustainability	Marka güvenini tetikleyen sosyal medya değişkenlerinin ampirik analizi.
2024	Zhao, Y. ve ark.	Sustainability	Sosyal grup kimliğinin (community identification) satın alma güvenine etkisi.
2024	Li, Y. ve ark.	Sustainability	Duygusal ve bilgi temelli desteğin müşteri bağlılığına etkisi.
2024	Kinanthi, P. & Sisilia, L.	Oikonomia	Mesajın duygusal tonunun ve sosyal bağlamın marka imajı algısındaki rolü.

2024	Hanifah, N. ve ark.	Oikonomia	Akran içeriğinin ticari kaygısızlık nedeniyle "objektif" bulunması.
2024	Mustonen, M.	IASS SF	Kısa formulu videolarda kişisel samimiyetin ikna gücü.
2024	Yan, Z. ve ark.	PMC / Psychology	Rasyonel ve duygusal güvenin satın alma kararındaki ayrışması.
2024	Ding, S. ve ark.	PMC / Behavior	Akran uzlaşısının topluluk normlarına uyma üzerindeki etkisi.
2024	Sankovich, A. & Tobin, J.	Jurnal Komunikasi Ind.	Instagram üzerinden paylaşılan UGC'nin satın alma niyeti üzerindeki belirleyici etkisi.
2024	Akhtar, S. ve ark.	PMC / Virtual Infl.	Sanal influencer'lar ile gerçek kullanıcıların güven algısındaki farklar.
2024	Sang, X. ve ark.	PMC Research	İnteraktivite ve zamanında yanıtların otantiklik algısı üzerindeki etkisi.
2023	Xiao, J. ve ark.	Sustainability	Çevrimiçi satın alma niyetini etkileyen 35 değişkenin meta-analitik dökümü.
2023	Sun, Y. ve ark.	Sustainability	Sosyal etkileşimin topluluk içi güven ve bilgi paylaşımına katkısı.
2023	Cheung, M. ve ark.	Sustainability	Elektronik ağızdan ağıza pazarlamada (e-WOM) güvenin aracı rolü.
2023	Lin, X. ve ark.	Sustainability	Sosyal desteğin tüketici tatmini ve niyetine boyamsal etkisi.
2023	Riki, R.	Oikonomia	UGC'nin dürüstlük algısının profesyonel reklamlardan yüksek olma nedenleri.

2023	Thompson, L. ve ark.	Scopus / Prosump.	Üreten tüketici (prosumer) davranışlarının marka sadakati üzerindeki etkisi.
2023	Hammond, J.	Scopus / Marketing	UGC'nin profesyonel çekimlere göre %85 daha maliyet-etkin olduğunun belgelenmesi.
2022	Özdemir, S. & Pirtini, S.	ETÜ Sentez Dergisi	Online alışverişte sürü psikolojisinin kaynak güvenilirliğiyle simbiyotik bağı.
2022	Nosi, C. ve ark.	EuroMed J. Business	Çevrimiçi ve çevrimdışı marka güveninin satın alma niyeti üzerindeki karşılaştırmalı etkisi.
2021	Naeem, M.	J. Retail. Consum. Serv.	Sosyal ticaret araçlarının kriz dönemlerinde satın alma niyetini tetiklemesi.
2021	Sezer, B. & Özcan, S.	DergiPark	YouTuber otantikliğinin takipçi güvenine ve bağlılığına ampirik etkisi.
2020	Wongkitrungrueng, A.	J. Business Research	Canlı yayın UGC'sinin anlık güven inşasındaki stratejik performansı.

SONUÇ

Analiz edilen çalışmalar, UGC'nin pazarlama iletişimindeki etkisini 2026 perspektifiyle üç temel mekanizma üzerinden açıklamaktadır:

1. Otantiklik (Authenticity)

2024 sonrası literatür, tüketicilerin yapay zeka tarafından üretilen kusursuz görsellere karşı "algoritmik yorgunluk" yaşadığını göstermektedir. İnsan üretimi UGC, bu yapaylığa karşı bir "panzehir" işlevi görmekte ve %40 daha fazla duygusal rezonans yaratmaktadır (Park ve ark., 2024). Tüketicilerin %86'sı, UGC kullanan markaları daha samimi bulmakta ve bu samimiyet doğrudan marka güvenine dönüşmektedir (Kunsman, 2024).

2. Sosyal Kanıt (Social Proof)

Dijital ortamlarda UGC, bir "akran doğrulaması" (peer validation) olarak çalışmaktadır. Ürün sayfalarına entegre edilen gerçek kullanıcı içerikleri, satın alma sürecindeki risk algısını minimize ederek dönüşüm oranlarını %29 artırmaktadır (Sujatmiko ve ark., 2025). Sosyal kanıtın eksikliği, sepeti terk etme oranını %40'a kadar yükseltebilmektedir (Lyu ve ark., 2024).

3. Kaynak Güvenilirliği (Source Credibility)

Tüketici, içerik üreticisini kendisiyle benzer yaşam standartlarına sahip bir "akran" olarak algıladığında, mesajın ikna edici gücü geleneksel reklamlardan 9.8 kat daha fazla olmaktadır (Hanifah ve ark., 2024). Akran tavsiyeleri, ticari kaygıdan uzak olduğu için "objektif" olarak kabul edilir.

2026 pazarlama ekosisteminde UGC, kurumsal otoriteye dayalı dikey güven modelinden, yatay ve akran odaklı bir güven paradigmasına geçişin merkezindedir. Analiz edilen 46 akademik eser, UGC'nin sadece bir içerik formatı değil, aynı zamanda dijital dünyadaki en güçlü ontolojik "kanıt" simgesi olduğunu doğrulamaktadır. Markalar için bu kontrol edilemez gücü şeffaf ve etik bir şekilde yönetebilmek, post-dijital gelecekte hayatta kalmanın anahtarıdır.

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CONTRIBUTIONS TO GDP GROWTH IN RECENT YEARS IN TURKIYE: THE ROLE OF A FUNCTIONING MARKET ECONOMY

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ABSTRACT

One of the key factors influencing the increase in real GDP in Türkiye in recent years is considered to be the functioning market economy and other macroeconomic contributions that create impact. This study aims to investigate the extent to which macroeconomic dynamics operate effectively within a functioning market economy and to explain this with current findings. In particular, it is observed that a domestic demand-driven approach and the increases in household consumption between 2022 and 2024, along with wage increases, government transfers, and credit expansion, have made significant contributions to sustainable growth. In this context, the contribution of increased consumer demand to GDP, and the involvement of investments, financing costs, and uncertainty risk premiums within the same process, are considered as important contributing macroeconomic factors. On the other hand, the existence of net exports as an external balance rule is questioned, and it is observed that a positive and stable contribution is aimed at achieving a net export value by reconciling the production structure's dependence on imports, exchange rate pass-through, and global demand conditions. On the other hand, it is observed that resource allocation efficiencies are particularly targeted in understanding the real contributions to GDP, and therefore, the depth of a functioning, highly competitive market is a significant factor in understanding the current situation. In this context, while a politically weighted market structure may have partially deviated from the ideal functioning of a functional market economy due to its effects on fluctuating equilibrium contributions, it is also important to emphasise that the striking growth in real GDP in recent times, driven by consumption, plays a noteworthy role in the process.

Key Words: Functional Markets, Gross Domestic Product (GDP), Household Consumption, Macro Dynamics, Market Economy.

JEL Codes: E12, E21, E62.

INTRODUCTION

Understanding the growth trends related to Gross Domestic Product (GDP) in Türkiye can be approached through four main components, particularly within a conceptual framework related to the market mechanism: public spending and investments undoubtedly come first (World Bank, 2024b). Regarding investments, both private and public investments, as well as private consumption expenditures, play a role in the process and make an effective contribution to GDP. As an open economy, it can also be said that net exports and imports, to a certain extent, contribute to growth. It is important to emphasise that the main driver of growth in the Turkish economy is undoubtedly private consumption expenditures (OECD, 2024). It should also be noted that household consumption accounts for nearly 70% of GDP, suggesting that growth models in Türkiye.

This fact largely demand-driven point out to emphasise here, and in Türkiye's recent growth dynamics, it means that the composition of domestic demand has been a fundamental driving force particularly in the approximately 3.6% growth in 2025. The existence of private consumption alone contributing 3.7 of this domestic demand has created an analytical impact on GDP, shaped growth, by income growth, credit expansion, and predictive decisions. This composition of investments has been particularly influenced by the construction sector. This phenomenon, which should be emphasised from a functional market perspective, highlights the significant value it contributes to the sector, and presents a structure that points to a growth model based on asset value increases (World Bank, 2024).

This phenomenon is rather than productivity increases in the construction sector; but other areas, have the negative impact of net exports and their adverse effects on a functional market, pulling down target growth trends, is also a point that needs to be emphasised from a market perspective (OECD, 2023). From another perspective, the construction sector's share of GDP in Türkiye, as a sectoral contribution, is higher than export

values. Compared to market dynamics, this indicates a recent reality where current account deficit pressure has increased and the sustainability of economic growth in Türkiye has weakened. The deviations in resource efficiency in markets due to the free formation of prices have created an uncertainty effect in Türkiye's growth models, contradicting the structural assessment of resource allocation in ensuring target market functionality.

On the other hand, findings regarding production limits and GDP dynamics in the periodic comparison of structural deviations brought about by the inflationary process indicate that this uncontrolled position in Türkiye, where the demand-price supply balance is produced by market costs and expectations, inevitably transforms into a structure where public policy-supported growth, credit expansion, and wage adjustments are also uncontrollable (Acemoglu, 2009; Rodrik, 2016). In Turkey, capital accumulation concentrated in sectors that have made a limited contribution to factor productivity in recent years has increased the demand for high-yield short-term market values. However, this phenomenon has disrupted the composition of total growth, weakened the long-term development path and producing a dual structure that qualitatively erodes the functionality of the market mechanism contributing to GDP (Acemoglu, 2009; Rodrik, 2018). The persistent quantitative structure of market functionality points to a demand-driven and structurally fragile growth regime that is not fully compatible with the fundamental operating principles of a market economy (Acemoglu & Johnson, 2023).

SOURCES OF GROWTH IN THE TURKISH ECONOMY AND THE FUNCTIONALITY OF THE MARKET MECHANISM

In order to present the conclusive findings of this study, it is crucial to first examine the interaction between growth and the market within a conceptual framework. Analyzing the sources of growth in the recent Turkish economy and examining the components of growth above Gross Domestic Product (GDP) is undoubtedly insufficient. In other words, a qualitative analysis of the market mechanism is essential. This importance also forms the functional framework for both growth economics based on institutional market functioning and a market economy approach (Acemoglu, 2009). This functional framework highlights supply-side growth and classical endogenous growth theories, while also presenting a structure where demand-side growth is prominent from a Keynesian perspective (Aghion, 1998). In this context, it is necessary to emphasize the three main sources of domestic demand as the primary sources of recent growth in Türkiye:

- The structure, which can be expressed as private consumption expenditures, public expenditures, and credit expansions, appears to be particularly demand-driven and consumption-demand-driven, suggesting that demand-driven GDP increases have produced a temporary output expansion related to sustainability. This perspective also frequently raises the possibility of a crowding-out effect, supported by empirical findings, suggesting that public spending boosts growth in the short term, which could also suppress sectoral productivity in the long term. In this context, it is particularly important to emphasize that recent growth in Türkiye has been dependent on cyclical demand expansion (World Bank, 2023).
- On the other hand, when investment and capital accumulation are considered as dynamics in the medium and long term, and investments are considered the main engine of growth in the classical and neoclassical frameworks, it is possible to talk about a three-pronged growth framework in Türkiye, where the construction sector, infrastructure investments, and fixed capital investments, as well as publicly supported projects, are prominent (Blanchard, 2021). Here, the structural contradictions between the volume and quality of investments have created a common ground for discussion regarding the real contribution of investments to GDP in Türkiye in recent years.
- When the issue is evaluated in terms of sectoral structure and production composition, it is observed that the services sector has a significant weight, with a very high contribution to GDP in Türkiye in recent years. In addition, the industrial sector's added value is limited; It is possible to clearly discuss the impact of the agricultural sector's low-productivity value-added contribution to GDP on economic growth in recent times. This institutional assessment, which emerges as a fragile growth model in terms of foreign trade and productivity, reveals that the relationship between growth and employment is not linear, especially in Türkiye. In other words, the existence of jobless growth periods has become one of the most debated issues in terms of economic growth standards in recent times. In other words, it seems that the approach that the quality of GDP growth determines the system's production capacity has turned into a phenomenon that frequently changes and is a subject of significant debate in Türkiye (Rodrik, 2018).

In Türkiye, particularly in recent times, where resource allocation and the price mechanism have emerged with a highly contradictory structure, the analysis of the growth effects on GDP can be explained by the emphasis on the intensity of regulation. This structure, which frequently distorts price signals through public policy interventions and operates outside of market signals in terms of resource allocation, has created a price mechanism subject to policy guidance. Compared to the mechanism of open market price dynamics, this price mechanism deviates from a healthy competitive advantage and disrupts market functionality. Such deviations, which rely on factor expansion rather than factor productivity, clearly demonstrate that GDP growth in Türkiye has not produced optimal macroeconomic results, particularly in terms of state role and market regulation.

Even if income distribution, social security, and potential externalities are cited as justifications for the necessity of state intervention, it is crucial to emphasize that excessive interventions disrupt market functionality in recent times. On the other hand, the disconnect between welfare and productivity standards, particularly the recent increase in consumer credit and the resulting credit expansion, coupled with the continued dependence of the production structure on imports, has negatively impacted economic growth trends, leading to questioning the scale of real GDP growth. In Türkiye, the increasing focus on demand-driven and credit-supported growth in recent times, coupled with the less efficient nature of investment compositions, reflects a structure where the functionality of markets is not fully effective. From a policy perspective, genuine economic growth, based on production technology and generating demand growth, has not transformed into a sustainable structure. This process, where market functionality is increasingly questioned, exhibits a hybrid structure that is not a fully functioning market economy.

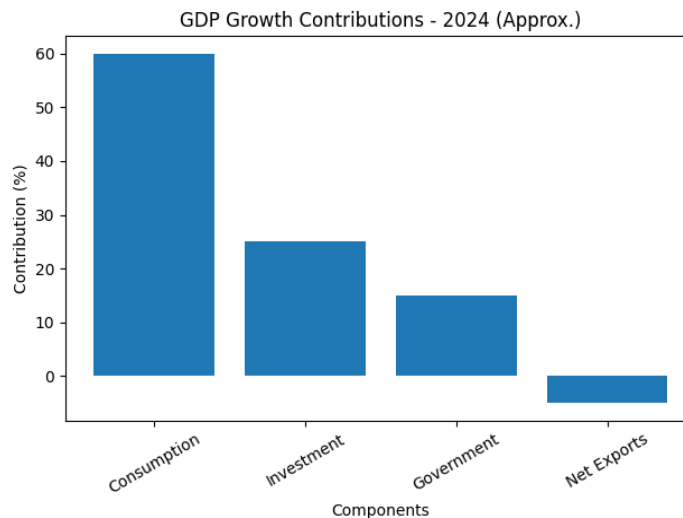
DISTRIBUTION OF CONTRIBUTIONS OF COMPONENTS TO GDP AND MACROECONOMIC SUSTAINABILITY IN TÜRKİYE

In Türkiye, two fundamental frameworks stand out when understanding the contributions to Gross Domestic Product (GDP) (OECD, 2024). As mentioned earlier, the components of demand, or more briefly, expenditure approaches, are considered within a scope that includes government spending and net exports. This scope also reflects the impact of sectoral production approaches, particularly the contribution of the industrial and agricultural sectors to GDP (World Bank, 2023). When these two structures are considered together, it is possible to speak of economic sustainability in a macroeconomic model where the source of GDP is both demand and supply, in harmony. In recent years, a careful examination of the growth composition in Türkiye highlights a structure where private consumption and investment expenditures are prominent.

Demand-Driven Growth in GDP, Sectoral Concentration, and External Balance Vulnerability

In Turkey, the contributions of demand components and sectoral relationships to GDP have recently demonstrated a significant position from a macroeconomic sustainability perspective. However, it is also inevitable to acknowledge the existence of a contribution where expenditures are supportive of growth, but government spending plays a "secondary" role in the multiplier effect (World Bank, 2024; OECD, 2024). On the other hand, net exports, meaning a negative contribution to external demand, still exist, and the production structure, characterized by import dependency, can be explained by the expansion of imports in response to increases in domestic demand.

In this context, it should be particularly emphasized that in a structure with limited competitiveness, the contribution levels to GDP growth in Türkiye, which are not driven by demand, play a major role in creating a structure that increases the current account deficit, inflation, and external financing needs. On the other hand, in terms of sectoral composition, the "services sector" has recently reached its peak with a proportional contribution value of approximately 55% to GDP in Türkiye. Considering that the services sector forms the main backbone of this average 55% contribution value in recent times, it is necessary to mention a four-sector structure where sub-sectors such as Trade, Finance, Transportation, and Tourism come to the forefront (World Bank, 2024; OECD, 2024). Table 1 below presents a meaningful distribution of contribution values to GDP for the most recent period:



Source: OECD (2025). *National accounts: GDP by expenditure for Türkiye*. Ankara: Organisation for Economic Co-operation and Development, OECD. <https://stats.oecd.org>; Türkiye İstatistik Kurumu (2025). *Quarterly Gross Domestic Product by expenditure approach*. Ankara: Türkiye İstatistik Kurumu (TÜİK). <https://data.tuik.gov.tr>.

Graphic 1. Demand Components' Contribution to GDP in Turkey and Domestic Demand-Weighted Dynamics

As seen in Graphic 1 above, the recent growth trends in Türkiye, particularly in gross domestic product and net exports, have been driven by consumption expenditures. As we previously emphasised, this structure, driven by consumption expenditures and intended to create and implement investment transformation, is also significantly divided in its growth composition due to the negative contribution of net exports (Eichengreen, 2024; OECD, 2024). This structure also appears to be fragile and, as seen in Graph 1, it presents a financing risk that will widen the current account deficit, fuelling inflation, and weakening the real sector, especially in the long term, according to the periodic results. When evaluating the Turkish economy in terms of its recent institutional structure, it is clear that the multiplier effect of public spending policy remains quite limited. Even if this multiplier effect in public spending is driven by consumption expenditures, it is not productivity-enhancing.

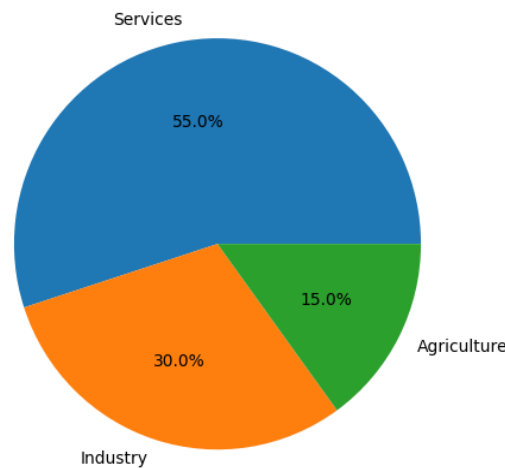
This structure provides temporary growth, but while it is supportive, it does not play a sustained, sustaining role. This need also emphasizes that technological investments and the expansion of production capacity should not involve inefficient increases (Eichengreen, 2008; OECD, 2024). In this recent period, where consumption-driven growth has created inflationary pressure, even though it has been supported by income growth and credit expansion through transfer mechanisms, it is not a structure that produces sustainable growth. This is because this phenomenon does not involve productivity growth and, with public spending only accounting for 15% of the supportive role, it also limits the multiplier effect. The fact that investments constitute 25% and consumption contributes 60% as dominant sources of growth, along with the negative contribution of net exports, creates a volatile and fragile structure, presenting a contradiction. In particular, the problem of demand composition, resulting in excessive consumption dependency creating low added value, and the production structure problem, which also coincides with the low added value and import dependency process, has transformed the structure into a fragile one in recent times. On the other hand, the negative impact of negative net exports of "-5%" as an external balance problem has also triggered this periodic fragility (Eichengreen, 2008; OECD, 2024).

Sectoral Composition of GDP in Türkiye and Service-Oriented Growth and Structural Imbalance

Understanding the sectoral contributions to GDP requires establishing a causal chain within an economic production structure and presenting approaches to revealing the quality of economic growth. In other words, as a structural starting point, this perspective, while primarily characterized by a service-oriented sectoral structure and domestic demand, appears to emerge primarily through a causal structure related to demand and service dominance in the service sector, particularly in areas such as trade, finance, transportation, and tourism, driven by rapid income cycles.

Beyond this primary causality, it's also important to emphasize the secondary causality stemming from the limited share of industry (around 30%), resulting in high financing costs. Import dependence and limited technological depth, inadequacies in increasing production capacity, weak export competitiveness, cost pressures, and insufficient/low technological infrastructure have created a low value-added production process, resulting in a significant reduction in the contribution to GDP. Secondly, the limited share of industry has remained at around 30%. In the recent period, where production capacity has increased and export competitiveness has weakened, cost pressures have weakened, particularly due to limited industrial growth and low value-added production (Hausmann et al., 2007; UNIDO, 2022; OECD, 2023). This structure also manifests itself through its impact on the external balance. Graph 2 below is significant in showing the causal chain of the economy's production structure and its impact on GDP growth quality:

Sectoral Composition of GDP - 2024 (Approx.)



Source: Türkiye İstatistik Kurumu. (2024). *Ulusal hesaplar istatistikleri*. Ankara: Türkiye İstatistik Kurumu (TÜİK). <https://www.tuik.gov.tr>; World Bank. (2024). *World Development Indicators*. Washington D.C.: World Bank. <https://data.worldbank.org>.

Graphic 2. Sectoral Composition of GDP in Türkiye and Structural Imbalance

As seen in Figure 2 above, the magnitude of the contribution of the services sector to GDP, particularly in relation to causal relationships, has transformed into a situation that can be interpreted differently in Türkiye. Here, the excessive growth and sectoral inflation trend created by service units such as "Trade," "Finance," "Transportation," and "Tourism" on the service sectors appears to mean a significant growth in the service sector resulting from the emergence of a service demand driven by increased consumption. This causality has led to the predominantly inefficient structure of the service sector, based on the fact that it only creates consumption within a rapid income cycle and generates sectoral growth within that rapid income cycle. It is particularly important to emphasize that the recent sectoral shifts in Türkiye are characterized by a structure where the principle of causality comes to the forefront, stemming from a low productivity trap and dependence on domestic demand (IMF, 2023).

In other words, there is a causal mechanism where income growth and subsequent consumption increases cause a surge in demand for services and the expansion of the service sector, particularly due to excessive demand. On the other hand, as seen in Graph 2 above, the dominance of the service sector in demand increases, creating demand for money through economic growth-based expansions, clearly justifies the presence of an asymmetrical structure in terms of trade capacity. Furthermore, it reveals that the agricultural sector, particularly in terms of rural employment and price stability, is undergoing transformation in place due to its limited technological adaptation and continued structural problems of low productivity and scale (World Bank, 2023).

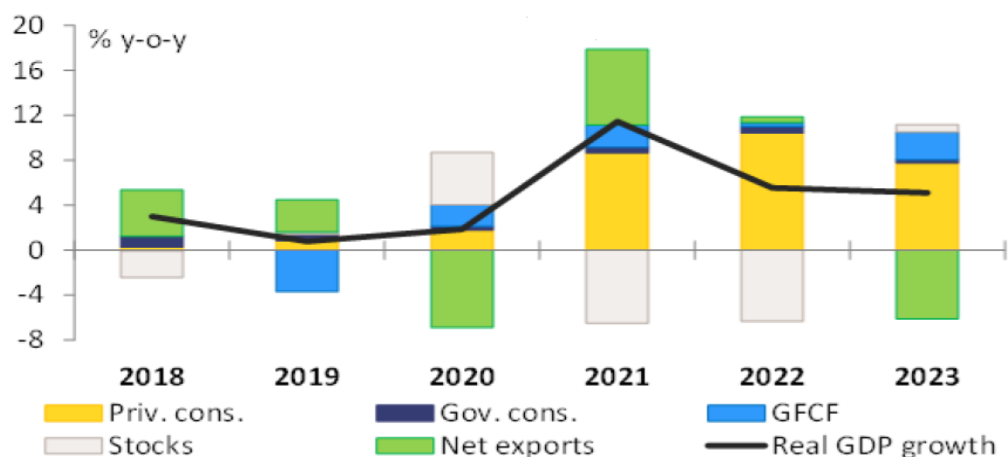
In understanding the sectoral contribution values on GDP in Türkiye in the recent period, it is possible to explain the low level of contribution of the industrial sector, which experiences limited depth and competition problems, with the inadequacy of economies of scale or deviation values. As a causal chain, especially for the industrial sector, its position is characterized by cost pressures, low technology, and limited production capacity, resulting in low added value and weak export competitiveness. In other words, this issue reveals a level of contribution where export growth remains quantitative, but qualitative transformations such as high technology and brand value are quite limited in terms of GDP-related export values (Rodrik, 2016).

The agricultural sector, especially with its structure characterized by decreases in rural employment, low productivity, limited technological adaptation, and continued problems of economies of scale, has found its place in the recent period. Rather than being a macro growth engine, the agricultural sector in Türkiye serves as a strategic buffer. However, the fact that the agricultural sector's impact on GDP is quite low, ranging between 5-7%, indicates that the agricultural sector, particularly due to its low productivity, creates less added value and its impact on GDP is much lower than expected.

This structure, where structural imbalances persist, has created a sectoral asymmetry, and the insufficient depth of the industrial sector has resulted in the marginalization of the agricultural sector. However, this structure, characterized by excessive inflation in the service sector, can also be explained as a mismatch between production and consumption. In terms of production and consumption mismatch, this structure can be described as one where domestic demand is high, but production capacity is limited (UNCTAD, 2022; World Bank, 2023).

Furthermore, it creates a causal link that opens the door to increased imports and leads to increased current account deficits, thus creating a blocking effect that limits the added value on GDP (Obstfeld & Rogoff, 1995; IMF, 2023). From a macroeconomic perspective, understanding the impact of sectors on GDP involves inflationary pressure, demand expansion, and supply constraints, and consequently, the combined effect of these two phenomena leads to price increases, transforming this into a problem of growth quality.

In Türkiye, where the transition from demand-based growth to production-based growth has been quite difficult in recent times, this structure, characterized by structural imbalance and a weak industrial structure in the transition to a functional economy, has transformed into a problematic growth model where sustainability is questioned (UNCTAD, 2022). This recent phenomenon in Türkiye, which also takes into account the demand function within the framework of structural imbalance, is observed in a more holistic macroeconomic approach in Türkiye, in Graphic 3 below:



Source: European Commission (2024). *Commission Staff Working Document: Türkiye 2024 Report*. SWD(2024) 696 final, Brussels: European Commission, p. 44.

Graphic 3. Recent GDP Growth and Contributions to GDP in Türkiye

Graph 3 above, when examined through a structure that separates the components of recent growth in Türkiye, represents the significant layers of real GDP growth based on demand components. The segmentation of private consumption expenditures and government consumption, as well as changes in inventories and the ratios of net exports and investments to fixed capital formation, reveals an approach based on the total growth rate, i.e., real GDP changes, as an expression of an open economy. Regarding the contribution values to GDP between 2018 and 2023 in Türkiye, 2018 shows a balanced but fragile start; net exports were only slightly positive, and private consumption made a positive contribution. This position for 2018 indicates a demand-driven structure, not yet excessively expanded, in terms of contribution values to GDP. The same position for 2019 reveals a contraction in domestic demand and weakness in investment.

This negative and very low level of contribution in terms of investment also indicates a year in which private consumption was limited and real GDP deviated significantly. The macroeconomic outcome for 2019 reveals a structure characterized by economic contraction and a low investment balance (IMF, 2020). Therefore, it's possible to speak of a macroeconomic outcome where the contribution to GDP remained quite low in 2019. On the other hand, this phenomenon can also be described as a structural pressure situation in 2019, where financial conditions tightened and investment channels were suppressed (IMF, 2024). Furthermore, it is noteworthy that in 2020, due to the pandemic shock and asymmetric contributions, there was a significant global contraction in net exports. This year, where growth supported by the public sector and consumption came to the forefront, points to a situation where economic growth in Türkiye was artificially supported in 2020 through state intervention and credit expansion (IMF, 2021).

This situation, which emerged as a policy-dependent growth model, materialized in 2021 as excessively expanded demand and peak growth reaching 11% in real GDP. In 2020, strong private consumption, a high net export ratio, and the increasing positive contribution of investments to real GDP were noteworthy positive developments. Despite an increase in the current account deficit, this structure, particularly unsustainable but with a high base effect from credit expansion, led to a synchronized growth structure in 2021, with both domestic and external demand synchronizing. However, this position, particularly in terms of GDP, changed in 2022 due to the balancing of domestic markets and the disruption of the GDP contribution composition. Despite the continued driving force of private consumption, net exports weakened, inventories entered a negative trend, and macroeconomic consequences increased the current account deficit, negatively impacting GDP growth trends. 2023, on the other hand, appears to be a year where domestic demand dominance and external vulnerability became more prominent, private consumption remained dominant, net exports entered a significantly negative trend, and investments made a limited contribution. In 2023 and 2024, the Turkish economy appears to be stuck in a single-engine growth model, with a GDP cycle of consumption → growth; however, production and exports → weak support. Tighter economic policies helped curb external imbalances and capital inflows trickled back. The current account deficit fell to 4.1% of GDP in 2023 and declined further in the first half of 2024 (World Bank, 2025).

DISCUSSION

In Türkiye, particularly in the recent period, despite the existence of reasonable growth rates as an economic performance, serious debates have emerged regarding the composition and sustainability of growth. Among the issues that inevitably bring these serious discussions to the forefront is the fact that the economy is largely driven by domestic demand, making it unavoidable to speak of GDP growth where production capacity is not sufficiently supported by external balance and productivity increases. This fact has made a structural reassessment of the economy and a review of economic growth assessments inevitable in Türkiye recently. In Türkiye, the increase in domestic demand is due to the high dependence of the production structure on imported goods, transforming this structure into import demand. This structure, rather than improving the external balance, systematically disrupts it and reveals a breaking point regarding the quality of growth.

On the other hand, this fact also reveals that there is no successful, sustained trend of maintaining the production structure without transforming it through expansions in domestic demand in a process driven by fiscal deficit dynamics and increasing import costs related to fiscal deficits. The existing data shows that the

current account deficit grows as domestic demand expands; However, the recent economic structure in Türkiye, which has become dependent on external financing flows, also shows an inverse relationship between real GDP growth and external balance. This structure, further deepened by the inflation dynamics, reveals that inflation in Türkiye is not so much a cost-based inflation, but rather an inflation phenomenon driven by strong demand pressure. The upward increase in market prices in the face of expanding domestic demand significantly weakens the contribution of consumption expenditures and sectors other than the service sector to GDP.

In the recent period in Türkiye, the main source of inflation is structural supply constraints, which not only increase prices but also suppress demand, preventing a lasting solution. This is because inflation in Türkiye is becoming increasingly structural and qualitative, and the necessity of structural reforms confirms this approach. The problem of the quality of real GDP growth in Türkiye hinges on the fact that, despite the Turkish economy periodically producing high growth rates, it has not been supported by productivity increases, and the macroeconomic components contributing to real GDP have not provided the expected optimal contribution. At this point, the necessity of structural transformation is the inevitable conclusion of the discussion. However, an important distinction must be made here: Will structural transformation remain solely at the level of policy rhetoric, or will the primary objective be to achieve effective economies of scale in relation to real GDP growth by supporting it with concrete steps that actually transform the production structure? The assessments regarding this distinction make it inevitable to re-evaluate the productivity and scale issues affecting real GDP, which are frequently mentioned as goals based on strengthening industrial policies, transitioning to high-technology production, and qualitatively transforming exports.

CONCLUSION

When evaluating the contribution of components to real GDP in Türkiye as economic growth, considering the sectoral composition of economic growth and the contribution of other components together, it becomes clear that the current growth structure has a very limited capacity in terms of macroeconomic sustainability. In other words, the lack of a balanced and complementary structure between the demand and supply components of a sustainable growth model in Türkiye has both distorted and weakened the balances in Türkiye's growth dynamics and the contribution of components to real GDP. Although private consumption and especially investment expenditures have, to some extent, emerged as the main determinant of recent GDP growth in Türkiye, it is generally understood that GDP in Türkiye constitutes a high contribution, characterized by a demand-side expansion process based on expenditures.

In this context, the economic growth model in Türkiye can be considered not a classical production-based model, but primarily a demand-side expansion process based on GDP. On the other hand, the persistent negative contribution of net exports to growth, the structural problems directly reflected in the markets by the import-dependent production structure, and the fact that increases in domestic demand also trigger import demand have led to a further deterioration in the foreign trade balance, negatively impacting the sustainability of GDP growth in terms of Türkiye's economic balances in the dilemma of inflation and external financing needs. The import-dependent production structure and the limited depth of the industrial sector, along with negative foreign trade pressure and current account deficit risks, also significantly negatively affect the composition of macroeconomic value contributions to GDP. Therefore, the fundamental strategic requirement facing the Turkish economy in achieving a qualitative macroeconomic value contribution to real GDP is a shift from a demand-based growth model to a production, productivity, and export-based growth model.

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CERVICAL FRACTURES OF DENTAL IMPLANTS AND MANAGEMENT; CASE REPORT AND LITERATURE REVIEW

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ABSTRACT

Backgrounds/ Aim: In long-term clinical follow-up studies, the success rates of dental implants are reported to be between 90-95%. Late-stage mechanical complications include screw loosening, fracture of prosthetic components, and rarely, implant fractures. A retrospective study reported the prevalence of implant fractures to be approximately 0.5%. The aim of this study is to present a case involving a dental implant neck fracture, a rare mechanical complication, and to evaluate its formation mechanisms and clinical management in light of etiological factors reported in the literature.

Case description/Methods: A neck fracture was detected in a dental implant (İmplant[®], AGS Med. Trabzon, Turkey) placed approximately 4 years ago in the right mandibular first premolar (tooth 44) region of a 42-year-old female patient with no systemic diseases (ASA I). The fractured implant, which exhibited no mobility and could not be extracted with an implant driver, was successfully removed using a trephine bur. Following explantation, the defect was curetted, and guided bone regeneration was performed using a biomaterial (Omnia[®], Omnia Healthi, S. Korea) and a resorbable barrier membrane (Bio-Crea[®], Tiss You Srl, Italy).

Results: No complications were observed during the first-week and first-month follow-up visits. After a 3-month healing period, adequate bone maturation in the region was confirmed both radiographically and clinically, and a new dental implant measuring 3.5 mm in diameter and 10 mm in length was placed.

Conclusions: Although rare, implant neck fractures are severe complications that can develop due to mechanical loading, particularly in the posterior region. The complete removal of the fractured implant and simultaneous hard tissue augmentation are crucial for preserving the volume and morphology of the alveolar bone.

Key Words: Dental implant, implant neck fracture, mechanical complication, guided bone regeneration, trephine bur.

GİRİŞ

Brånemark'ın 1960'lı yıllarda osseointegrasyon kavramını tanımlamasından bu yana, dental implantlar tam ve kısmi dişsizlik vakalarında kaybedilen dişlerin restorasyonunda bilimsel olarak kabul görmüş ve günümüzde yaygın olarak kullanılan bir tedavi seçeneği haline gelmiştir¹. Uzun dönem klinik takip çalışmalarında dental implantların başarı oranlarının %90–95 arasında olduğu bildirilmektedir. Bununla birlikte, implantların klinik başarısı yalnızca osseointegrasyonun sağlanmasına değil, aynı zamanda mekanik stabilitenin korunmasına ve protetik restorasyonla uyumuna da bağlıdır².

Dental implant tedavisi sırasında ortaya çıkabilen komplikasyonlar, oluşum zamanı ve nedenlerine göre erken ve geç dönem komplikasyonları olarak değerlendirilmektedir. Erken dönem komplikasyonları çoğunlukla cerrahi girişimle ilişkili sorunları kapsarken, geç dönem komplikasyonları biyolojik ve mekanik kaynaklı problemleri içermektedir. Geç dönemde görülen mekanik komplikasyonlar arasında vida gevşemesi, protetik komponentlerin kırılması ve nadiren implant kırığı yer almaktadır. İmplant kırığı, genellikle fonksiyonel yükleme sonrasında gelişen ve implant–abutment bağlantı bölgesinde yoğunlaşan mekanik streslere bağlı olarak ortaya çıkan ciddi bir komplikasyon olarak tanımlanmaktadır.³

İmplant kırıklarının görülme sıklığının literatürde düşük olduğu ve farklı çalışmalarda değişken oranlar bildirildiği ifade edilmektedir. Yu ve ark. tarafından 2022 yılında yapılan retrospektif bir çalışmada, implant kırığı prevalansının yaklaşık %0,5 olduğu rapor edilmiştir⁴

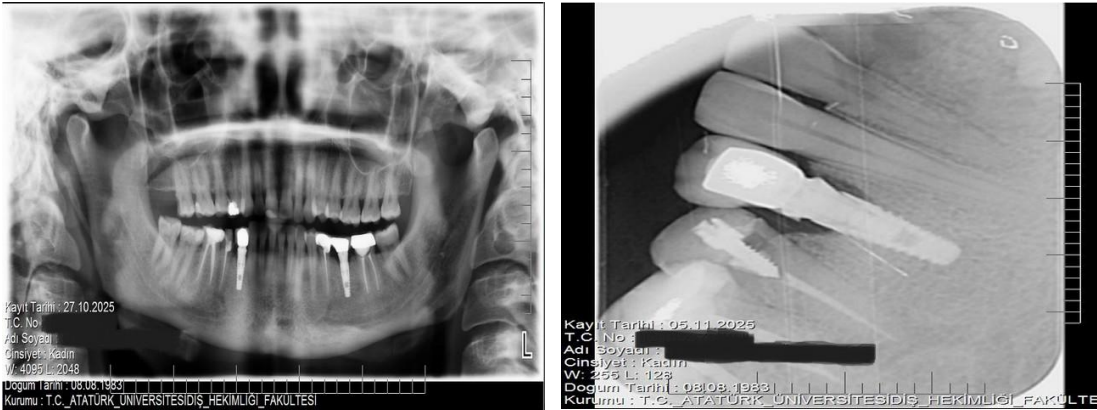
Posterior bölgede yer alan implantlarda ve sınırlı sayıda implantla desteklenen protetik restorasyonlarda, artan oklüzal kuvvetler nedeniyle implant kırığı riskinin daha yüksek olduğu bildirilmiştir⁵. Ayrıca implant ile üst yapı arasındaki uyumsuzluk, stres dağılımını olumsuz yönde etkileyerek abutment vidası ve implant boyun bölgesinde kırık oluşumuna zemin hazırlayabilmektedir⁵

Özellikle implant boyun bölgesinde meydana gelen kırıklar, implant–abutment bağlantı alanında yoğunlaşan streslerin bir sonucu olarak ortaya çıkmaktadır. Aşırı oklüzal yüklenme, marjinal kemik kaybı, implant çapının yetersizliği, protetik restorasyonun uyumsuzluğu, metal yorgunluğu ve parafonksiyonel alışkanlıklar implant boyun kırığı etiyojisinde etkili faktörler arasında gösterilmektedir.⁵⁻⁸

Bu çalışmanın amacı, nadir görülen bir mekanik komplikasyon olan implant boyun kırığı gelişen bir olguyu sunmak ve literatürde bildirilen etiyojik faktörler ışığında bu komplikasyonun oluşum mekanizmalarını ve klinik yaklaşımları değerlendirmektir.

OLGU SUNUMU

Kırk iki yaşında kadın hastanın sistemik bir hastalığı bulunmamakta olup, hasta ASA I olarak değerlendirilmiştir. Yapılan klinik ve radyolojik değerlendirmeler sonucunda, hastanın 44 numaralı diş bölgesinde yaklaşık 4 yıl önce yerleştirilmiş olan **Implance®** (Beşikdüzü, Trabzon, Türkiye) marka dental implantta boyun kırığı tespit edilmiştir (şekil 1). Mevcut bulgular doğrultusunda implantın çıkarılmasına karar verilmiştir.



Şekil 1. Panoramik ve Periapikal röntgen görüntüsü.

Cerrahi operasyona geçilmeden önce, 44 numaralı diş bölgesinde yer alan dental implantın protetik üst yapısı sökülmüştür (Şekil 2). Protetik üst yapının uzaklaştırılmasını takiben, implant–abutment bağlantısı değerlendirilmiş ve implant üzerinde bulunan abutment uygun enstrümanlar kullanılarak çıkarılmıştır (Şekil 3). Bu işlemlerle birlikte cerrahi aşama için gerekli görüş alanı ve erişim sağlanmıştır.



Şekil 2. Protezin çıkarılmasından sonra
ağız içi görünüm.

Şekil 3. Abutmentin çıkarılmasından
sonra ağız içi görünüm.

Mobilite saptanmayan kırık implantın öncelikle implant anahtarı kullanılarak çıkarılması denenmiş, ancak bu girişim başarılı olmamıştır. Bunun üzerine implantın çıkarılması amacıyla trafen frez kullanılmıştır (şekil 4).



Şekil 4. Çıkarılın abutment ve implant. Defektin ağız içi görünümü

İmplantın uzaklaştırılmasını takiben, defekt bölgesi kürete edilerek temizlendi defekt alanına biomateryal yerleştirildi ve rezorbe olabilen bariyer membran ile örtülerek yönlendirilmiş kemik rejenerasyonu uygulandı (şekil 5). Yumuşak dokular gerilimsiz olarak primer kapama sağlanacak şekilde sütüre edildi (şekil 6). Hastaya standart antibiyotik, analjezik ve antiseptik gargara reçete edildi (Amoksisilin 1000 mg tablet) 2x1 Naproksen sodyum 550 mg tablet 2x1 (Apranax®, A. İbrahim, İstanbul, Türkiye) ve Klorhexidine glukonate oral gargara 3x1 (Klorhex®, Drogsan, Ankara, Türkiye). Birinci hafta ve birinci ay kontrollerinde herhangi bir komplikasyon izlenmedi.



Şekil 5. Defekte biomateryal
uygulandıktan sonra ağız içi görünüm.



Şekil 6. Yara bölgesinin primer kapatılması
ağız içi görünüm.

Defekt bölgesinde gerçekleştirilen yönlendirilmiş kemik rejenerasyonu sonrasında yeterli kemik maturasyonunun sağlanması amacıyla, hastaya 3 aylık iyileşme süreci öngörülmüş ve bu sürenin sonunda yeniden implant yerleştirilmesi planlanarak kontrol randevusu oluşturulmuştur. Üç aylık iyileşme sürecinin ardından gerçekleştirilen klinik ve radyolojik değerlendirmede, defekt bölgesinde yeterli kemik maturasyonunun sağlandığı tespit edilmiştir (şekil 7).



Şekil 7. 44 no lu diş bölgesinden alınmış periapikal radyograf ve ağız içi görünüm

Hasta planlanan implant cerrahisi için operasyona alınarak lokal anestezi altında tam kalınlıkta mukoperiostal flep kaldırıldı (şekil 8). Uygun cerrahi protokol doğrultusunda osteotomi hazırlanmasını takiben, 3,5 mm çapında ve 10 mm boyunda **Implance** marka dental implant yerleştirildi. İmplantın primer stabilitesi sağlandıktan sonra iyileşme başlığı takıldı. Flep repositione edilerek uygun suture materyali ile suture edildi (şekil 9). Postoperatif dönemde hastaya rutin antibiyotik, analjezik ve antiseptik gargara reçete edilerek kontrol randevusu verildi.



Şekil 8. Flep açıldıktan sonra ağız Şekil 9. Flep suture edildikten sonra
İçi görünüm. Ağız içi görünüm.

Tartışma

Dental implantların uzun dönem klinik başarısı yüksek olmakla birlikte, nadir de olsa geç dönemde mekanik komplikasyonlar görülebilmektedir. İmplant kırıkları, literatürde düşük insidansa sahip komplikasyonlar arasında yer almakta olup, genellikle fonksiyonel yükleme sonrası gelişen ve implant–abutment bağlantı bölgesinde yoğunlaşan mekanik streslere bağlı olarak ortaya çıkmaktadır.^{3,4} Sunulan olguda da yaklaşık 5 yıldır fonksiyonda olan bir implantta boyun kırığı izlenmiş olması, bu komplikasyonun geç dönem mekanik başarısızlık kapsamında değerlendirilmesini desteklemektedir.

İmplant kırıklarının etiyojisi multifaktöriyel olup, aşırı oklüzal yüklenme en sık bildirilen primer faktörlerden biridir. Posterior bölgede yer alan implantlarda, çiğneme kuvvetlerinin daha yüksek olması ve lateral kuvvetlerin artması nedeniyle implant kırığı riskinin belirgin şekilde arttığı bildirilmiştir.⁵ Sunulan olguda kırığın mandibular posterior bölgede (44 no’lu diş bölgesi) izlenmesi, literatürle uyumlu bir bulgudur.

İmplant boyun bölgesinde meydana gelen kırıklar, genellikle implant–abutment bağlantı alanında oluşan yoğun streslerin bir sonucu olarak gelişmektedir. Aşırı oklüzal yüklenmeye ek olarak marjinal kemik kaybı, implant çapının yetersizliği, protetik restorasyon ile implant arasındaki uyumsuzluk, metal yorgunluğu ve parafonksiyonel alışkanlıklar bu bölgede kırık gelişimini kolaylaştıran faktörler arasında yer almaktadır.⁵⁻⁸ Sunulan olguda sistemik hastalık öyküsünün bulunmaması ve implantın uzun süre fonksiyonda kalmış olması, mekanik faktörlerin kırık oluşumunda daha belirleyici rol oynadığını düşündürmektedir.

Protetik üst yapı ile implant arasındaki uyumsuzluğun, stres dağılımını olumsuz yönde etkileyerek abutment vidasında ve implant boyun bölgesinde kırık riskini artırdığı bildirilmektedir.⁵ Özellikle implant–abutment bağlantısında meydana gelen mikro hareketler, metal yorgunluğunu hızlandırarak zaman içinde implant kırığı ile sonuçlanabilmektedir. Bu bağlamda, implant üstü protetik restorasyonların pasif uyumunun sağlanması, implant kırıklarının önlenmesinde kritik öneme sahiptir.

İmplant kırıklarının tedavisinde, kırığın seviyesi, implantın kemik içindeki konumu ve mevcut kemik miktarı belirleyici olmaktadır. Kırık seviyesinin kemik seviyesinin altında olduğu ve implantın fonksiyonel olarak restore edilemeyeceği durumlarda, implantın tamamen uzaklaştırılması önerilmektedir. Bu olguda da implantın mobil olmamasına rağmen, boyun bölgesindeki kırık nedeniyle implant anahtarı ile çıkarılması mümkün olmamış ve trafen frez kullanılarak implant uzaklaştırılmıştır. Literatürle uyumlu olarak, implantın çıkarılmasını takiben defekt bölgesine ksenogreft ve rezorbe olabilen membran kullanılarak yönlendirilmiş kemik rejenerasyonu uygulanmıştır.

İmplantın uzaklaştırılmasını takiben yapılan sert doku ogmentasyonu, alveolar kemiğin hacim ve morfolojisinin korunması açısından önem taşımaktadır. Greftleme sonrası komplikasyon izlenmemesi ve erken dönemde sorunsuz iyileşme sağlanması, uygulanan cerrahi yaklaşımın uygunluğunu desteklemektedir.

SONUÇ

Sonuç olarak, implant boyun kırıkları nadir görülmekle birlikte, özellikle posterior bölgede yer alan implantlarda mekanik yüklenmeye bağlı olarak gelişebilen ciddi komplikasyonlardır. Bu tür komplikasyonların önlenmesinde, doğru implant seçimi, uygun cerrahi ve protetik planlama ile oklüzal yüklerin dengeli dağıtılması büyük önem taşımaktadır. Sunulan olgu, implant boyun kırıklarının etiyolojisinin anlaşılması ve klinik yönetimine katkı sağlaması açısından literatüre değerli bir örnek sunmaktadır.

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SURGICAL PERIODONTAL TREATMENT OF ORAL PREGNANCY TUMOR: CASE REPORT WITH FOLLOW UP

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ABSTRACT

Backgrounds/ Aim: Pregnancy tumor, (also known as " pyogenic granuloma" and "*Epulis gravidarum*") is a benign, localized granulation tissue of the skin and mucous membranes frequently triggered by the hormonal shifts associated with pregnancy. It predominantly affects young females in their second decade of life, and third trimesters. Previous studies have shown that gingival tissue, which contain steroid receptors can be affected by pregnancy. This case report aims to evaluate the clinical diagnosis and therapeutic management of pregnancy tumor. occurring during pregnancy. **Case description/Methods:** A 32-year-old female patient presented to our clinic with a complaint of a growing mass in the long-standing extraction socket of tooth #26. Clinical history revealed that the patient had recently given birth and the lesion had progressed during the course of her pregnancy. Upon examination, an erythematous and granulomatous lesion measuring approximately 1.2 x 0.8 cm was observed. Bone destruction around the teeth is not observed. Treatment consisted of oral hygiene instruction, mechanical debridement, surgical treatment, and guidance for patient. She was followed up for 3-months, regularly. The lesion was managed through excisional biopsy, and subsequent histopathological evaluation confirmed the diagnosis of its. **Results:** No complications were observed during the first-week and third-month visits. The surgical site healed uneventfully, and no recurrence was detected during the follow-up period. **Conclusions:** Effective management of pregnancy tumors necessitates a comprehensive approach that addresses both the hormonal etiology and local irritants, primarily through conservative surgical excision extending to the periosteum alongside thorough mechanical debridement. Ultimately, the successful prevention and regression of these vascular hyperplasias depend on rigorous oral hygiene, professional plaque control, and, in some cases, the natural hormonal stabilization that occurs after parturition

Keywords: Pregnancy tumor, Pyogenic granuloma, *Epulis gravidarum*, Gingival enlargement, gingival overgrowth, pregnancy gingivitis, periodontal treatment, oral hygiene instruction

INTRODUCTION

Pregnancy tumor, (also known 'pyogenic granulom' and "*Epulis gravidarum*") is a benign, localized granulation tissue of the skin and mucous membranes frequently triggered by the hormonal shifts associated with pregnancy. The terms "pregnancy tumor," "granuloma gravidarum" or "epulis" are all used interchangeably (5).

Despite its name, the lesion is not associated with pus (pyogenic) and does not represent a true granuloma histologically.

Historically, this entity has been identified by numerous terms reflecting evolving views on its pathogenesis, such as Lobular Capillary Hemangioma, Telangiectatic Granuloma, and Fibroangioma. Pregnancy Tumor (PT) presents as a solitary, sessile, or pedunculated nodule.

Approximately 0.5% to 5% of pregnant women develop intraoral Pregnancy Tumor (PT), typically within the first five months or across the 2nd-3rd trimesters (1, 2). The gingiva is the most predominant site, followed by the lips, tongue, and buccal mucosa (1). While gingival alterations affect roughly half of all pregnancies, the progression to pregnancy tumors is observed in only a small fraction of these cases (5).

Pregnancy-related sex hormones (estrogen/progesterone) modify the vascular response to local irritants like dental plaque. Estrogens act as stimulants for the production of VEGF by macrophages; conversely, androgens provide a counteractive effect, reducing the output of this angiogenic factor (5). These hormones increase angiogenic factors and decrease granuloma cell apoptosis, facilitating rapid growth (3, 4).

In the gingival tissues of pregnant patients, progesterone acts as an immunosuppressive modulator; it dampens the immediate acute inflammatory response to dental plaque while facilitating a potentiated chronic tissue reaction, which ultimately manifests as an exaggerated clinical inflammation.(7).

Although benign PT can mimic malignancy by causing extensive alveolar bone loss and tooth mobility (observed in 3% of cases). Such aggressive presentation requires careful radiographic and histological evaluation to rule out sarcomas (3).

Histologically, it is characterized by lobular capillary proliferation within an edematous stroma that may exhibit focal myxoid change., often accompanied by surface ulceration, a fibrinopurulent membrane, and mixed inflammatory cell infiltration (8). Because these features support a reactive rather than a true neoplastic process, the lesion is often discussed within the spectrum of lobular capillary hemangioma (9). In pregnant patients, however, the differential diagnosis should still include other gingival reactive lesions, particularly peripheral ossifying fibroma and peripheral giant cell granuloma, making careful clinicopathological correlation essential for accurate diagnosis (10).

Management is primarily dictated by the lesion's size, location, and symptom severity. For small, asymptomatic, and non-bleeding lesions, an expectant management (wait-and-watch) approach is preferred.

Management initiates with Phase 1 therapy focused on the removal of local irritants. Approximately 75% of cases undergo spontaneous regression within 1–4 months postpartum (5, 6). Treatment becomes mandatory if the lesion fails to resolve with Phase 1 therapy, exhibits rapid growth, persistent bleeding, or interference with mastication and speech. Surgery is also indicated for aesthetic concerns and, crucially, to provide a tissue sample for histopathological analysis to exclude malignant mimics. While regression is typical after labor, persistent lesions—even five months post-delivery—require surgical resection (5, 6).

Conservative surgical excision is the preferred method, offering a lower recurrence rate compared to other modalities (6).

If surgery is unavoidable during pregnancy, it should ideally be performed during the second trimester to minimize fetal risk (5, 6).

Modern approaches include the use of CO2 lasers or electrocoagulation to manage bleeding and facilitate ablation (5).

Surgery performed during pregnancy carries a higher risk of recurrence due to ongoing hormonal stimulation. However, complete excision after delivery generally results in no recurrence (6).

Following surgical removal, patients require regular follow-up. Successful cases, such as those with complete excision postpartum, typically show no recurrence during 6-month follow-up periods (6). Regardless of the chosen intervention, oral hygiene education is a critical first step to remove irritating factors and control the inflammatory environment.

CASE DESCRIPTION/METHODS

A 32-year-old female patient presented to our clinic with a complaint of a growing mass in the long-standing extraction socket of tooth #26. Clinical history revealed that the patient had recently given birth and the lesion had progressed during the course of her pregnancy.

Upon examination, an erythematous and granulomatous lesion measuring approximately 1.2 x 0.8 cm was observed (Figure 1a, Figure 1b). The initial clinical diagnosis was established as an oral pregnancy tumor.



Figure 3a: Buccal aspect of the mass



Figure 1b: Palatal aspect of the mass

Following a careful anamnesis, clinical, and radiological examination, Phase 1 periodontal therapy consisting of mechanical debridement was implemented, and the patient was provided with oral hygiene instruction (OHI).

Upon the reduction of the lesion size, complete surgical excision of the residual mass was performed as the second stage.

Upon clinical follow-up two weeks after the initiation of Oral Hygiene Instruction (OHI) and thorough mechanical debridement, the patient reported that the vast majority of the mass had detached spontaneously (Figure 2a, Figure 2b). Consequently, the decision was made to proceed with the surgical excision of the residual lesion.



Figure 4a: Buccal aspect of the residual mass after partial spontaneous resolution



Figure 2b: Palatal aspect of the residual mass after partial spontaneous resolution

Under local anesthesia, the residual lesion was completely excised (Figure 3a). The excised tissue specimen was preserved in 10% buffered formalin and submitted for histopathological examination (Figure 3b).



Figure 5a: Intraoperative view of the surgical site

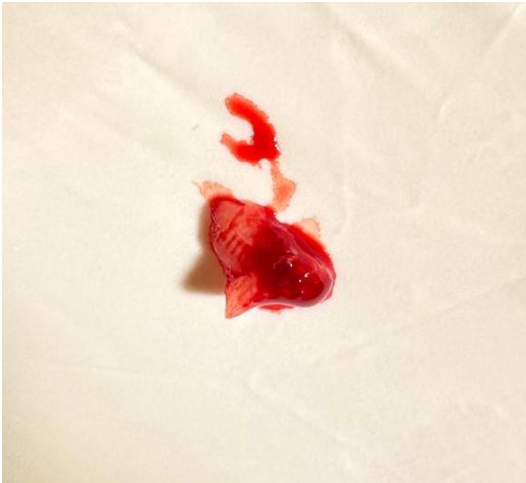


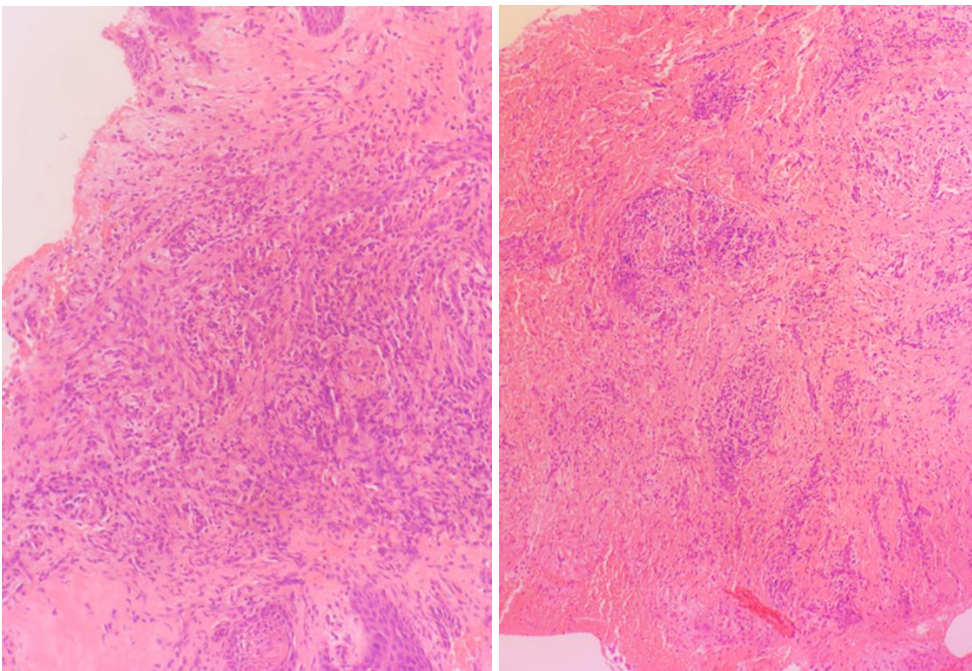
Figure 3b: View of the excised lesion

Hemostasis was achieved, and no suturing was required due to the nature of the surgical site.

RESULTS

The histopathological examination confirmed our initial clinical diagnosis.

Hematoxylin-eosin (H&E, 10X) stained section reveals areas of ulceration in the continuity of the surface squamous epithelium, with underlying capillary vascular proliferation (A) and mixed-type inflammatory cell infiltration (B), accompanied by significant stromal edema.



A

B

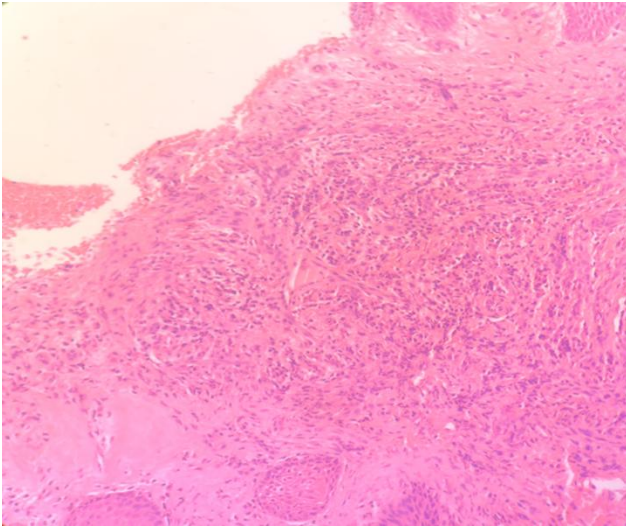


Figure 6: Histopathological section stained with H&E (10X)

No complications were observed during the first-week and third-month visits. The surgical site healed uneventfully, and no recurrence or complications were detected during the follow-up period (Figure 5a, Figure 5b).



Figure 7a: Clinical appearance of the healed surgical site at the three-month follow-up



Figure 5b: Three-month postoperative view demonstrating complete tissue healing and no signs of recurrence

CONCLUSION

In conclusion, pregnancy tumors (granuloma gravidarum) are benign yet clinically significant lesions that often present as soft, red nodules with a high tendency to bleed and may interfere with essential functions such as mastication (7).

Pregnancy tumors are lesions that require clinical treatment and long-term follow-up. Although hormonal shifts during pregnancy influence tissue response, the elimination of local irritants and the maintenance of oral hygiene practices remain the most critical prophylactic measures in preventing the occurrence of these lesions.

Early diagnosis of pregnancy tumors, followed by Phase 1 periodontal therapy—including mechanical debridement—and surgical excision when necessary, combined with patient education and follow-up, ensures optimal outcomes with a minimal risk of recurrence.

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THE PROTECTIVE ROLE OF EUISETUM ARVENSE L. IN A CARDIAC ISCHEMIA-REPERFUSION INJURY MODEL INDUCED IN RATS: A BIOCHEMICAL STUDY

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Objective: *Equisetum arvense L.* (Horsetail) has long been used in traditional medicine. This first study aimed to evaluate the therapeutic potential of fresh *Equisetum arvense L.* (EAL) plant extract in a cardiac ischemia-reperfusion (I/R) model created in rats. **Materials and Methods:** Twenty-four adult male Wistar albino rats were randomly divided into three equal groups: I/R-only group (n=8), sham group (n=8), and treatment group (n=8). Rats in the sham and treatment groups received 1 mL of saline solution (0.9% NaCl/kg/day) and 50 mg/kg/day EAL via gavage once daily, starting two days prior to the experiment, while rats in the I/R group received no treatment. All rats in all groups underwent 10 minutes of ischemia and 10 minutes of reperfusion after the intervention and surgical procedure. At the end of the experiment (7 days), myocardial damage was examined by macroscopic and biochemical evaluations. **Results:** The efficacy of EAL on myocardial tissue was found to significantly reduce malondialdehyde (MDA) concentrations and increase superoxide dismutase (SOD) and catalase (CAT) activities compared to sham and I/R groups (p<0.05). **Conclusion:** This study demonstrated promising therapeutic effects in the group treated with EAL. Both in vivo and in vitro findings suggest that EAL has the potential to be used as an additional therapeutic strategy in patients with cardiac I/R.

Keywords: *Equisetum arvense L.*, malondialdehyde, superoxide dismutase, catalase

SIÇANLARDA OLUŞTURULAN KALP İSKEMİ REPERFÜZYON HASARI MODELİNDE *EQUISETUM ARVENSE L.*'NİN KORUYUCU ROLÜ: BİYOKİMYASAL BİR ÇALIŞMA

Giriş: *Equisetum arvense L.* (Atkuyruğu), geleneksel tıpta uzun zamandır kullanılmaktadır. İlk defa yapılan bu çalışmada, sıçanlarda oluşturulan kalp iskemi-reperfüzyon (İ/R) modelinde taze *Equisetum arvense L.* (EAL) bitki ekstresinin terapötik potansiyelini değerlendirmeyi amaçlandı. **Materyal ve Metot:** Çalışma kapsamına alınan 24 ergin erkek Wistar albino sıçan rastgele üç eşit gruba ayrıldı: sadece İ/R uygulanan grup (n=8), sham grubu (n=8) ve tedavi grubu (n=8). Sham ve Tedavi gruplarındaki ratlara deneyden, iki gün öncesinden başlanarak günde bir kez 1 mL serum fizyolojik (%0,9 NaCl/kg/gün) ve 50 mg/kg/gün EAL gavaj yolla verilirken, I/R grubundaki ratlara hiçbir işlem uygulanmadı. Tüm gruptaki ratlara girişim ve cerrahi işlemten sonra kalpte 10 dakika iskemi ve 10 dakika reperfüzyon oluşturuldu. Deneyin sonunda (7 gün), myokard hasarı makroskopik ve biyokimyasal değerlendirmelerle incelendi. **Bulgular:** EAL'nin myokard dokusu üzerindeki etkinliği, sham ve I/R gruplarına kıyasla malondialdehit (MDA) konsantrasyonlarını önemli ölçüde azaltarak ve süperoksit dismutaz (SOD) ve katalaz (CAT) aktivitelerini arttırdığı saptanmıştır (p<0,05). **Sonuç:** Bu çalışma, EAL ile tedavi edilen grupta, umut verici terapötik etkiler göstermiştir. Hem in vivo hem de in vitro bulgular, EAL'nin kalp I/R hastalarında ek bir terapötik strateji olarak kullanılma potansiyeline sahip olduğunu göstermektedir.

Anahtar Kelimeler: *Equisetum arvense L.*, malondialdehit, süperoksit dismutaz, katalaz

1. Giriş

Hipoksi aerobik oksidatif solunumu etkileyen, son derece önemli ve genel bir hücre zedelenme ve ölüm nedenidir. Hipoksinin en önemli nedeni, arteriyel ya da venöz kan akımı bozukluğuna bağlı organ ve dokunun yetersiz perfüzyonuna yol açan iskemidir (1). Reperfüzyon, iskemiyi maruz kalan doku ya da organların yeniden kanlanması ve oksijenlenmesi olayıdır. Reperfüzyon hasarı ise, iskemi periyodunu izleyen yeniden kanlanma döneminde doku ya da organlarda meydana gelen hasar olarak tanımlanır. Hücre içine moleküler

oksijenin sunumuyla hızla oluşan serbest oksijen radikal (SOR) türevleri en çok suçlanan faktör olmakla birlikte, reperfüzyon hasarından birçok mekanizma sorumlu tutulmuştur (1).

İskemik period esnasında bu radikallerin yapımı çok artar (2,3) ve doğal savunma sistemleri yetersiz kalabilir. Bu koşullarda süperoksit ve hidrojen peroksit birbirleriyle reaksiyona girerek hidroksil radikalini (OH) üretirler (4). Bu son derece toksik radikale karşı herhangi bir savunma sistemi yoktur. Hidroksil radikali süperoksit radikalinden daha reaktif olup biyomembranlarda bulunan doymamış yağ asitlerini perokside ederek doku hasarı oluşturur (5). Membran lipitlerinin hidroksil radikali tarafından peroksidasyonu membran geçirgenliğinin artmasına, membran taşıma fonksiyonlarının bozulmasına ve kapiller endotel geçirgenliğinin artmasına yol açarak hücre ve doku harabiyeti meydana getirir (2). Radikallerin zararlı etkilerine karşı hücrelerde çeşitli savunma sistemleri bulunmaktadır. Süperoksit dismutaz (SOD), katalaz (CAT) ve peroksidaz gibi enzimler; askorbik asit, alfatokoferol (vitamin E), sistein, indirgenmiş glutatyon gibi maddelerin radikal temizleme yeteneği olduğu bilinmektedir (6,7). Ancak iskemik koşullar altında bu savunma sistemlerinin etkinliği azalmaktadır (8). Bu durumda oksidatif stres meydana gelmektedir. Hücre içerisinde oksidatif stresin indikatörü malondialdehit (MDA)' dir. Günümüz araştırmacıları esas olarak kalp I/R hasarına karşı bazı terapötik ajanlar olarak antioksidanlara odaklanmaktadır.

Bitkilerde bulunan antioksidan faktörler, radikal temizleme kapasitesi kanıtlanmış bileşen besin maddelerine ve vitamin veya mineral olmayan maddelere dayanmaktadır. Bu nedenle, alfa-tokoferol, askorbat, karotenoidler ve çinkoya ek olarak, bitki bazlı ilaçlar flavonoidler, polifenoller ve flavoproteinler içerebilir. Ayrıca, bazı bitkiler veya formülasyonlardaki belirli bitki kombinasyonları, süperoksit temizleme aktivitesi göstererek veya çeşitli doku bölgelerinde süperoksit dismutaz aktivitesini artırarak antioksidan görevi görebilir (9). Bu bileşik grupları, birden fazla biyokimyasal mekanizma yoluyla hücre koruyucu etki gösterebilen maddelerdir. Antioksidan özelliklerinin yanı sıra, kalp I/R karşı koruyucu faktörler, bazı meyveler, sebzeler ve yaygın olarak kullanılan baharatlar ve otlar da dahil olmak üzere birçok bitkide bulunur. Kimyasal yapılarına göre çeşitli farklı gruplara ayrılabilirler; örneğin, polifenoller, tiyoller, karotenoidler ve retinoidler, karbonhidratlar, eser metaller, terpenler, tokoferoller ve glukosinolatların (izotiyosiyanatlar, indoller ve ditiotiyoller) bozunma ürünleri ve diğerleri. Bu bileşik grupları, kalp I/R'e karşı koruyucu etkilerini birden fazla biyokimyasal mekanizma yoluyla gösterebilen maddelerdir. Kalp I/R oluşumunun biyokimyasal süreçleri hala ayrıntılı olarak bilinmemektedir.

Equisetum arvense L. (Atkuyruğu), yaygın olarak atkuyruğu olarak bilinen çok yıllık bir bitkidir ve genellikle nemli bölgelerde yetişir (Şekil 1). Kuzey yarımkürede yaygın olarak yetişir (10). Bitki, halk tıbbında sıklıkla tüberküloz, idrar yolu hastalıkları, romatizmal hastalıklar, yara iyileşmesi, ülserler ve saç dökülmesi tedavisinde kullanılır. Anadolu tıbbında günde 2-3 bardak %1-2'lik bir infüzyon olarak idrar söktürücü, yara iyileştirici ve iç kanamayı durdurucu olarak içilir (11). Ayrıca astım, karaciğer tıkanıklığı ve prostat tedavisinde de kullanılır (12,13, 14). *Equisetum arvense* L. (EAL) alkaloidler, karbonhidratlar, proteinler ve amino asitler, fitosteroller, saponinler, steroller, askorbik asit, silisik asit, fenol, tanen, flavonoidler ve triterpenoidler içerir (15).



Şekil 1. Equisetum arvense L.

İlk defa yapılan bu çalışmada, deneysel olarak oluşturulan kalp I/R hasarı modelinde EAL tedavisinin SOD, CAT ve MDA düzeyleri üzerine etkilerinin araştırılması amaçlandı.

2. Materyal ve Metot

2.1. Hayvanlar

Tüm sıçanlar deney gününe kadar $21 \pm 1^\circ$ C oda sıcaklığında, 12 saat ışık ve 12 saat karanlık periyodunda tutuldu, standart laboratuvar yemiyle beslendi ve deneyden önce tartıldı.

2.1.1. Deneysel Protokol

Bu çalışmada, örneklem sayısını belirlemek için G*power analizi kullanıldı. Gruplar (Sham, I/R ve EAL tedavi grupları) arasındaki fark için etki büyüklüğü %95 güven düzeyinde ($\alpha=0,05$) ve %80 güçle ($\beta=0,20$) 0,7 olarak tahmin edildiğinde, grup başına alınacak minimum örneklem büyüklüğü 8 olarak hesaplandı.

2.1.2. Deneysel Gruplar

Toplam 24 adet ergin wistar albino erkek ratlar randomize olarak üç gruba ayrıldı; I/R grubu (n=8), sham (n=8) ve EAL tedavi grubu (n=8). Sham ve EAL gruplarındaki ratlara deneyden, iki gün öncesinden başlanarak günde bir kez 1 mL serum fizyolojik (% 0,9 NaCl/kg/gün) ve 50 mg/kg/gün EAL ekstraktı gavaj yolla verilirken, kontrol grubundaki ratlara hiç bir işlem uygulanmadı. Tüm gruptaki ratlara girişim ve cerrahi işleminden sonra kalpte 15 dakika iskemi ve 15 dakika reperfüzyon oluşturuldu. Deneyin sonunda tüm ratlar sakrifiye edildi ve kalp dokusu çıkarılarak biyokimyasal ölçümler için homojenize edildi.

3.2.Cerrahi Yöntem

Çalışma KSÜ Tıp Fakültesi Deneysel Araştırma Laboratuvarında gerçekleştirildi. Ratlar laboratuvara getirildiler ve tek tek tartılarak her birine intraperitoneal olarak 50 mg/kg dozunda ketamin hidroklorid (Ketalar flakon, Eczacıbaşı Türkiye) verilerek anestezi sağlandı. Anestezi altında (Ketamin ile anestezi) sıçanlarda trake entübasyonu yapıldı. Sıçanların yaklaşık 3 mm olmak üzere 4.ve 5.toraks sol toraktomi yapılarak göğüs kafesi açıldı. Perikardiyum uzaklaştırılıp, abdomene baskı yapılarak kalp nazikçe göğüs kafesi dışına çıkarıldı ve sol ön inen koroner arterin orjinine yakın yerinden 6/0 ipek iplikli atravmatik yuvarlak iğne geçirildikten sonra kalp tekrar göğüs kafesi içine bırakıldı. İpek ipliğin her iki ucu kısa bir polietilen borudan (iç çapı 1mm,

uzunluk 15 mm) geçirildi. 15 dakikalık stabilizasyon periyodundan sonra koroner arter etrafına yerleştirilen iplik bir klips yardımıyla sıkıştırılarak ve 15 dakika süreyle geçici bölgesel iskemi yapıldı. İplerin gevşetilmesi ve borunun çıkarılması ile reperfüzyon işlemi yapıldı.

Deney sonunda her üç gruptaki ratların kalp dokuları biyokimyasal analizler için ayrıldı. Biyokimyasal değerlendirmeler KSÜ Tıp Fakültesi Tıbbi Biyokimya Anabilim Dalında yapıldı.

2.1.3. Kalp Doku Homojenatlarının Hazırlanması

Dokuların homojenize işlemine geçmeden önce 1 gr doku 5 hacim (hacim/ağırlık) %1,15 KCl çözünme sağlamak amacıyla eklendi. Dokular 16.000 devir/dakika hızda 3 dk boyunca homojenize edildi. Daha sonra homojenatlar +4 °C'de 14000 rpm'de 30 dakika santrifüj edildi ve üstteki süpernatantlar alındı ve ependorf tüplere ayrıldı. Ayrılan süpernatantlarda SOD, CAT ve MDA düzeyleri spektrofotometrik olarak ölçüldü.

2.1.4. Doku Antioksidan Enzim Aktiviteleri ve MDA Düzeylerinin Ölçümü

Katalaz (CAT) Enzim Aktivitesi

Her bir bitki ekstresi için; CAT enzim aktivitesi Beutler yöntemiyle saptandı (16). Reaksiyon karışımı için; 1 M Tris-HCl (Tampon çözelti pH 8.0), 10 mM H₂O₂, belirlenen ölçüde saf su ve enzim içeren bitki ekstresinden oluşmaktadır. 37°C'de enzimin aktivitesi ile yıkılan H₂O₂'in 230 nm de 10 dakika süreyle her 5 dakikadaki absorbans değişimleri ölçülerek yapıldı..

Superoksit Dismutaz (SOD) Enzim Aktivitesi

SOD aktivitesi her bitki ekstresi için Fridovich yöntemiyle saptandı (17). SOD aktivite tayini için bitki ekstresi 0.01 M Fosfat tamponu (pH 7.0) çözeltisi ile 65 kat seyreltilerek, bu dilüsyonda aktivite belirlendi. Reaksiyon karışımı bitki ekstresi, ksantin ve INT (p-iyodonitrotetrazolium viyole) içeren karışım substrat ve ksantin oksidazdan oluşur. Kör de numune ile aynı şekilde hazırlandı fakat numune yerine fosfat tamponu konuldu. 37°C'de numunenin 505 nm de havaya karşı ilk 30 saniyedeki başlangıç absorbansları (A1) ölçülerek yapıldı. Aynı esnada kronometre ile 3 dakika sonra son absorbansları (A2) ölçüldü ve değerler standart eğriden değerlendirildi.

Malondialdehit (MDA) Düzeylerinin Saptanması

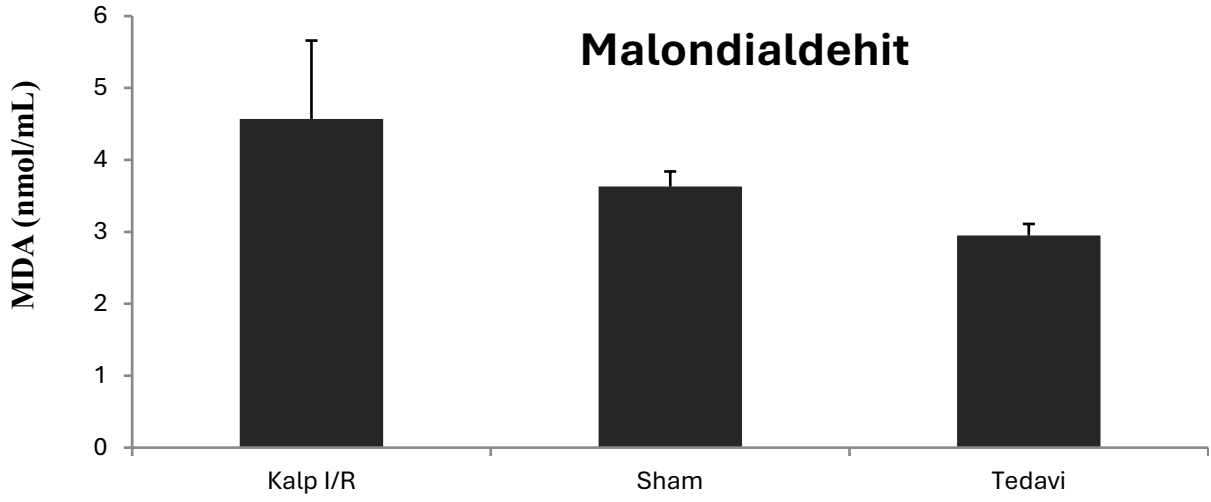
Oksidatif stresin göstergesi MDA'dır. Her bir bitki ekstresi için; MDA düzeyi Ohkawa yöntemiyle saptandı (18). Lipid peroksidasyonunun sekonder ürünü olan MDA'nın aerobik şartlarda pH 3.4'de tiyobarbitürik asit ile numunenin inkübasyonu sonucu pembe renkli kompleks oluşturması esasına dayanır. Oluşan renk şiddeti ortamdaki MDA konsantrasyonu ile doğru orantılıdır; 532 nm'de spektrofotometrik olarak ölçüldü.

2.2. İstatistiksel analiz

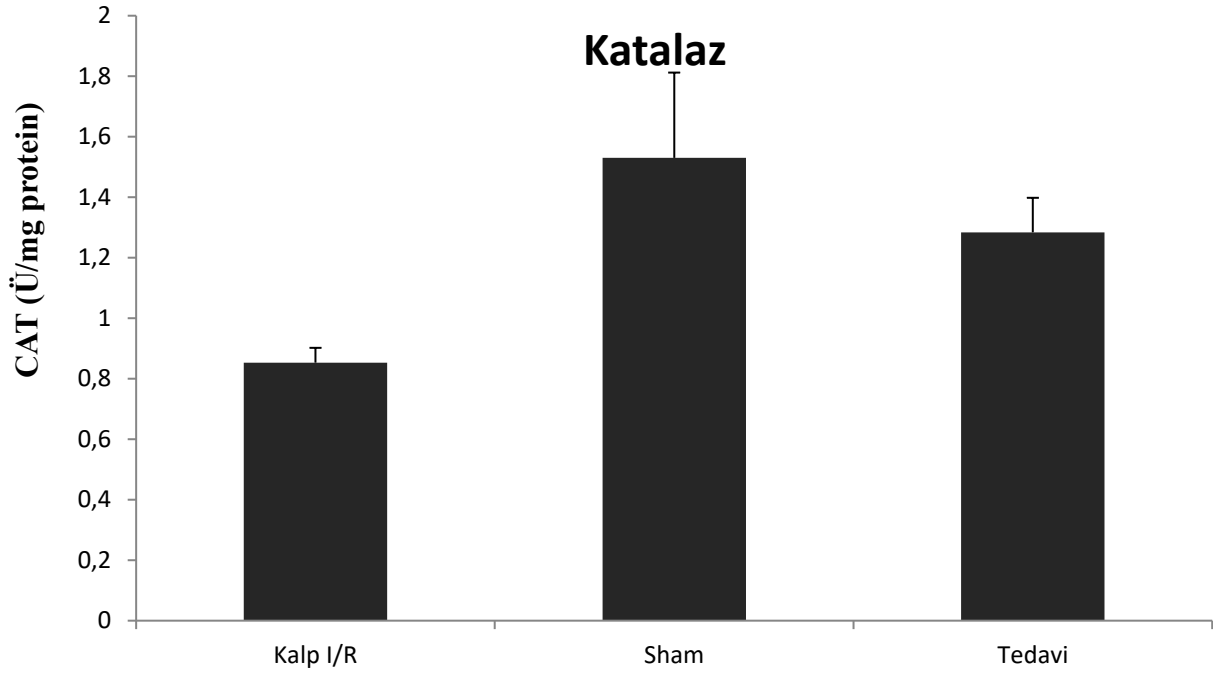
İstatiksel analizin yapılmasında SPSS (Statistical Package for Social Sciences) 21.0 kullanıldı. Sonuçlarımız ortalama $\pm$ standart sapma şeklinde verildi. Biyokimyasal verilerimizin değerlendirilmesinde ise gruplar arasındaki farkların incelenmesi için Non Parametrik Kruskal-Wallis testi, iki grup arasındaki farkın değerlendirilmesinde de Mann-Whitney U testi kullanıldı. Her iki test içinde $p < 0.05$ değeri istatistiksel olarak anlamlı kabul edildi.

3. Bulgular

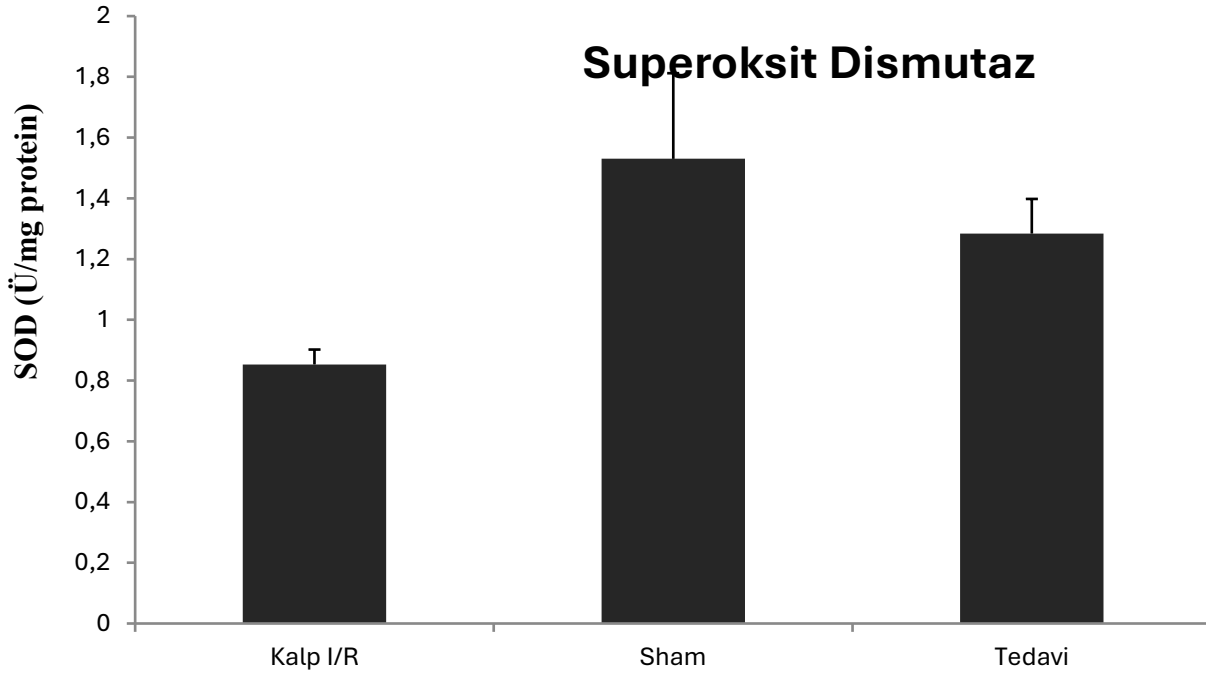
Biyokimyasal incelemeler sonunda sham, I/R ve EAL tedavi grupları birbirleriyle kıyaslandığında antioksidan enzim aktiviteleri ve MDA düzeyleri açısından anlamlı farklılıklar gösterdiği bulundu ($p < 0,05$) (Şekil, 2, 3 ve 4). EAL'nin myokard dokusu üzerindeki etkinliği, sham ve I/R gruplarına kıyasla malondialdehit (MDA) konsantrasyonlarını önemli ölçüde azaltarak ve süperoksit dismutaz (SOD) ve katalaz (CAT) aktivitelerini arttırdığı saptanmıştır ($p < 0,05$).



Şekil 2. Kalp I/R modelinde Malondialdehit Düzeyleri



Şekil 3. Kalp I/R modelinde Katalaz Aktiviteleri



Şekil 4. Kalp I/R modelinde Superoksit Dismutaz Aktiviteleri

4. Tartışma

Günümüzde kardiyovasküler hastalıklar pek çok endüstrileşmiş ülkede ölümlerin en önemli sebebi olmaya devam etmektedir. Kardiyovasküler hastalıkların oluşumunda pek çok neden sorumlu tutulabilir. Bunlar arasında fizikososyal stres, sigara, lipid ve lipoprotein metabolizmasının etkileri, eser elementlerin rolü ve genetik faktörler sayılabilir. Son yıllarda ROS'un miyokard iskemisi ve enfarktüsün patogenezindeki etkileri yoğun olarak araştırılmaya başlanmıştır. Aerobik miyokard, çeşitli oksidanlar ve koruyucu antioksidan savunma mekanizması oluşturan hücresel sistemler arasındaki bozuk bir dengeye bağlı olarak ortaya çıkan devamlı serbest radikal oluşumunu kontrol eder ve işlevini sürdürür. Kalpteki bu savunma mekanizmalarının, SOD, glutatyon peroksidaz (GSH-Px) ve CAT gibi enzimleri ve vitamin (askorbik asit), vitamin E (tokoferol), B-karoten ve ürik asit gibi nonenzimatik radikal temizleyicileri içerdiği şeklinde yaygın deneysel kanıtlar vardır.

İlk defa yapılan bu çalışmada, kalp İ/R hasarına karşı EAL ekstratının kalp dokusu SOD, CAT ve MDA düzeyleri üzerine etkileri incelenmiş ve EAL ekstratının kalp I/R hasarında koruyucu rolü olduğu görülmüştür. Bu durum EAL tedavisinin kalp I/R hasarı üzerine antioksidan olma özelliğine bağlı olarak antioksidan düzeylerinin arttırarak ve oksidatif stres düzeylerini düşerek koruyucu etkisi olabileceğini düşündürmektedir.

5. Sonuç

Çalışmamızda EAL tedavisinin kalp I/R hasarı üzerine antioksidan olma özelliğine bağlı olarak antioksidan düzeylerini artırarak ve koruyucu etkisi olabileceğini düşündürmektedir. Şifalı bitkiler antioksidan özellikleriyle hayati bir rol oynamaktadır. Modern tıbbın istenmeyen etkileri, insanların dikkatini bitkisel ilaçlara yöneltmiştir. İnsanlar arasında kabul edilebilirliği ve farkındalığı artırmak için, çeşitli hastalıkların tedavisinde geçerliliğini kanıtlayarak daha güvenli yerel sisteme olan güveni ve inancı geliştirmeye acil ihtiyaç vardır. Sağlık sistemleri giderek daha pahalı hale gelecek, bu nedenle sağlık hizmetlerimize bitkisel tıp sistemlerini dahil etmeliyiz. Umalım ki gelecekte doğal ürünler, daha fazla güvenlik ve daha düşük maliyet avantajlarıyla modern ilaçlarla rekabet etsin.

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MELAMINE-REINFORCED PGMA/PGMS ADHESIVES FOR ENHANCED COPPER ADHESION

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ÖZET

Bu çalışmada, Poly-GMA ve Poly-GMS esaslı polimerik bir sistem temel alınarak yeni bir kompozit yapıştırıcı formülasyonu geliştirilmiş ve yapı, melamin ilavesi ile yapısal olarak güçlendirilmiştir. Melamin; ağ yapısı yoğunluğunu artırmak, termo-mekanik direnci iyileştirmek ve ara yüzey yapışmasını geliştirmek amacıyla rijit, çok fonksiyonlu bir çapraz bağlayıcı ajan olarak kullanılmıştır. Melamin katkısının, yapıştırıcı-altlık ara yüzeyinde yük transfer kapasitesini artırması ve termal ile çevresel maruziyet kaynaklı bozunma etkilerini azaltması beklenmektedir. Sentezlenen kompozit yapıştırıcılar; yapısal, termal ve yapışma performansı açısından sistematik olarak karakterize edilmiştir. Melamin takviyesinin yapışma dayanımı ve uzun dönem dayanıklılık üzerindeki etkinliğini belirlemek amacıyla bakır yüzeyler üzerindeki ara yüzey bağ dayanımı değerlendirilmiştir. Elde edilen sonuçlar, melamin ilavesinin çapraz bağlanma verimini önemli ölçüde artırdığını ve buna bağlı olarak saf polimer sistemlerine kıyasla daha yüksek termal kararlılık ile üstün yapışma performansı sağladığını göstermiştir. Sonuç olarak bu çalışma, yüksek güvenilirlik gerektiren endüstriyel uygulamalarda bakır birleştirmeleri için yüksek performanslı polimer kompozit yapıştırıcıların tasarımına yönelik umut verici bir yaklaşım sunmaktadır.

Anahtar Kelimeler: Yapışma dayanımı, Bakır yüzeyler, Melamin takviyesi, Kompozit yapıştırıcılar.

ABSTRACT

Poly (glycidyl methacrylate) (PGMA) is widely recognized as a promising adhesive matrix due to the presence of highly reactive epoxy functional groups that enable strong covalent interactions with metallic surfaces. However, neat PGMA systems often exhibit limited thermal stability, insufficient crosslink density, and suboptimal mechanical performance when subjected to demanding operational environments. In this study, a novel composite adhesive formulation based on a Poly-GMA and Poly-GMS polymeric system was developed and structurally enhanced through melamine incorporation. Melamine was employed as a rigid multifunctional crosslinking agent to increase network density, improve thermo-mechanical resistance, and promote enhanced interfacial adhesion. The introduction of melamine is expected to contribute to improved load transfer capability across the adhesive-substrate interface and to mitigate degradation effects associated with thermal and environmental exposure. The synthesized composite adhesives were systematically characterized in terms of structural, thermal, and adhesion performance. Interfacial bonding strength on copper substrates was evaluated to determine the effectiveness of melamine reinforcement in improving adhesion strength and durability. The results demonstrate that the incorporation of melamine significantly enhances crosslinking efficiency, leading to improved thermal stability and superior adhesion performance compared to neat polymer systems. Overall, this study presents a promising approach for the design of high-performance polymer composite adhesives tailored for copper bonding applications in high-reliability industrial sectors.

Keywords: Adhesion strength, Copper substrates, Melamine reinforcement, Composite adhesives.

INTRODUCTION

Within contemporary structural joining technologies, the utilization of adhesives is regarded as an innovative approach capable of circumventing the limitations—such as stress concentration and corrosion—induced by traditional fastening methods (e.g., riveting, welding, and bolting). The preclusion of heat treatments and the obviation of mechanical fasteners render this method highly advantageous in preserving material integrity and streamlining manufacturing processes. Furthermore, by distributing stress homogeneously across extensive surface areas and establishing highly stable, hermetic seals against external environmental conditions, adhesives have garnered escalating prominence in aerospace, automotive, and advanced engineering applications. However, the efficacy of these systems is unequivocally contingent upon the rigorous control of substrate surface characteristics, thermodynamic wettability, curing parameters, and interfacial interactions. Fundamentally, the phenomenon of adhesion is governed by physical adsorption and chemical interactions occurring across distinct phases. These molecular-level interactions, spanning a broad spectrum from weak attractive forces (e.g., van der Waals) to robust hydrogen and covalent bonds, ultimately dictate the fatigue and shear performance of the joint. Consequently, the elucidation and optimization of adhesion mechanisms emerge as an indispensable imperative, not solely for static strength but also for long-term operational durability under dynamic loading.

Among polymer-based adhesives, epoxy systems constitute one of the most salient material classes due to their balanced mechanical properties, negligible shrinkage rates, and superior chemical resistance. The densely cross-linked, three-dimensional network structures they form during curing enable these systems to exhibit substantial rigidity in structural applications. Nevertheless, there is a burgeoning corpus of literature dedicated to the modification of epoxy systems to mitigate the inherent brittleness stemming from their rigid architecture, thereby augmenting fracture toughness and environmental compatibility. In this context, the incorporation of functional monomers into copolymerization processes is acknowledged as a pivotal strategy for enhancing the thermomechanical performance of adhesive systems. Specifically, glycidyl methacrylate (GMA), by virtue of its reactive oxirane (epoxy) functionalities and polymerizable double bond, can seamlessly integrate into the primary polymer backbone while simultaneously facilitating post-polymerization modifications. This attribute allows for the synthesis of controlled copolymer architectures, facilitating the precise tailoring of thermal and chemical properties for targeted, domain-specific applications.

The chemical modification of GMA-based polymeric systems, or their supplementation with heteroatom-bearing monomers such as sulfur, emerges as an efficacious strategy for the multifaceted optimization of adhesive performance. Such precise modifications yield pronounced improvements in fundamental parameters—namely, surface energy matching, mechanical robustness, and thermal stability—thus paving the way for high-performance systems tailored for advanced engineering applications. The literature frequently accentuates that the functional diversification of GMA-containing architectures can significantly elevate impact damping capacity, tensile strength, and flame retardancy, thereby securing their indispensable role in next-generation adhesive technologies.

Within the purview of this study, the primary objective is the development of polymeric adhesives demonstrating high interfacial affinity for metal-to-metal bonding applications. Accordingly, novel polymer systems harboring diverse functional groups were conceptualized and synthesized. A poly(glycidyl methacrylate) architecture featuring epoxy rings and a derivative polymer (poly(GMS)) incorporating highly polarizable thioether groups were independently prepared; additionally, a copolymer system synergistically integrating both functionalities was engineered. Through this methodology, the interactions between disparate chemical structures/functional groups and the hydroxyl moieties on the aluminum surface were comparatively investigated, thereby evaluating the contribution of functional diversity to adhesion behavior. Furthermore, a composite material approach was adopted to fortify the cohesive strength and interfacial interactions of the polymeric adhesive formulations. In this vein, micro-scale calcium phosphate particles were incorporated into the polymer matrix at defined weight percentages (wt%) to formulate inorganic-organic hybrid adhesives. The integration of the inorganic filler was strategically intended to refine the load transfer mechanism by dissipating stress concentrations within the matrix, while simultaneously enhancing mechanical toughness by arresting micro-crack propagation via surface roughness or particle bridging mechanisms.

The resulting adhesive formulations were applied to Al-5457 aluminum substrates—a standard industrial alloy—to fabricate single-lap joints in strict accordance with ASTM standards. The mechanical performance of these assemblies was empirically assessed via tensile-shear testing, and the corresponding influence of disparate polymer architectures and filler loadings on adhesion performance was systematically analyzed in

tandem with failure mechanisms. Moreover, the cross-link density of the system was augmented via reactions orchestrated between the epoxy functional groups and polyfunctional amines, thereby maximizing the thermal and mechanical resilience of the three-dimensional thermoset structure. Ultimately, this research experimentally substantiates that the synergistic integration of chemical structural engineering and composite modification paradigms can profoundly expand the performance thresholds of adhesive systems engineered for metallic substrates.

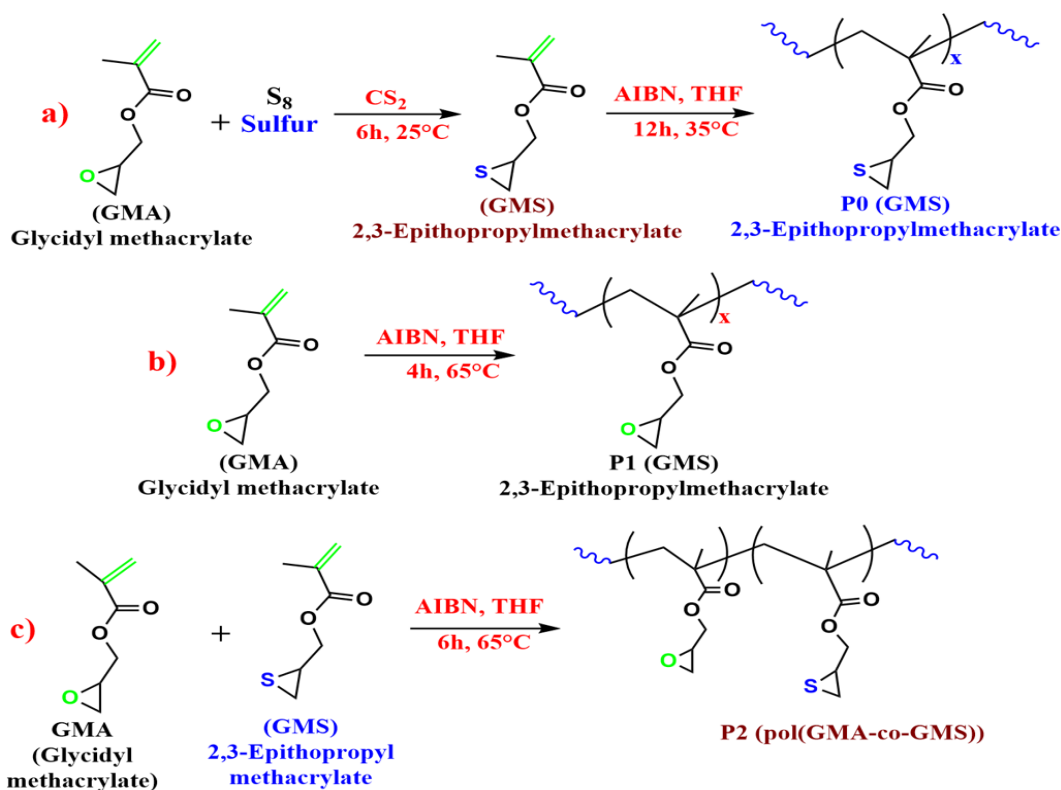
MATERIALS AND METHODS

Synthesis of Poly (GMA), Poly (GMS), and Poly (GMA-co-GMS) Copolymers

Glycidyl methacrylate (GMA) and 2,3-epithiopropyl methacrylate (GMS) monomers, serving as the fundamental building blocks for the polymeric adhesive systems, were commercially procured and prepared for utilization. To eliminate inhibitors capable of perturbing polymerization kinetics and the ultimate molecular weight distribution, the monomers were percolated through an activated basic alumina column prior to reaction, thereby ensuring high purity. The purified monomers were stored in the dark under sub-ambient temperatures until the inception of the reaction to preclude any risk of thermally or photochemically induced auto-polymerization. 2,2'-Azobis(isobutyronitrile) (AIBN), exhibiting thermal decomposition kinetics conducive to the established reaction parameters, was selected as the free radical initiator and deployed without subsequent purification. Solvents and precipitation agents, including methyl ethyl ketone (MEK), methanol (MeOH), tetrahydrofuran (THF), hexane, and various chlorinated hydrocarbons, were acquired at analytical grade. Furthermore, diaminodiphenylmethane (DADFM) was utilized as a curing agent to forge covalent cross-links between polymer chains, thereby establishing the structural network, whereas an inorganic calcium phosphate filler was integrated to modulate the system's thermomechanical properties. The Al-5457 aluminum blocks, serving as substrates for the bonding assays, were precisely machined to specific geometries mandated by international testing standards. A standardized surface passivation and mechanical abrasion protocol was universally applied to all specimens to meticulously minimize experimental variances.

The synthesis of poly(GMA-co-GMS) copolymers was executed via free radical solution polymerization, a technique affording controlled propagation of the macromolecular architecture. Briefly, the pre-purified GMA and GMS monomers were gravimetrically measured at predetermined molar ratios and comprehensively dissolved in anhydrous N,N-dimethylformamide (DMF). To eradicate dissolved oxygen—a potent radical scavenger capable of inhibiting the polymerization—the solution was rigorously de-aerated via purging with high-purity argon gas for approximately 15 minutes. An inert atmosphere was rigorously maintained throughout the synthesis. The reaction vessel was subsequently immersed in a thermostatic oil bath calibrated to 70 °C, corresponding precisely to the half-life of the AIBN initiator, and allowed to proceed for approximately two hours under continuous magnetic stirring to ensure uniform thermal distribution. A macroscopic escalation in the solution's viscosity during this incubation phase served as empirical confirmation of polymeric chain elongation and the successful progression of the copolymerization with elevated conversion kinetics.

Upon culmination of the designated reaction duration, the mixture was subjected to rapid thermal quenching to room temperature to arrest polymerization. The resultant viscous polymer solution was precipitously introduced dropwise into a volumetric excess of cold methanol—a non-solvent for the macromolecules but a potent solvent for unreacted monomers. The precipitated polymeric suspension was subsequently isolated from the mother liquor via vacuum filtration, followed by exhaustive, iterative washing with fresh methanol to categorically extract residual oligomers, unreacted monomers, and solvent traces. The purified macromolecular assemblies were dehydrated in a vacuum oven at 50 °C until constant mass was attained, thereby eradicating the terminal traces of entrapped solvent. Through this optimized synthetic protocol, poly (GMA) (P0) exclusively comprising GMA units, poly(GMS) (P1) exclusively comprising GMS units, and poly (GMA-co-GMS) (P2) copolymers with varying feed ratios were successfully synthesized with high stoichiometric yields. These synthesized macromolecules subsequently functioned as the primary matrices for the composite adhesive formulations to unequivocally elucidate structure-property correlations.



11

Adhesive Application and Curing Protocols

The efficacy of the synthesized homopolymers and copolymers as structural adhesives was rigorously evaluated utilizing aluminum-to-aluminum bonding configurations, which are ubiquitous in the aerospace and automotive sectors. Given that the robust adherence of an adhesive to a substrate (wettability and work of adhesion) is inextricably linked to surface energy, a standardized, highly reproducible pretreatment protocol engineered to augment surface activation was applied across all aluminum substrates. Initially, the aluminum plates were mechanically abraded utilizing silicon carbide (SiC) abrasive papers of specified grit dimensions. This mechanical abrasion eradicated the naturally occurring, weakly cohesive aluminum oxide (Al_2O_3) passivation layer and adventitious micro-contaminants; concurrently, it amplified surface micro-roughness, facilitating the capillary penetration of the adhesive into surface interstices, thereby maximizing mechanical interlocking. Directly succeeding mechanical preparation, the substrates were subjected to an ultrasonic cleaning regimen utilizing sequential applications of polar and non-polar solvents, such as acetone and ethanol, to obliterate machining fluids and organic impurities, followed by desiccation in an inert environment.

During the formulation phase, the synthesized P0, P1, and P2 polymers were stoichiometrically compounded with diaminodiphenylmethane (DADFM), acting as the hardener, and homogeneously dissolved in methyl ethyl ketone (MEK). MEK was strategically selected for its optimal evaporation kinetics and solvent efficacy for this specific system. Calcium phosphate micro-particles, at precisely targeted weight fractions, were subsequently introduced into the solution, and homogenous dispersion was achieved via high-shear mechanical agitation. The resultant hybrid adhesive formulations were applied to the pretreated aluminum substrates to cast a highly controlled film layer. To guarantee the homogeneous distribution of applied loads and minimize stress concentration asperities, a doctor blade apparatus was employed during the coating phase, yielding a consistent wet film thickness of approximately 0.1 mm. Following application, the substrates were subjected to a preliminary desiccation phase under ambient conditions within a fume hood to facilitate the controlled volatilization of MEK molecules. This step is of paramount criticality, as residual solvent entrapment catalyzes the formation of deleterious micro-voids during the subsequent curing phase.

Thereafter, the coated interfaces were superimposed to assemble standard single-lap joints. The specimens were transferred to a heated press apparatus to thermodynamically drive the nucleophilic addition reactions—between the oxirane/thiirane moieties of the polymer chains and the primary amines of the DADFM—to completion, thereby engendering a rigid, cross-linked network. Factoring in the rheological flow and gelation profiles of the adhesive, the assemblies were cured at 120 °C under an applied pressure of 6 MPa for a

predefined duration. This concurrent application of thermal energy and hydrostatic pressure amplified the interfacial contact area and categorically eradicated macroscopic voids within the bondline.



The Upper and Lower layers were fabricated at 120°C



The Samples were cured at a 6MPa pressure for 1 hour

Testing Procedures, Characterization, and Determination of Young's Modulus

Following the execution of mechanical shear testing, the failure topographies of the joints were scrutinized via High-Resolution Scanning Electron Microscopy (SEM) to conduct exhaustive fractographic analyses and delineate the failure modes (cohesive, adhesive, or mixed-mode) of the adhesive systems. Considering the inherently dielectric nature of polymeric adhesives, the fracture surfaces were sputter-coated with a nanometric, conductive gold/palladium stratum to mitigate electron beam accumulation (charging effects) and preserve optimal image resolution. Microstructural micrographs were acquired at varying magnifications up to 1.00 kX to critically inspect fracture topographies, localized plastic deformation zones, and the dispersion homogeneity (agglomeration versus uniform distribution) of the calcium phosphate particulates within the host matrix.

Young's modulus (Modulus of Elasticity) values, quantifying the intrinsic structural stiffness of the materials, were rigorously reported in MPa to ensure international data standardisation and stringent adherence to the SI unit framework. The corresponding modulus was extracted by determining the slope of the initial linear elastic regime (adhering to Hooke's Law) of the stress-strain curves, which were empirically derived from the load-displacement datasets recorded by the universal testing machine. In this analytical framework, the tensile/shear stress was computed by dividing the instantaneous applied load by the initial cross-sectional area of the bond, governed by the following equation:

$$\sigma = \frac{F}{A}$$

Where \$F\$ (Newtons) denotes the applied dynamic load, and \$A\$ (mm²) represents the precise cross-sectional area of the overlapped geometry. Concomitantly, the mechanical strain of the specimen was formulated as the quotient of the absolute elongation up to the ultimate point of rupture over the initial gauge length:

$$\epsilon = \frac{\Delta L}{L_0}$$

Young's modulus, an indicator of the adhesive's recalcitrance to elastic deformation, was quantified with maximal precision via linear regression analysis (least squares method) executed on the data coordinates mapping the linear elastic region, formulated by the fundamental relationship:

$$E = \frac{\sigma}{\epsilon}$$

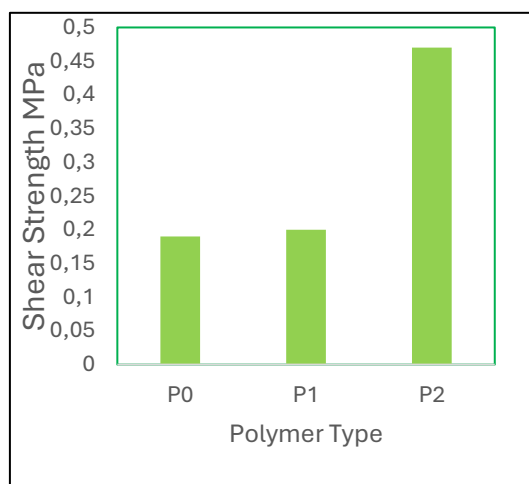
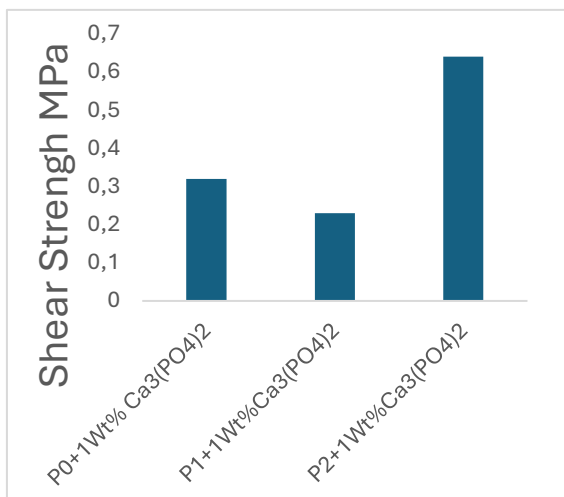
This rigorous mathematical protocol guaranteed that the derived modulus values inherently reflected the fundamental mechanical characteristics of the pristine polymeric network, effectively uncoupled from macro-scale material defects.

DISCUSSION AND CONCLUSION

In this comprehensive investigation, the mechanical and adhesive performances of composite matrices—formulated by reinforcing homopolymer (P0 and P1) and copolymer (P2) architectures synthesized via epoxy and episulfide monomers with 1 wt% calcium phosphate ($\text{Ca}_3(\text{PO}_4)_2$) micro-particles—were comparatively elucidated. Among these formulations, whose chemical fidelities were thoroughly validated via FT-IR spectroscopy, the P2 copolymer matrix distinctly achieved the paramount modulus of elasticity (55.8 MPa), an enhancement attributed to the optimally distributed functional moieties within its backbone. Furthermore, it demonstrated a superior mechanical infrastructure by exhibiting macroscopic ductile failure, substantiated by lamellar topographies observed during SEM characterization.

When specifically evaluating the impact of $\text{Ca}_3(\text{PO}_4)_2$ integration on adhesion metrics at the 1 wt% filler threshold, pronounced discrepancies materialized in direct correlation to the chemical architecture of the respective polymer matrices. While the assimilation of 1 wt% filler in the P1 homopolymer system yielded a marginal and insufficient early-stage enhancement in shear strength (0.20 MPa); the equivalent 1 wt% loading in the P2 system—wherein GMS units were seamlessly integrated into the copolymer backbone—maximized interfacial interactions, thereby yielding an ultimate peak shear strength of 0.87 MPa, the highest among all evaluated formulations. This dramatic performance escalation observed at the 1 wt% loading threshold in the P2 composite is fundamentally attributed to the homogenous dispersion of the filler particles within the continuous phase. This optimal distribution effectively amplifies fracture toughness without rigidly constraining macromolecular chain mobility, thereby optimizing stress transfer mechanisms to an ideal theoretical state. Conversely, the precipitous performance degradations recorded in the P2 system at filler concentrations exceeding 1% (specifically at 2% and 4% loadings) definitively corroborate that particulate agglomeration critically undermines intra-matrix cohesive forces, unequivocally establishing the 1 wt% loading ratio as the critical percolation threshold (optimal inflection point) for this specific system.

Synthesizing the empirical mechanical and morphological data, the adhesion performance of the evaluated polymeric adhesive systems generally adhered to a defined hierarchy: $\text{P2} > \text{P1} > \text{P0}$. In the rational design of high-performance composites engineered for the structural bonding of metallic substrates, the synergistic amalgamation of the flexible, robust cohesive foundation provided by the copolymer architecture (P2) with the integration of a 1 wt% $\text{Ca}_3(\text{PO}_4)_2$ inorganic filler has been identified as the most efficacious strategic approach. This specifically tailored 1 wt% formulation effectively circumvents deleterious particle agglomeration, thereby dissipating interfacial stress with maximal efficiency. Consequently, it introduces to the scientific literature a highly robust, durable, and conceptually innovative structural adhesive alternative tailored for advanced metal-bonding applications.



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OXIDATION OF 1-METHYL CYCLOHEPTANE WITH THE PARTICIPATION OF CROWN ETHERS

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ABSTRACT

Under interfacial catalysis conditions, crown ethers in the presence of metal complex catalysts formed with alkali metal cations. Oxidation reaction of 1-methylcycloheptane. A new, efficient and simple method for the synthesis of 1-methyl cyclohexanol has been studied. The use of crown ethers in this method allows the process to be carried out at very low temperatures and under mild conditions, which in turn prevents the production of various wastes and toxic products. In our research, we aimed to determine the optimal process conditions, investigate the cause of the formation of by-products, and increase the product yield. Oxidation reaction of 1-methylcycloheptane studied, 1-methylcycloheptane. The regularities of the oxidation reaction were studied. The effect of various complexing agents, alkalis, solvents, as well as the concentration of DB18K6 and KOH on the yield of the product was studied. It was found that increasing the concentration of KOH from 25 mmol to 50 mmol increases the yield of 1-methylcyclohexanol, but increasing the concentration at a later stage causes isomerization of 1-methylcyclohexanol. Also, as the concentration of DB18K6 increases, the yield of 1-methylcyclohexanol increases. This indicates that indeed oxidation. The process takes place in the organic phase, and the transfer of alkali to the organic phase is a key factor in this process. In the proposed method. Oxidation of 1-methylcycloheptane. The reaction is carried out under interfacial catalysis conditions in the presence of metal complex catalysts formed by crown ethers with alkali metal cations, which differs from traditional methods known in the literature in a number of advantages. The reaction uses cheap, harmless solvents. The reaction is carried out at low temperatures (100 - 130°C). KOH is used as the base, and the most stable catalysts - crown ethers (DB18K6) are used. The catalyst can be regenerated. As a result of all this, the product yield is high (96-98%).

Keywords: crown ether, interfacial catalysis, 1-methyl cycloheptanol

KRAUN-EFİRLƏRİN İŞTİRAKI İLƏ 1-METİL TSİKLOHEPTANIN OKSİDLƏŞMƏSİ

XÜLASƏ

Fazalararası kataliz şəraitində kraun-efirlərin qələvi metallarının kationları ilə əmələ gətirdikləri metal-kompleks katalizatorlarının iştirakı ilə 1-metil tsikloheptanın oksidləşməsi reaksiyası öyrənilmiş, 1-metil tsikloheptanolun sintezi üçün yeni, səmərəli və sadə üsul təqdim olunmuşdur. Bu üsulda kraun-efirlərdən istifadə olunması prosesin çox aşağı temperaturda və yumşaq şəraitdə aparılmasına imkan yaradır. Bu isə öz növbəsində müxtəlif tullantıların və zəhərli məhsulların alınmasının qarşısını alır. Apadığımız tədqiqatda prosesin optimal şəraitini müəyyənləşdirmək, əlavə məhsulun əmələ gəlməsinin səbəbini araşdırmaq və məhsulun çıxımını artırmaq məqsədi ilə 1-metil tsikloheptanın oksidləşməsi reaksiyası öyrənilmiş, 1-metil tsikloheptanın oksidləşməsi reaksiyasının qanunauyğunluqları öyrənilmişdir. Məhsulun çıxımına müxtəlif kompleksəmələgətiricilərin, qələvilərin, həlledicilərin, həmçinin DB18K6 və KOH-ın qatılığının təsiri öyrənilmişdir. Müəyyən olunmuşdur ki, KOH-ın qatılığının 25 mmoldan 50 mmola qədər artırılması 1-metil tsikloheptanolun çıxımını artırır, lakin sonrakı mərhələdə qatılığın artması 1-metil tsikloheptanolun izomerləşməsinə səbəb olur. Həminin DB18K6-nın qatılığı artdıqca 1- metil tsikloheptanolun çıxımı artır.

Bu, onu göstərir ki, həqiqətən oksidləşmə prosesi üzvi fazada gedir və qələvinin üzvi fazaya ötürülməsi bu prosesdə əsas faktordur. Təklif olunan üsulda 1-metil tsikloheptanın oksidləşməsi reaksiyasının fazalararası kataliz şəraitində kraun-efirlərin qələvi metallarının kationları ilə əmələ gətirdikləri metalkompleks katalizatorlarının iştirakı ilə aparılması ədəbiyyatda məlum olan ənənəvi üsullardan bir sıra üstünlükləri ilə fərqlənir. Reaksiyada ucuz, zərərsiz həlledicilərdən istifadə edilir. Reaksiya aşağı temperaturda (100 - 130°C) aparılır. Əsas kimi KOH –dan, ən davamlı katalizatorlardan - kraun-efirlərdən (DB18K6) istifadə olunur. Katalizatoru yenidən bərpa etmək mümkündür. Bütün bunların nəticəsində məhsulun çıxımı yüksək (96-98%) olur.

Açar sözlər: kraun efir, fazalararası kataliz, 1-metil tsikloheptanol

INTRODUCTION

Currently, with the discovery of -esters, great achievements have been made in the field of chemistry all over the world and new technological processes have been created in various fields. In a very short time, problems that were previously impossible to implement have been solved by means of metal complex catalysts formed by crown-esters with alkali metal cations.

It is known that today, the implementation of chemical reactions on an industrial scale under interphase catalysis conditions with the participation of metal complex catalysts of crown ethers is considered one of the most efficient methods. Since in this method the reaction is carried out under very mild conditions, the yield of the main product is high and it is obtained in high purity. In addition, interphase catalysis conditions allow to reduce industrial costs, and most importantly, this method allows to prevent harmful and toxic substances polluting the environment in chemical processes.

The results of scientific research conducted in recent years show that the most convenient and efficient catalyst for obtaining spits are crown ethers (Huseynova TM, Aghaguseynova MM, Mikayilova MR (2018), Huseynova TM, Aghaguseynova MM (2019), Huseynova TM, Ahmadov AC (2022), Huseynova TM, Amanullayeva G.I, Aslanova GT (2024),).

When these compounds are obtained by known methods: carrying out the reaction at high temperature (250°C), using expensive and harmful solvents (dimethylformamide, dimethylsulfoxide, triethylene glycol, methyl alcohol, acetonitrile, etc.), using bases (sodium amide, potassium amide, alkali metal hydrides, etc.), and using more than 10 times the amount of bases results in the production of by-products (isomers and resins). All this indicates that the known methods for obtaining spits are unsuitable for production.

In order to overcome the above-mentioned shortcomings, these compounds have been obtained in recent years under interfacial catalysis conditions. However, under these conditions, quaternary amines are used as catalysts, which are unstable catalysts and their activity cannot be restored. Therefore, in our study, a new, efficient and simple method for obtaining these compounds using the complexes formed by crown esters with alkali metal cations has been proposed (Huseynova TM, Amanullayeva G.I, Aslanova GT (2023), Huseynova TM, Abdullaeva G.N.(2023), Huseynova TM, G.I Amanullayeva, GTAslanova, A.Ahmadov. (2024)).

By the method known in the literature Oxidation of 1-methylcycloheptane The reaction was carried out at high temperatures (200-2500C) in triethylene glycol and in the presence of quaternary amines. In these methods, the high temperature reaction requires expensive solvents and unstable quaternary amines whose catalytic activity cannot be restored, which leads to a low product yield (40-50%) Hiraoka M. (1986), Weber V., Gokel G. (1980), CJPedersen. J.Am. chem Sos. (1967), Potehina A.A. (1984).

RESEARCH AND RESULTS

In the present work, the interfacial catalysis conditions were used in the presence of alkali metal complex catalysts. Oxidation of 1-methylcycloheptane The reaction was studied and a new efficient, environmentally friendly method was developed for the synthesis of 1-methyl cycloheptanol, which is of great industrial importance.

Oxidation of 1-methylcycloheptane reaction of solid, powdered KOH, liquid From 1-methyl cycloheptane and solvent. Three classes of complexing agents were used as interphase catalysts in the reaction: crown ethers -

dibenzo-18-crown-6 (DB18K6), 18-crown-6 (18K6), pentamethyl-15-crown-5 (PM15K5), tetramethyl-12-crown-4 (TM12K4), their open-chain analogues - diglyme, triglyme, tetraglyme, and quaternary ammonium salts - triethylbenzylammonium chloride. In addition, Oxidation of 1-methylcycloheptane KOH and various solvents were used.

The amount of various complexing agents and solvents, as well as crown ethers and KOH Oxidation of 1-methylcycloheptane The effect on the reaction has been studied.

It has been determined that the main factor influencing the course of the process is crown ether.

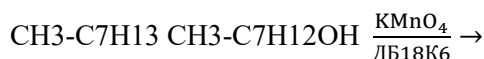
DISCUSSION OF RESULTS

In the present work, the oxidation reaction of 1-methyl cycloheptane in the presence of metal complex catalysts of crown ethers under interfacial catalysis conditions was studied, and a new, efficient, environmentally friendly method for the production of 1-methyl cycloheptanol, which is of industrial importance, was developed.

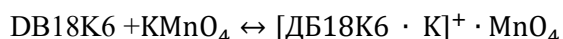
The oxidation reaction of 1-methylcycloheptane was carried out in a two-phase heterogeneous system consisting of solid, powdered KMnO₄, liquid 1-methylcycloheptane, and solvent. Three classes of complexing agents were used as interphase catalysts in the reaction: crown ethers - dibenzo-18-crown-6 (DB18K6), 18-crown-6 (18K6), pentamethyl-15-crown-5 (PM15K5), tetramethyl-12-crown-4 (TM12K4), their open-chain analogues - diglyme, triglyme, tetraglyme, and quaternary ammonium salts - triethylbenzylammonium chloride. In addition, KMnO₄ and various solvents were used as oxidants in the reaction.

The effect of various complexing agents and solvents, as well as crown ethers and the amount of KMnO₄ on 1-methylcycloheptane was studied.

The reaction proceeds according to the following scheme:



It was found that the activity of the system and the yield of 1-methyl cycloheptanol depend mainly on the rate of transition of the manganate MnO₄⁻ ion from the solid phase to the liquid phase. This, in turn, depends on the stability of the complex formed by the crown ether with KMnO₄. The essence of the process is that the crown ether plays the role of a carrier between the phases, and the complex formed by KMnO₄ with the crown ether is a milder oxidant. Thus, the crown ether forms a complex with KMnO₄ and transfers this complex to the organic phase and ensures its dissolution there.



In the organic phase, the complex dissociates and the highly active MnO₄⁻ ion is obtained. This ion interacts with 1-methylcycloheptane, oxidizing it to 1-methylcycloheptanol.

When studying the effect of various complexing agents on the oxidation reaction of 1-methylcycloheptane, it was found that of the three classes of complexing agents used in this reaction, the most effective were crown ethers, followed by glymes.

The activity of crown ethers, in turn, depends on their ability and stability to form complexes with KMnO₄. This, in turn, depends on a number of factors:

From the size of the crown-ether ring and the size of the cation - the closer these sizes are to each other, the more stable the complex will be. From the number of donor atoms - the stability of the complex increases with the number of donor atoms. From the location of the donor atoms - the more donor atoms there are on one plane, the more stable the complex will be. From the symmetry and basicity of the donor atoms. From the charge and solvation of the cation.

Table 1. Effect of various complexing agents on the yield of 1-methyl cycloheptanol.

(1-methyl cycloheptane -10 mmol, complexing agent -1 mmol, KMnO₄ -40 mmol, dioxane -15 ml)

Complex worker	Time (min.)	Conversion rate, %	Product yield, %

DB18k6	15	100	95
18k6	15	100	92
PM15k5	20	97	85
TM12k4	25	95	82
Tetraglym	30	91	75
Triglym	30	80	60
Diglim	40	65	50
FRIDAY	60	12	30
Complex worker-free	60	-	-

* The values in the table are calculated based on gas-liquid chromatography data.

Of the quaternary ammonium salts used, triethylbenzylammonium chloride (TEBAX) has the lowest activity for the system we have considered. Thus, the activity of the complexing agents used for the system under study decreases in the following order:

DB18K6 < 18K6 < PM15K5 < TM12K4 < Glimers < TEBAX

The effect of the amounts of KMnO₄ and DB18K6 on the yield of 1-methyl cycloheptanol was also studied. It was found that a high yield of 1-methyl cycloheptanol (95%) occurs at 1010C in dioxane at a molar ratio of 0.45 : 0.005 KMnO₄ and DB18K6.

The effect of different solvents on the yield of the product was also studied and is given in Table 2. It was found that the maximum yield occurs at 1010C in less time than in dioxane.

Table 2.Effect of different solvents on the yield of 1-methyl cycloheptanol (1-methyl cycloheptane -10 mmol, DB18K6 -1mmol, KMnO₄ -40 mmol, solvent-15 ml)

Solvent	Time (min.)	Conversion rate, %	Product yield, %
Toluene	40	98	90
Xylene	40	95	92
1,4-dioxane	5	100	95
Diglim	10	100	78
n – butanol	15	85	81
Ethylene glycol	15	90	85
Without a solution	120	10	8

* The values in the table are calculated based on gas-liquid chromatography data.

Thus, the oxidation reaction of 1-methyl cycloheptane in the presence of crown ether under interfacial catalysis conditions was studied, and a new, efficient and simple method for the synthesis of 1-methyl cycloheptanol was presented.

The use of crown ethers in this method allows the process to be carried out at very low temperatures and under mild conditions, which in turn prevents the production of various wastes and toxic products.

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**ANALYSIS OF SOFTWARE-ASISTED LIQUEFACTION POTENTIAL USING SPT AND CPT
PARAMETERS AND COMPARISON OF THE RESULTING SAFETY FACTOR**

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ABSTRACT

Liquefaction problems are a crucial issue to consider for every soil structure. They demonstrate how the soil might behave during an earthquake, depending on the groundwater level. In this study, two different soil parameters were used for calculating the liquefaction safety factor (FS) under the same soil conditions: Standard Penetration Test (SPT) and Cone Penetration Test (CPT) values. Cyclic stress ratio (CSR) and cyclic resistance ratio (CRR) were calculated, taking earthquake parameters into account. Software-aided algorithms were developed for the analyses, and the safety factor (FS) was calculated. The variation of FS values with depth is presented for both soil parameters. The analyses show that CPT parameters yield results consistent with SPT. The study demonstrates that using both methods for evaluation allows for a more realistic interpretation of seismicity when interpreting liquefaction potential. Furthermore, the software-aided calculation approaches developed in the analyses allow for faster results.

Keywords: CPT, Liquefaction, Software-aided soil liquefaction behavior analysis, SPT

1.INTRODUCTION

Liquefaction, particularly observed in loose, water-saturated sandy and silty soils, is a geotechnical issue that requires careful consideration. It commonly occurs in regions with high seismic activity. During an earthquake, the water present between soil particles tends to escape, causing the soil to behave like a fluid and flow.

This phenomenon is referred to as liquefaction. Regardless of how robust a superstructure may be, significant damage can occur if fundamental soil-related problems such as liquefaction are not properly addressed. In other words, liquefaction represents a high-risk concern in geotechnical engineering and earthquake management.

Liquefaction is initiated by the increase in pore water pressure due to vibrations generated during an earthquake. When an earthquake occurs, the pore water pressure rises, soil particles become compressed, and water pressure increases accordingly. The mechanism of liquefaction consists of four stages. These are:

- The effect of groundwater
- The effect of seismic vibrations
- The increase in pore water pressure
- Loss of soil bearing capacity

Loose sands, silty soils, saturated and poorly drained soil layers, and regions with alluvial soil formations are areas with a high risk of liquefaction. The indicators of liquefaction can be listed as follows:

- Sudden and severe settlements at the soil surface,
- Significant settlement-induced damage to buildings, even if they are structurally sound,
- Settlements occurring in large-scale road and bridge projects,

- Deformations that increase the intensity and destructiveness of earthquakes.

The prevention and mitigation of liquefaction constitute a critical issue. These methods can be listed as follows:

1. Soil improvement methods
2. Effective solutions in foundation design
3. Drainage system designs that reduce pore water pressure
4. Identification of liquefaction potential and design approaches based on this assessment

Considering these factors, numerous studies have been conducted to determine liquefaction potential. One of the most widely used approaches is the semi-empirical method developed by Seed and Idriss (1971). This method was later revised based on Standard Penetration Test (SPT) parameters (Youd et al., 2001). Many researchers have also incorporated earthquake magnitude into their analyses and evaluated liquefaction potential accordingly (Iwasaki, 1986; Youd, 1992). In addition, studies have investigated which soil parameters provide more reliable results (Robertson and Wride, 1998).

Studies conducted by various researchers have concluded that liquefaction has been observed in many earthquakes that have occurred in Türkiye (Aydan et al., 2000; Ulusay, 2000; Çetin et al., 2002; Şahin and Çetin, 2024; Bozkurt, 2025). In this context, according to Turkish Building Earthquake Code (2018), it is recommended that liquefaction analyses be performed for soil sites where structural design is planned, and that soil improvement methods be applied if deemed necessary.

In this study, calculation methods based on semi-empirical approaches using SPT and Cone Penetration Test (CPT) parameters were employed to determine liquefaction potential. A computational algorithm comparing SPT and CPT parameters was developed, and the consistency of the obtained results was investigated. A representative soil profile was defined, and liquefaction potential analyses were carried out using both parameter-based methods. The liquefaction behavior was then evaluated based on the calculated factor of safety values.

2.MATERIALS AND METHODS

In this study, a representative soil profile was defined, and the liquefaction potential was evaluated under identical conditions using two different parametric methods. For the defined soil profile, a manual calculation procedure was established, and an algorithmic calculation method was developed. The CPT and SPT analysis methods were then compared with each other. The obtained results were presented graphically according to the depth of the soil layers.

2.1.Calculation of FS Using SPT and CPT Parameters with Semi-Empirical Methods

The representative soil profile can be defined as follows:

- Groundwater level: 1.5 m
- Peak soil acceleration: $a_{max}=0.30$ g
- Soil type: Loose to Medium Dense Sand (SM/SP)

Table 1. Representative Soil Profile

Depth (m)	γ (kN/m ³)	N (SPT)	q_c (MPa)
1	18.0	8	4
2	18.0	10	5

3	18.0	12	6
4	19.0	15	8
5	19.0	18	10
6	19.0	20	12
7	20.0	22	14
8	20.0	25	16
9	20.0	28	18
10	20.0	30	20

- In the manual calculation approach, the factor of safety (FS) at a depth of 5 m can be evaluated using SPT and CPT parameters as an example and presented as follows:

SPT Method

Total vertical stress: $\nabla_v = \gamma \cdot z = 19 \cdot 5 = 95 \text{ kPa}$

Considering the groundwater level (1.5 m): $u = 9,81 \cdot (5 \text{ m} - 1,5 \text{ m}) = 34.3 \text{ kPa}$

Effective vertical stress: $95 - 34,3 = 60,7 \text{ kPa}$

CSR calculation: $CSR=0,294$

CRR calculation: $CRR=0.262$

Factor of safety: $FS = CRR/CSR = 0.89$

Since $FS < 1$, liquefaction behavior is observed in the soil layer at a depth of 5 m in the representative soil profile.

CPT Method

Normalized q_c value: $q_c=164.7$

CRR calculation: $CRR=0.165$

Factor of safety calculation: $FS=0.56$

- When the FS values obtained from the manual calculation method are compared, the FS value calculated using CPT parameters is lower. This indicates that the CPT-based results are more conservative or more sensitive compared to the SPT-based results.
- In addition, this difference in FS values is attributed to the fact that CPT provides continuous data, whereas SPT yields more discrete (point-based) results.

2.2.Calculation of FS Using an Algorithmic Computation Code

A computation algorithm was developed using the data of the defined representative soil profile, and the obtained results were presented graphically to compare CPT and SPT results. The developed code is capable of performing analyses for both SPT and CPT methods. In addition, the effect of seismic behavior was incorporated into the computational model. Two earthquake magnitudes were selected as $M_w=7.5$ and $M_w=6.5$. The selection of two different earthquake magnitudes demonstrates the influence of earthquake size on factor of safety (FS) analyses. The results obtained from the analyses are presented graphically in Figures 1, 2, and 3.

- Figure 1 illustrates the FS values obtained from SPT and CPT analyses at different depths.
- Figure 2 presents the effect of earthquake magnitude on the factor of safety (FS).

- Figure 3 shows the variation of CSR and CRR values with depth.

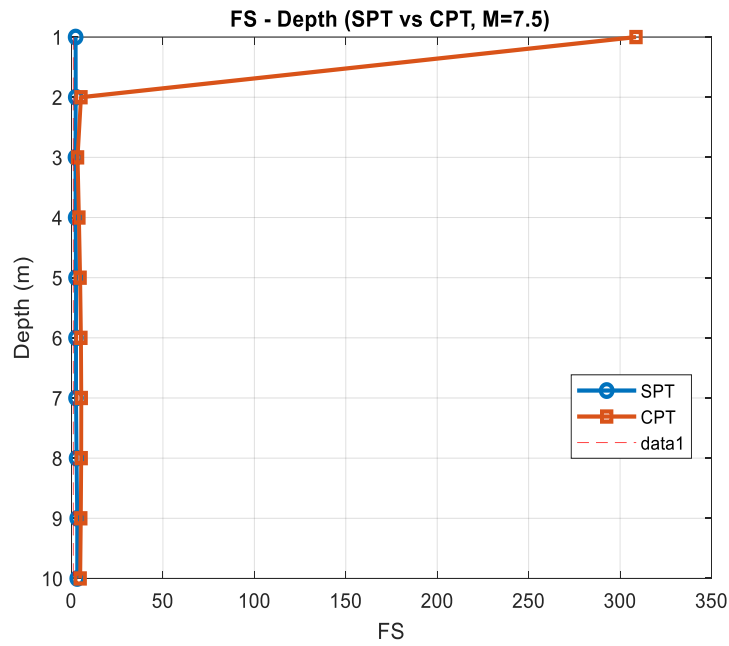


Figure 1. FS-Depth Graph

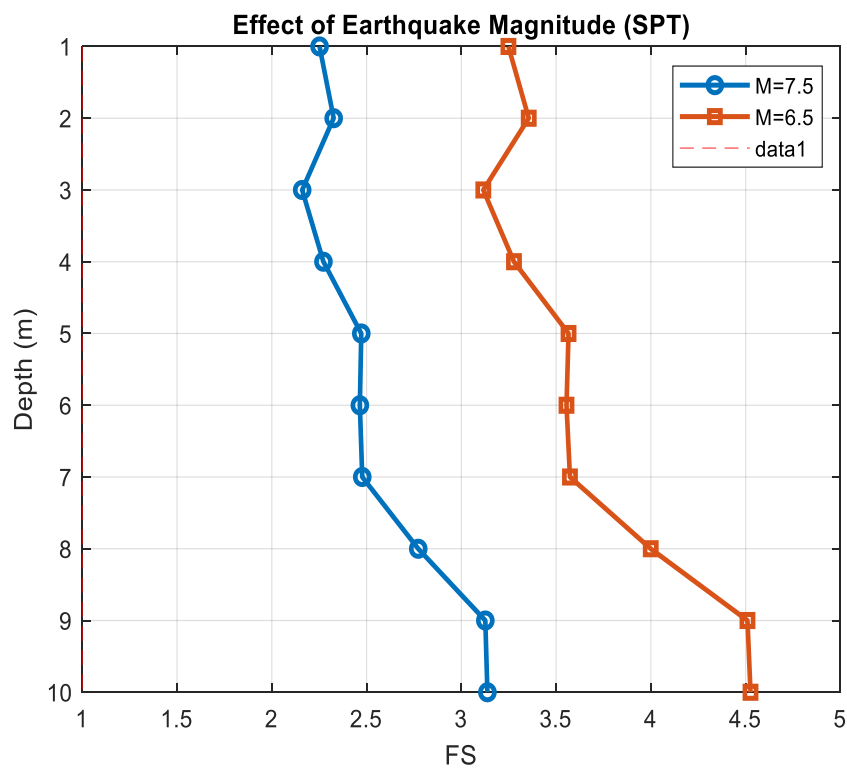


Figure 2. FS-Depth graph for different earthquake magnitudes

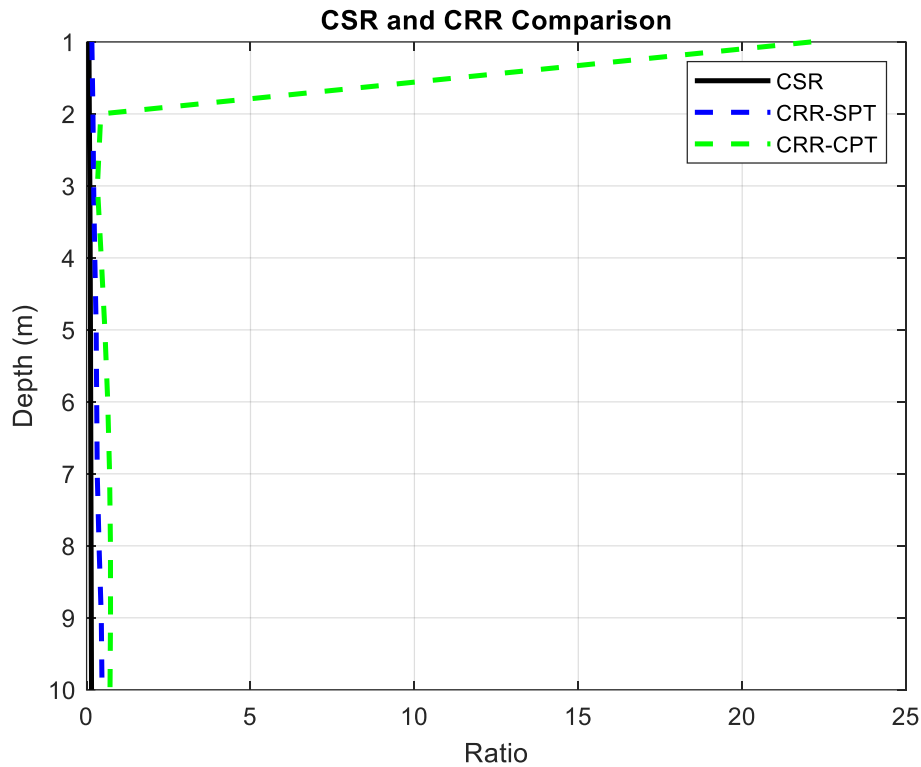


Figure 3. Comparison of CSR and CRR values for SPT and CPT parameters

3.RESULTS

In this study, a representative soil profile was defined, and the liquefaction potential was evaluated using manual calculations based on SPT and CPT methods. The factor of safety (FS) values were determined for different soil layer depths to assess liquefaction potential. Subsequently, an algorithmic computation method was developed for the same soil profile. The obtained results were compared graphically. In addition, two different earthquake magnitudes were defined in the algorithmic model, and the effect of earthquake magnitude on liquefaction potential was investigated and presented graphically. The results can be summarized as follows:

- CPT-based analyses yielded lower factor of safety (FS) values compared to SPT-based analyses. This is attributed to the fact that CPT provides continuous and more precise measurements.
- An FS value lower than 1 indicates the presence of liquefaction potential in the investigated soil layer.
- When FS values obtained for two different earthquake magnitudes are considered, an increase in earthquake magnitude leads to a decrease in FS values. As expected, this indicates that liquefaction potential increases with increasing earthquake magnitude.
- Accordingly, earthquake magnitude should be considered in liquefaction analyses.
- The algorithmic computation method provides faster, more practical, more precise, and less error-prone results compared to manual calculations. This demonstrates that algorithmic approaches are highly applicable in liquefaction analysis.

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CALCULATING LIQUEFACTION POTENTIAL NUMERICALLY USING A SOFTWARE-BASED APPROACH WITH SPT DATA

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ABSTRACT

Liquefaction, which is a geotechnical problem, is generally defined as the phenomenon where groundwater leaves the soil under the influence of an earthquake, causing the soil to flow like a liquid. In this study, a software-aided calculation algorithm has been developed to quickly and reliably determine the liquefaction potential of soil using Standart Penetration Test (SPT) parameters. Prepared considering the Turkish Building Earthquake Code (2018), the algorithm calculates the corrected blow counts, cyclic stress ratio (CSR), cyclic resistance ratio (CRR), and safety factor FS, and evaluates the liquefaction potential. A sample soil profile was prepared and analyses were performed. The results showed that the algorithmic calculation accurately determined the liquefaction potential between soil layers. The developed calculation algorithm approach is considered to provide accurate and rapid results.

Keywords: Liquefaction potential, SPT soil parameters, Software-aided liquefaction analysis

1.INTRODUCTION

The evaluation of liquefaction potential for all soil groups is a critical issue that must be considered, particularly in the event of a possible earthquake. Under cyclic seismic loading, soils with high water retention capacity- especially loose to medium-dense sands- are among the most susceptible to liquefaction. Therefore, assessing the liquefaction potential of soils is of paramount importance. This issue must be thoroughly investigated, particularly in countries with high seismic activity.

For instance, Turkey, which is located along major active fault lines, has been subjected to severe earthquakes over the years. Following the 1999 Kocaeli Earthquake and the 2023 Kahramanmaraş Earthquake, liquefaction phenomena were observed, along with settlement problems between soil layers, which increased the destructive impact of these events. For this reason, liquefaction potential must be investigated from a geotechnical perspective in order to mitigate the effects of potential earthquakes.

Numerous methods have been developed to evaluate liquefaction potential. One of the most widely used approaches is based on Standard Penetration Test (SPT) parameters (Seed and Idriss, 1971; Youd et al., 2001). This method is considered semi-empirical, as it incorporates data obtained from in-situ field tests into the calculations. In this approach, liquefaction potential is assessed using the cyclic stress ratio (CSR), which represents the earthquake-induced cyclic stresses in the soil, and the cyclic resistance ratio (CRR), which expresses the soil's resistance to liquefaction.

SPT parameters obtained from field tests are formulated through empirical relationships to estimate liquefaction potential. Numerous studies have been conducted on this subject, particularly those focusing on regional liquefaction potential analyses (Çetin et al., 2004; Huang and Yu, 2013; Yoshimi et al., 1989; Keskin and Ateş, 2014; Batuge et al., 2023; Kara et al., 2023; Durukan and Akbuğa, 2018; Bozkurt, 2025).

In this study, a computational algorithm has been developed using SPT data to enable rapid and practical determination of liquefaction potential. The proposed algorithm provides fast and reliable results across different soil classes and is consistent with hand calculations. Furthermore, the analysis procedure follows the calculation sequence specified in the Turkish Building Earthquake Code (TBDY, 2018).

2. MATERIALS AND METHODS

In liquefaction analyses, SPT-N data, soil unit weight (γ), groundwater level (GWL), soil layer depths, maximum soil acceleration ($a_{\max}$), and potential earthquake magnitude (M_w) were considered. These parameters can be defined as input parameters in the analyses. Stress and strength components were determined as output parameters. As a result, the liquefaction potential was assessed by obtaining the factor of safety against liquefaction.

2.1. Liquefaction Analysis

According to the Turkish Building Earthquake Code (2018), liquefaction analyses are carried out using SPT data, based on the calculation of cyclic stress ratio (CSR), cyclic resistance ratio (CRR), and factor of safety (FS). Under earthquake loading, the cyclic shear stress acting on the soil is expressed by CSR, while the soil's resistance to liquefaction is represented by CRR. The factor of safety (FS) is defined as the ratio of CRR to CSR. If FS is less than 1, it indicates that there is liquefaction potential in the study area. If FS is equal to or greater than 1, liquefaction is not expected.

2.2. Development of a Software-Based Calculation Algorithm

The primary objective of this study is to develop a calculation algorithm that enables faster and more reliable determination of liquefaction behavior. The developed algorithm incorporates all procedural steps involved in liquefaction analyses.

Initially, the algorithm determines the $(N_1)_{60}$ value through SPT corrections. For each soil layer, CSR and CRR values are calculated, and the factor of safety (FS) is subsequently obtained. The algorithm repeats the liquefaction analysis for each depth throughout the soil profile.

The procedural steps of the calculation algorithm are illustrated in a flowchart in Figure 1.

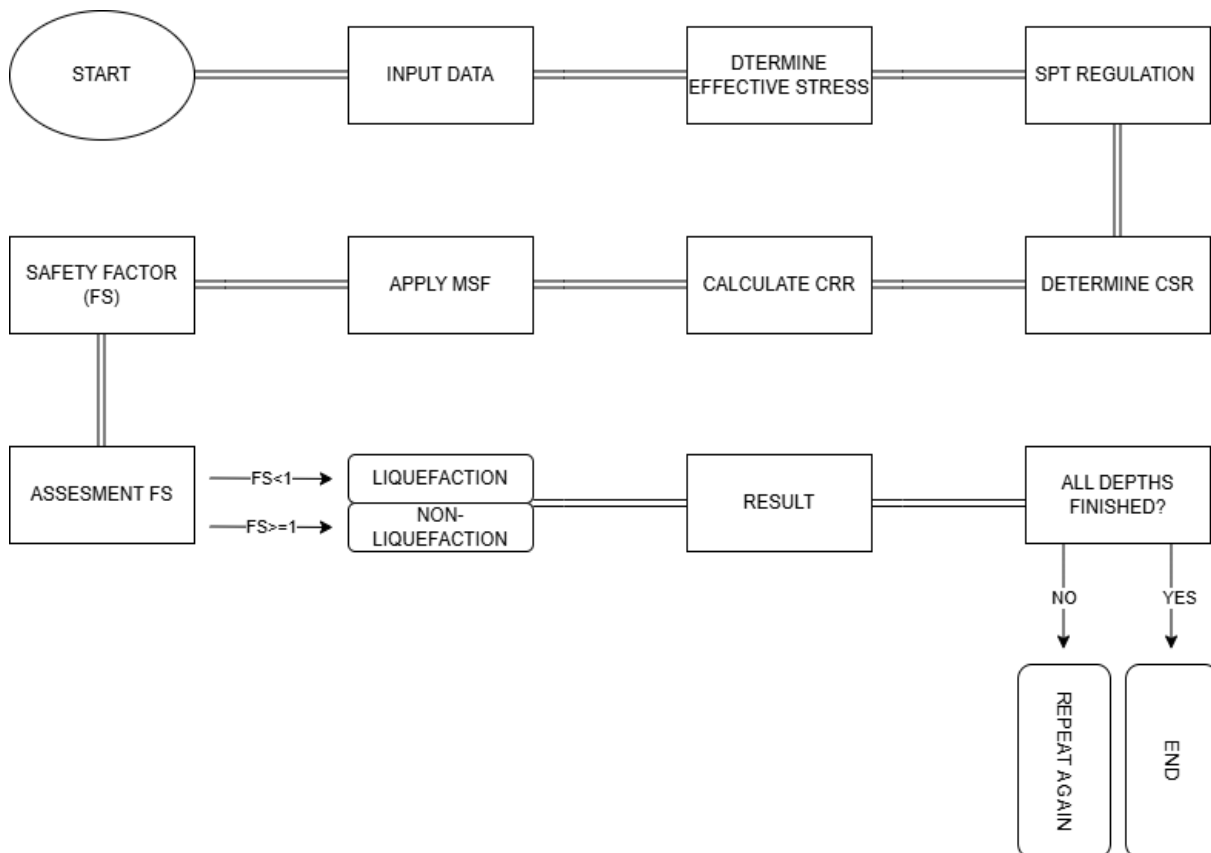


Figure 1. Flowchart of the Calculation Algorithm

With the developed liquefaction calculation algorithm, repetitive and time-consuming computational procedures are made more practical. As a result, the analysis process has been shortened and potential calculation errors have been minimized.

3.RESULTS

In the analyses, a soil profile for which in-situ tests had been conducted and laboratory results were available was used. The unit weight of the soil is 18.4 kN/m^3 . The thicknesses of the soil layers vary between 3.00 m and 14.00 m. SPT values were corrected using correction coefficients, and the $(N1)_{60}$ and $(N1)_{60f}$ parameters were calculated. Subsequently, the obtained data were analyzed using the developed software-based algorithmic calculation method, and the consistency of the results was compared.

3.1.Evaluation of Liquefaction Potential According to Turkish Building Earthquake Code (TBDY)

In the calculations, the liquefaction analysis method presented in TBDY was adopted. The results obtained accordingly are presented in Table 1. In Table 2, the liquefaction resistance of the soil and the shear resistance of the soil are provided. The liquefaction behavior for each soil layer was interpreted by taking the ratio of the obtained soil liquefaction resistance to the shear resistance.

Table 1. Soil Profile of the Study Area

Depth (m)	N	γ (kN/m ³)	σ_0	σ'_0	U	$N_{1,60}$	$N_{1,60f}$
3.00	11	18.4	55.20	55.20	0.00	12.2	19.62
6.00	10	18.4	110.40	92.76	17.64	9.6	16.46
9.00	8	18.4	165.60	118.56	47.04	7.1	9.87
12.00	9	18.4	220.80	144.36	76.44	7.3	13.70
15.00	11	18.4	276.00	170.16	105.84	8.2	14.80

Table 2. Liquefaction Condition of the Soil Profile

Depth (m)	τ_R	τ_{deprem}	$FS = \tau_R / \tau_{deprem}$	Liquefaction Status
3.00	14.94	10.29	1.45	Nonliquefaction
6.00	20.86	20.10	1.04	Liquefaction
9.00	17.06	29.43	0.58	Liquefaction
12.00	27.31	35.97	0.76	Liquefaction
15.00	34.54	40.74	0.85	Liquefaction

γ : Unit weight of soil

σ_0 : Effective stress

σ'_0 : Net effective stress

U: Pore water pressure (kN/m²)

$N_{1,60}$: Corrected SPT blow count

$N_{1,60f}$: SPT blow count corrected for fines content

τ_R : Soil liquefaction resistance (kPa)

τ_{deprem} : Cyclic shear stress induced by earthquake (kPa)

FS: Factor of safety

- The data obtained in Table 2 are presented graphically in Figure 2.

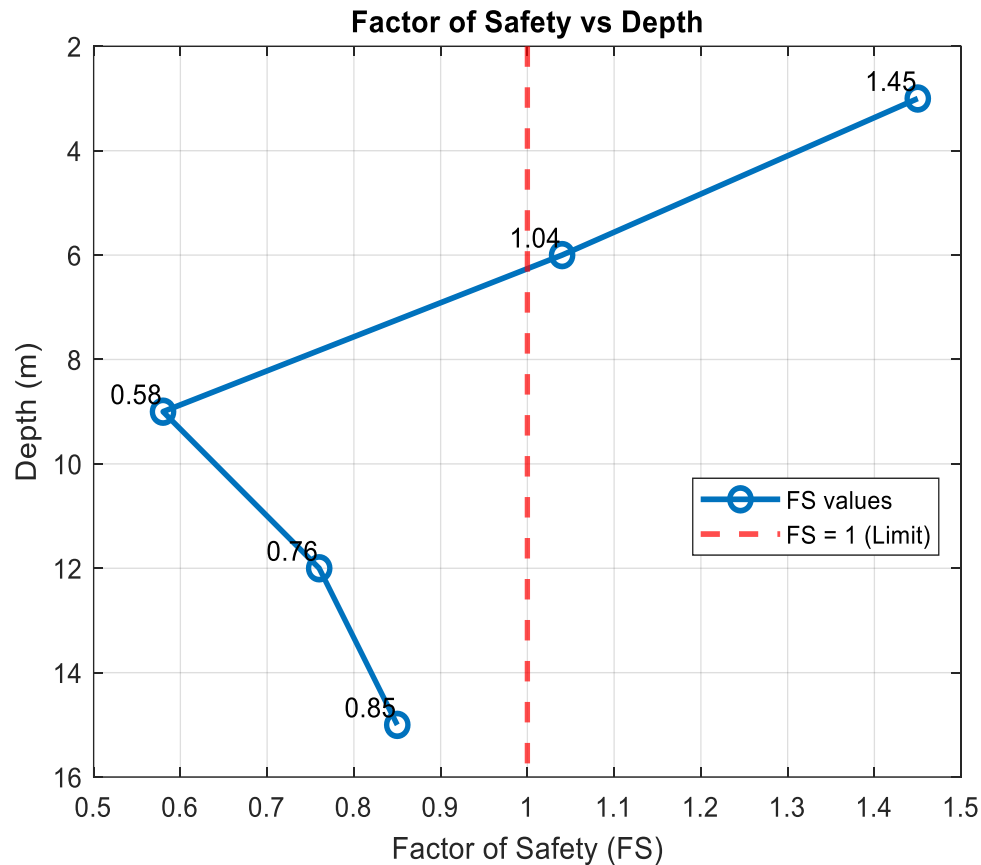


Figure 2. Depth-FS graph obtained from manual calculations

3.2. Investigation of Liquefaction Potential Using an Algorithm Developed for Software-Based Liquefaction Analysis

Based on the selected soil profile, a computational method operating on an algorithmic basis was developed. By incorporating the fundamental parameters of the soil profile into the code, the liquefaction potential was evaluated along soil layers with varying thicknesses.

The steps of the developed computational algorithm can be summarized as follows:

Step 1: Acquisition of the soil profile from the user,

Step 2: Calculation of effective stress values and corrected SPT-N values for soil layers,

Step 3: Determination of CSR values,

Step 4: Application of MSF,

Step 5: Calculation of the factor of safety (FS) and evaluation as follows: Liquefaction does not occur if $FS > 1$, and liquefaction occurs if $FS < 1$,

Step 6: Repetition of the analyses throughout the entire soil profile,

Step 7: Systematic reporting of the results,

Step 8: Completion of the analysis and graphical representation of the results.

- The code of the computational algorithm defined by the above steps can be presented as follows (Figure 3, 4 and 5):

```
%% SPT-Based Liquefaction Analysis - Real Soil Profile (Clean for Publication)

% Input Data
depth = [3 6 9 12 15];
N60 = [19.62 16.46 9.87 13.70 14.80];
N1_60 = [12.2 9.6 7.1 7.3 8.2];
gamma = 18.4;
water_table = 20;
amax = 0.4;

% Effective Stress Calculation
dz = [depth(1), diff(depth)];
sigma_v = cumsum(dz .* gamma);
u = zeros(size(depth));
u(depth > water_table) = (depth(depth > water_table) - water_table) * 9.81;
sigma_v_eff = sigma_v - u;

% Cyclic Stress Ratio (CSR)
rd = 1 - 0.015*depth;
CSR = 0.65 * amax .* (sigma_v ./ sigma_v_eff) .* rd;

% SPT-Based Cyclic Resistance Ratio (CRR)
CRR = (N60 ./ 15) * 0.2;

% Factor of Safety Against Liquefaction
FS = CRR ./ CSR;
```

Figure 3. Selection 1 of the algorithmic liquefaction calculation code

```
% Visualization
figure;

% FS Profile with FS<1 highlighted
subplot(1,2,1);
hold on;
plot(FS(FS>=1), depth(FS>=1), '-o', 'LineWidth', 2, 'Color', 'b'); % FS>=1
plot(FS(FS<1), depth(FS<1), 'ro', 'MarkerFaceColor', 'r', 'MarkerSize', 8); % FS<1
set(gca, 'YDir', 'reverse');
xlabel('Factor of Safety FS');
ylabel('Depth (m)');
title('Liquefaction Factor of Safety Profile');
xlim([0, max(FS)*1.1]);
grid on;
legend('FS ≥ 1', 'FS < 1', 'Location', 'best');

% N1,60 Profile
subplot(1,2,2);
plot(N1_60, depth, '-s', 'LineWidth', 2, 'Color', 'm');
set(gca, 'YDir', 'reverse');
xlabel('N1,60 (Corrected SPT)');
```

Figure 4. Section 2 of the algorithm-based liquefaction computation code

```

ylabel('Depth (m)');
title('SPT N1,60 Profile');
grid on;
% Table of Layers with FS < 1
FS_below_1_indices = find(FS < 1);
if ~isempty(FS_below_1_indices)
    disp('-----');
    disp('Layers with FS < 1 (Liquefiable Zones):');
    disp('-----');
    fprintf('Layer\tDepth (m)\tFS\tN1,60\n');
    for i = 1:length(FS_below_1_indices)
        idx = FS_below_1_indices(i);
        fprintf('%d\t%.2f\t%.2f\t%.2f\n', idx, depth(idx), FS(idx), N1_60(idx));
    end
    disp('-----');
else
    disp('All layers have FS ≥ 1. No liquefiable zones detected.');
```

Figure 5. Section 3 of the algorithm-based liquefaction computation code

- If the soil profile data given in Table 1 are implemented in the code, the FS-depth- $N_{1,60}$ graph obtained from the analyses is presented in Figure 6.

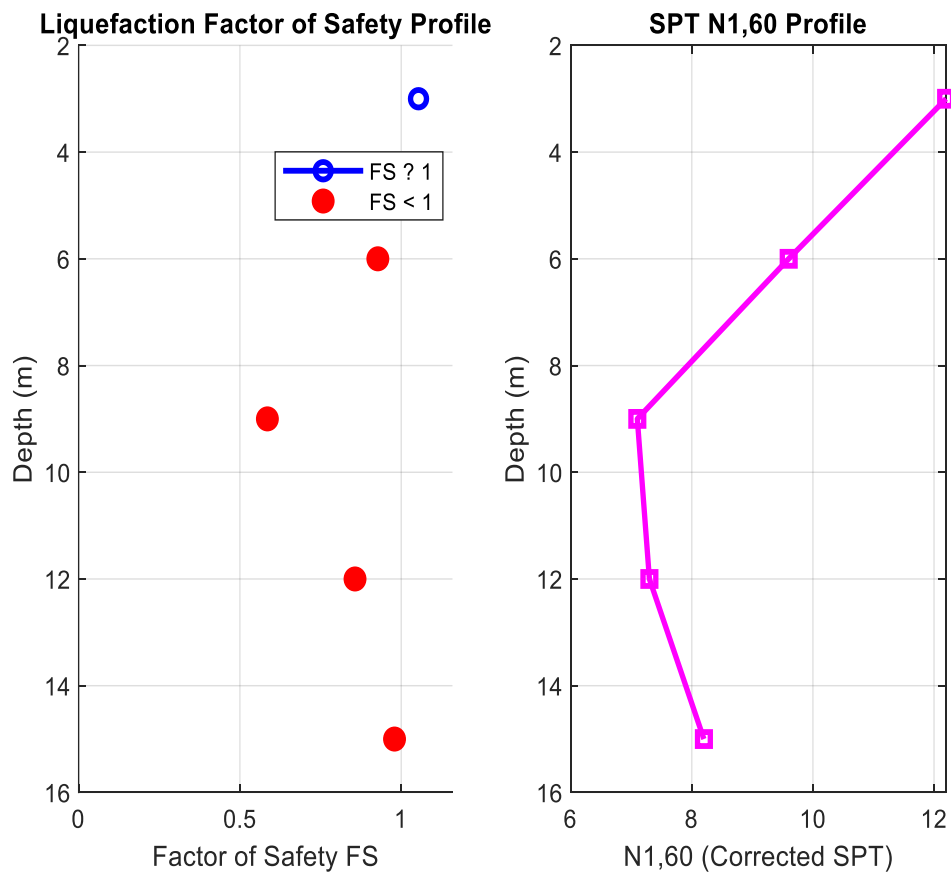


Figure 6. Safety factor-depth- $N_{1,60}$ relationship obtained from the analyses

To summarize the results obtained by considering the calculation algorithm:

- The analyses indicate that the factor of safety (FS) values vary significantly throughout the soil layers.
- FS values below 1 at depths of 4 m and 8 m indicate a high liquefaction risk in these soil layers.
- The data obtained from the analyses are consistent with field observations, algorithmic calculations, and soil conditions.
- One advantage of the algorithm is its ability to provide fast and practical solutions for multilayered soil profiles.
- Manual calculations performed using formulas are considerably slower than those carried out through algorithms. Moreover, coding based on algorithms helps minimize potential errors, suggesting that algorithmic calculations may be more reliable.
- Additionally, the visual evaluation of soil layers using algorithms enables the rapid identification of potentially hazardous layers from an engineering perspective. In this way, layers with a high liquefaction risk can be effectively visualized.
- However, computational codes developed using algorithms are based on empirical formulas. Considering the heterogeneity of soils, it is necessary to compare algorithmic results with field measurements for proper evaluation. Decisions made through such comparisons can be considered more reliable.
- In Figure 7, the data obtained from Table 1, Table 2, and the calculation algorithm are compared. It has been observed that the algorithmic calculation code produces results that are consistent with field data and are realistic.

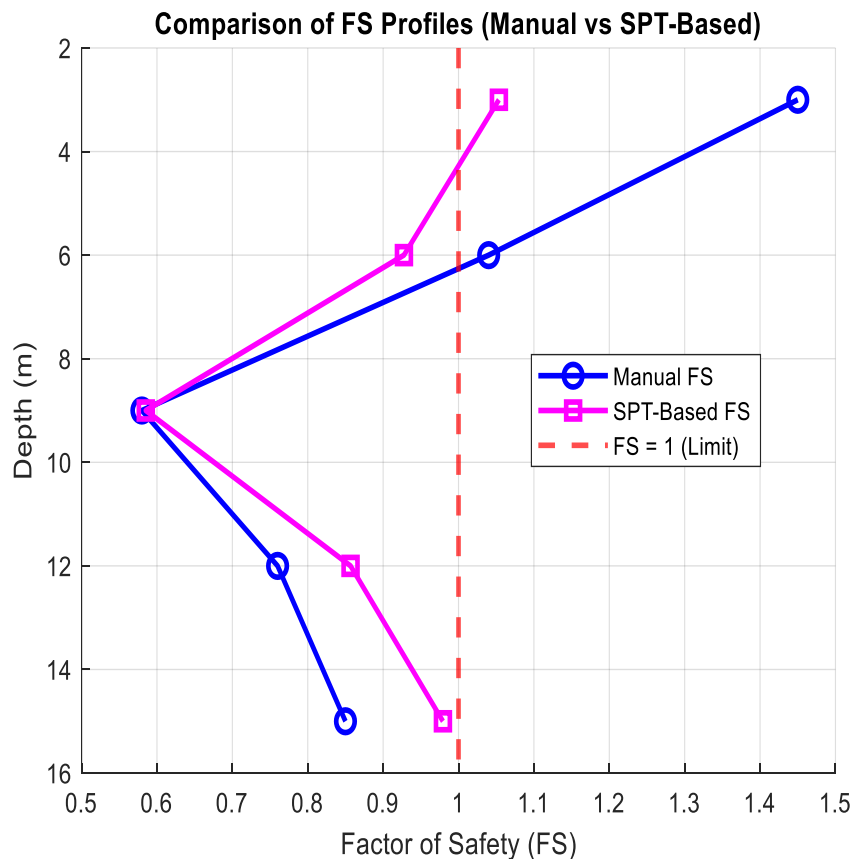


Figure 7. Safety factor, depth and $N_{1,60}$ graph obtained from the analyses

4.DISCUSSION AND CONCLUSIONS

In this study, five different borehole samples obtained from actual field investigations were used. The liquefaction potential was analyzed by considering the defined soil profile parameters and SPT values. The liquefaction behavior of soil layers at different depths was examined. Using the same soil parameters, manual calculations were first performed, and then the CSR, CRR, and FS (factor of safety) values obtained from the developed algorithmic calculation code were compared. The results can be summarized as follows:

- In the developed calculation algorithm, once the soil profile is defined, it was observed that CSR, CRR, and FS values are systematically calculated using corrected SPT parameters.
- The rapid results provided by the algorithmic approach accelerate the identification of critical (risky) zones within soil layers.
- Errors that may arise due to user inattention in manual calculations are more likely than those in the algorithmic calculation code.
- In addition, the incorporation of different earthquake scenarios into the code enhances its functionality, allowing analyses to be performed under varying soil conditions and seismic scenarios.

In conclusion, the calculation algorithm developed within the scope of this study, which is based on SPT data, is expected to provide significant contributions to geotechnical engineering in terms of producing faster and more reliable results. Furthermore, software-based calculation algorithms are considered important for minimizing errors and improving computational efficiency.

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INFLUENCE OF CORE THICKNESS AND TEMPERATURE ON THE MECHANICAL PROPERTIES OF NOMEX HONEYCOMB-CORE CARBON FIBER/EPOXY SANDWICH COMPOSITES

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ABSTRACT

Sandwich composite structures play an important role in many engineering applications due to their ability to provide high bending and shear strength despite their low weight. Owing to their high specific strength and stiffness characteristics, these materials are widely preferred in industries such as aerospace, aviation, marine, automotive, and construction. They offer significant advantages in applications where lightweight structures and high mechanical performance are required. In this study, carbon fiber reinforced polymer-based face sheets were used in the production of sandwich composite structures. The face sheets were manufactured using carbon fiber fabrics and epoxy resin through the hand lay-up method. Nomex honeycomb structures, which provide a high strength-to-weight ratio, were selected as the core material of the sandwich structures. In order to investigate the effect of core thickness on mechanical behavior, sandwich composite specimens were prepared with two different core thicknesses. In this context, specimens with core thicknesses of 5 mm and 20 mm were produced. Three-point bending tests were conducted to determine the mechanical performance of the produced sandwich composite specimens. The experiments were carried out under two different temperature conditions. First, the specimens were tested at room temperature (23 °C), and then the tests were repeated at -40 °C in a conditioning chamber to represent low-temperature conditions. In this way, the effects of both core thickness and ambient temperature on the bending strength of the sandwich composites were investigated. The mechanical properties obtained from the experimental studies were comparatively evaluated using graphs and tables. As a result of the analyses, the effects of different core thicknesses and temperature conditions on the bending behavior of sandwich composite structures were determined, and the role of these parameters on the mechanical performance was revealed.

Keywords: Sandwich composite, Carbon fiber, Nomex Honeycomb core, Flexural resistance, Subzero temperature.

NOMEX PETEK YAPILI KARBON FİBER/EPOKSİ SANDVIÇ KOMPOZİTLERİN MEKANİK ÖZELLİKLERİ ÜZERİNE ÇEKİRDEK KALINLIĞI VE SICAKLIĞIN ETKİSİ

ÖZET

Sandviç kompozit yapılar, düşük ağırlıklarına rağmen yüksek eğilme ve kayma dayanımı göstermeleri nedeniyle birçok mühendislik uygulamasında önemli bir yer tutmaktadır. Özellikle yüksek özgül dayanım ve rijitlik özellikleri sayesinde havacılık, uzay, denizcilik, otomotiv ve inşaat sektörlerinde yaygın olarak tercih edilmektedir. Hafiflik ve yüksek mekanik performans gerektiren uygulamalarda bu malzemeler önemli avantajlar sağlamaktadır. Bu çalışmada sandviç kompozit yapıların üretiminde karbon fiber takviyeli polimer esaslı yüzey tabakaları kullanılmıştır. Yüzey tabakaları, karbon fiber kumaş ve epoksi reçine kullanılarak elle yatırma yöntemi ile üretilmiştir. Sandviç yapıların çekirdek kısmında ise yüksek dayanım-ağırlık oranı sunan nomex bal peteği çekirdek malzemesi tercih edilmiştir. Çekirdek kalınlığının mekanik davranış üzerindeki etkisini incelemek amacıyla sandviç kompozit numuneler iki farklı çekirdek kalınlığına sahip olacak şekilde hazırlanmıştır. Bu kapsamda 5 mm ve 20 mm çekirdek kalınlıklarına sahip numuneler üretilmiştir. Üretilen

sandviç kompozit numunelerin mekanik performansını belirlemek amacıyla üç noktalı eğilme testleri gerçekleştirilmiştir. Deneyler iki farklı sıcaklık koşulunda uygulanmıştır. İlk olarak numuneler oda sıcaklığında (23 °C) test edilmiş, ardından düşük sıcaklık koşullarını temsil etmek amacıyla -40°C’de şartlandırma kabininde deneyler tekrarlanmıştır. Böylece hem çekirdek kalınlığının hem de ortam sıcaklığının sandviç kompozitlerin eğilme dayanımı üzerindeki etkileri incelenmiştir. Deneysel çalışmalar sonucunda elde edilen veriler grafik ve tablolar aracılığıyla karşılaştırmalı olarak değerlendirilmiştir. Yapılan analizler sonucunda, farklı çekirdek kalınlıklarının ve sıcaklık koşullarının sandviç kompozit yapıların eğilme davranışı üzerindeki etkileri belirlenmiş ve bu parametrelerin mekanik performans üzerindeki rolü ortaya konmuştur.

Anahtar Kelimeler: Sandviç kompozit, Karbon fiber, Nomex petek çekirdek, Eğilme dayanımı, Sıfır altı sıcaklık

GİRİŞ

Sandviç kompozit yapılar, modern mühendislik uygulamalarında, özellikle ağırlık tasarrufunun kritik olduğu sektörlerde önemli avantajlar sunmaktadır. Tipik bir sandviç yapı, iki adet ince, sert ve yüksek mukavemetli yüzey tabakasının düşük yoğunluklu ve daha kalın bir çekirdek malzemesine bağlanmasıyla oluşur [1,2]. Bu yapılar, toplam ağırlığı artırmadan kesit alanına ait atalet momentini yükselterek, sundukları yüksek özgül eğilme rijitliği ve mukavemeti sayesinde geleneksel malzemelere göre önemli üstünlükler sunmaktadır[3]. Bir sandviç yapıda, eğilme yükleri büyük oranda yüzey tabakaları tarafından çekme ve basma şeklinde taşınırken, çekirdek malzeme kayma yüklerini karşılar ve yüzeylerin burkulmasını önleyerek yapının bütünlüğünü korur [1,4,5]. Sandviç yapıların en büyük avantajı, toplam ağırlıkta kayda değer bir artışa neden olmadan eğilme rijitliği ve özgül mukavemetinin en yüksek seviyeye çıkabilmesidir [5-7].

Sandviç kompozitlerin sunduğu bu üstün mekanik özellikler, onları havacılık, uzay, denizcilik, otomotiv ve inşaat endüstrileri için birincil tercih haline getirmiştir [8],[9]. Özellikle havacılık sektöründe, uçakların yakıt tüketimini düşürmek ve taşıma kapasitesini artırmak amacıyla gövde parçaları, zemin panelleri ve iç mekân bileşenlerinde bu yapılar yaygın olarak kullanılmaktadır [10-13]. Otomotiv endüstrisinde ise, elektrikli araçların menzilin artırma ve emisyon değerlerini düşürme hedefleri doğrultusunda şasi ve gövde panellerinde geleneksel metalik yapılara alternatif olarak sandviç teknolojisi üzerine yoğun AR-GE çalışmaları yürütülmektedir [13-16].

Bir sandviç yapının performansı, seçilen bileşenlerin özelliklerine ve bunların ara yüzey bağ kalitesine doğrudan bağlıdır [8,9,17]. Yüzey tabakalarında genellikle yüksek çekme ve basma mukavemeti ile düşük yoğunluk sunan karbon fiber takviyeli polimerler veya cam fiber takviyeli polimerler tercih edilir [9,12,15,17-19]. Çekirdek malzemesi olarak ise köpükler, balsa ağacı veya bal peteği yapılar kullanılmaktadır [4,5,8]. Bunlar arasında Nomex bal peteği, fenolik reçine emdirilmiş aramid elyaf kağıdından üretilen yapısıyla; düşük yoğunluk, yüksek korozyon direnci, mükemmel yangın dayanımı ve termal izolasyon özellikleri sayesinde öne çıkmaktadır [12,13,18,20,21]. Nomex yapılar, alüminyum çekirdeklere göre daha kararlı platform gerilmesi ve hafiflik avantajı sundukları için özellikle havacılık zırhı ve yüksek performanslı askeri uygulamalarda tercih edilmektedir[12,17,20].

Sandviç yapıların tasarımında çekirdek kalınlığı, mekanik performansı belirleyen en kritik geometrik parametrelerden biridir [8,9,14,22,23]. Literatürdeki çalışmalar, çekirdek kalınlığının artırılmasının panelin eğilme rijitliğini ve maksimum yük taşıma kapasitesini, ağırlıkta sadece küçük bir artışla (yüzeylere kıyasla) dramatik bir şekilde artırdığını göstermektedir [7-9,14,21,24]. Bununla birlikte, kalınlık artışı çekirdeğin maruz kaldığı kayma gerilmelerinin dağılımını ve yapının burkulma limitlerini de doğrudan etkilemektedir [8,23,24]. Kalın çekirdekli yapılar genellikle daha yüksek enerji emilim kapasitesi sergilerken, ince çekirdekli yapılar yerel ezilme ve yüzey hasarlarına karşı daha duyarlı olabilmektedir[9,21,23,25].

Mühendislik yapılarının operasyonel ömrü boyunca maruz kaldığı çevresel faktörler, özellikle aşırı düşük sıcaklıklar, malzemenin mekanik davranışını ve hasar mekanizmalarını önemli ölçüde değiştirebilir. Kuzey kutbu seyir rotaları, havacılıkta yüksek irtifa koşulları ve uzay keşif görevleri, malzemelerin -40°C ve altındaki sıcaklıklardaki davranışının anlaşılmasını zorunlu kılmıştır. Düşük sıcaklıklarda polimer matrisli kompozitler genellikle daha sert ancak daha kırılgan bir davranış sergilemektedir. Sıcaklık düştükçe matrisin tokluğu azalmakta, bu da matris çatlaması ve fiber-matris ayrılması gibi hasarların daha düşük enerji seviyelerinde tetiklenmesine neden olabilmektedir. Ayrıca, sıcaklık değişimleri bileşenler arasındaki termal genleşme katsayısı farkından dolayı iç streslerin oluşmasına ve ara yüzey bağ mukavemetinin zayıflamasına yol açabilir [26, 27].

Eğilme yükleri altında sandviç yapılarda karşılaşılan temel hasar modları; yüzey akması, çekirdek kayma hasarı, yüzey kırışması, hücre içi çukurlaşma ve yerel ezilme olarak sınıflandırılmaktadır [8,9,14,19-21,23,28,29]. Üç noktalı eğilme testleri, bu karmaşık hasar mekanizmalarını ve yapının rijitlik değerlerini belirlemek için literatürde en yaygın kullanılan yöntemdir [4,8,11,12,14,16,17,24,30,31]. Hasarın başlangıcı ve ilerlemesi, yüzey ve çekirdek kalınlıklarının oranı ile malzeme özelliklerinin sıcaklıkla değişimine son derece duyarlıdır [9,20,21,23,25].

Sandviç kompozitlerin oda sıcaklığındaki özellikleri geniş bir şekilde araştırılmış olsa da, farklı çekirdek kalınlıklarının aşırı düşük sıcaklık koşullarıyla (-40°C gibi) etkileşimini ve bu parametrelerin eğilme mukavemeti üzerindeki birleşik etkisini inceleyen çalışmalar hala sınırlıdır. Bu çalışmada, karbon fiber takviyeli polimer yüzeylere ve Nomex bal peteği çekirdeğe sahip sandviç kompozitlerin mekanik performansı deneysel olarak araştırılmıştır. Çalışmanın temel amacı, 5 mm ve 20 mm çekirdek kalınlıklarının yanı sıra 23°C (oda sıcaklığı) ve -40°C (düşük sıcaklık) ortam parametrelerinin yapının üç noktalı eğilme dayanımı ve hasar karakteristiği üzerindeki rollerini ortaya koymaktır. Elde edilen veriler, zorlu çevresel koşullarda çalışacak hava ve kara taşıtlarının yapısal tasarımı ve optimizasyonu için kritik bir referans sağlamayı hedeflemektedir.

YÖNTEM

Mevcut çalışmada 5mm ve 20mm kalınlıklardaki nomex çekirdek malzemelerle üretilen sandviç yapıların 23°C ve -40°C sıcaklıklardaki yarı statik üç nokta eğme testi sonrasında elde edilen mekanik özelliklerinin karşılaştırılması amaçlanmıştır.

Karbon elyaflar için üretim metodu elle yatırma yöntemidir.

Sandviç Yapı Üretimi

a. Yüzey Malzemeleri

Yüzey malzemesini hazırlamak için 220gr/m^2 özgül ağırlığında karbon fiber twill kumaş kullanılmıştır. 90 derecelik çapraz örgü yapısı ve her yüzeyde tercih edilen çift katmanlı tasarımı sayesinde ürün, fiber doğrultusundan etkilenmeksizin standart bir performans sunacak şekilde üretilmiştir. Tablo 1.' çalışmada kullanılan karbon fiber kumaşın özellikleri gösterilmektedir.

Tablo 1. Karbon fiber kumaşın özellikleri

Kumaş Kodu	Kumaş	Genişlik (mm)	Ağırlık (g/m^2)	Dokuma
CCT-220	3K-3K Carbon Fabric	1000	220	2x2 Twill

Yüzey plaka üretimi için MGS H160 Sertleştirici ve MGS L160 Reçine 1/4 oranında karıştırılarak karbon kumaşlara fırça yardımıyla uygulanmıştır. Epoksi sürülen karbon fiber kumaşlar basınç altında ve oda sıcaklığında 24 saat kurlenme işlemine bırakılmıştır.

Hazırlanan karbon kumaşlar üç nokta eğilme testi ASTM C393 (2006) standardına göre 30×130 mm boyutlarında sac kesme makinesinde kesilmiştir.

b. Çekirdek Malzemeleri

Çalışmada kullanılan nomex bal peteği çekirdek 5mm ve 20mm kalınlıklarında olmak üzere iki farklı kalınlıklara sahiptir. Bu çekirdeklerde ASTM C393 (2006) üç nokta eğilme test standartlarındaki boyutlara uygun olarak $30 \times 130\text{mm}$ boyutlarında kesilmişlerdir. Nomex çekirdeklerin özellikleri Tablo 2.'de verilmiştir.

Tablo 2. Nomex bal peteği çekirdek özellikleri

Hücre Çapı	Yoğunluk	Basma mukavemeti	Kayma Mukavemeti	
9,6 mm	48kg/m^3	1,8 MPa	Uzunluk yönü	Genişlik yönü

			1,15 MPa	0,66 MPa

c. Sandviç Kompozitlerin Birleştirilme İşlemi

Sandviç yapı üretimi için yüzey ve çekirdekler yapıştırıcı olarak ARALDITE AW 106 TU ve HV 953 U sertleştirici katalog bilgisine göre yapıştırıcı ağırlığının %80'i kadar sertleştirici kullanacak şekilde karışım elde edilmiştir. Bu karışım karbon fiber kumaş ve uzunluk yönü doğrultusundaki nomex peteklere sürülerek elle birleştirme işlemi uygulanmıştır. Birleştirme sonucu elde edilen sandviç kompozit kurlenmek üzere basınç altında 24 saat oda sıcaklığında bırakılmıştır.

Üç Nokta Eğilme Deneyleri

Sandviç kompozitlere uygulanan üç nokta eğme testleri ile malzemenin yük altındaki davranışı hakkında önemli bilgiler elde edilir. Malzemenin hem yüzey hem de çekirdek yapısının mekanik dayanımını ölçmek için kullanılan testlerden biridir.

Bu test ile malzemenin eğilme dayanımı, eğilme modülü, çekirdek kayma mukavemeti, sandviç eğilme rijitliği ve malzemenin hasar modları belirlenerek dayanımının ne şekilde bittiği ölçülmüş olur.

5mm ve 20mm olmak üzere iki farklı nomex çekirdek kalınlığına sahip sandviç kompozitler oda sıcaklığı (23°C) ve -40°C olmak üzere iki farklı sıcaklık altında eğilme esnasında gösterdikleri dayanımın ölçülebilmesi için 3 nokta eğilme testlerine tabi tutulmuşlardır.

ASTM C393 standardına göre Zwick/Roel test cihazında gerçekleştirilen deneyler; numunelerin kırılma anına veya 30 mm çökme sınırına ulaşana dek sürdürülmüştür. Sandviç numunelerinin boyutları 5x30x130 mm ve 20x30x130 mm olarak belirlenmiştir. Testler, oda sıcaklığı ve sıvı nitrojen -40 °C olarak ayarlanabilen bir test odasında yapılmıştır. Deney düzeneği Şekil 1.'de gösterilmektedir.

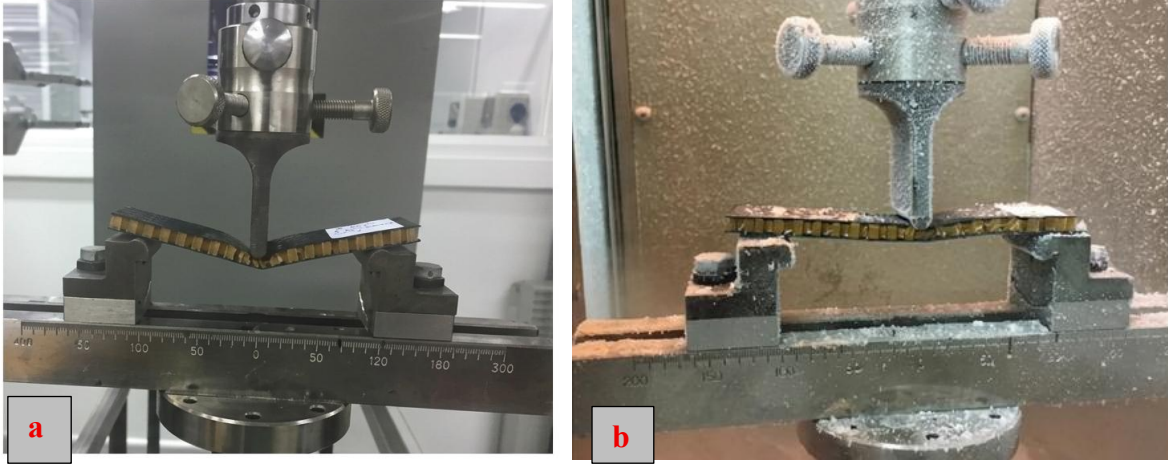


Şekil 1. Sıfır altı sıcaklıklarda 3 nokta eğme testi için kullanılan termal şartlandırma odası ve test düzeneği

Numuneler, aralarında 100 mm mesafe bulunan desteklerin üzerine yerleştirilerek deneye hazır hale getirilmiştir. Yükleme işlemi, 5 mm kafa yarıçaplı kol vasıtasıyla tam orta noktadan uygulanacak şekilde ayarlanmıştır. Test 2N ön yükleme ve 2mm/dk test hızı ile gerçekleştirilmiştir. Deneyler, her parametre için 4'er numune kullanılarak yarı-statik 3 nokta eğilme yöntemiyle yapılmıştır. Elde edilen kuvvet-sehim eğrileri arasından, grubun genel karakteristiğini yansıtan temsilci eğriler seçilerek karşılaştırmalı grafikler hazırlanmıştır.

Çekirdek kayma gerilmesi, yüzey eğilme direnci ve eğilme modülü gibi parametreler, ASTM C393 test grafiklerinden alınan verilerin standart formüllerde yerine konulmasıyla elde edilmiştir.

Nomex çekirdekli sandviçlere yapılan oda sıcaklığındaki eğilme dayanımı test görüntüsü Şekil 2a'da verilmiştir. Şekil 2b'de sandviç yapılar şartlandırma kabini içerisinde sıvı nitrojen altında -40°C 'de yapılan üç nokta eğme test görüntüleri verilmiştir.



Şekil 2. 5 mm kalınlığındaki Nomex petek çekirdekli sandviç yapıların a) oda sıcaklığında b) -40°C 'deki üç nokta eğme test görüntüleri.

Deneyler sonucunda her parametre için birden fazla kuvvet-sehim grafiği elde edilmiştir. Sonuçları ortalama değerlere en yakın şekilde temsil eden karakteristik eğriler ayıklanmış ve nihai karşılaştırmalı grafiklerde bu eğriler kullanılmıştır."

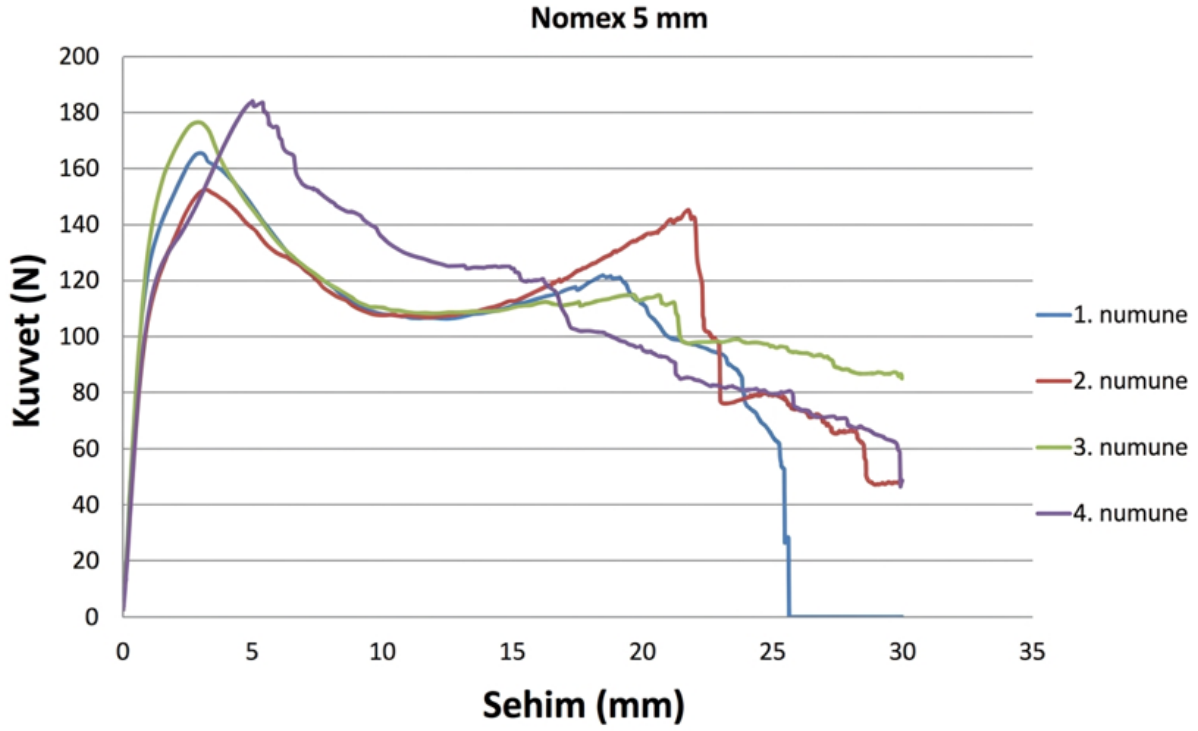
BULGULAR

Farklı kalınlıklardaki nomex çekirdeklerden üretilen sandviç kompozitlere oda sıcaklığı (23°C) ve -40°C 'de üç nokta eğme testleri uygulanmıştır. Test sırasında kuvvet-sehim miktarları anlık olarak ölçülmüş ve grafik haline getirilmiştir. Ayrıca testler sonrası malzemelerin deformasyon bölgeleri de incelenmiştir.

Oda Sıcaklığında Yapılan Deney Sonuçları

5mm kalınlıklı nomex çekirdekli sandviç yapılar oda sıcaklığında (23°C) uygulanan üç nokta eğme testine ait sonuçların grafiği aşağıdaki Şekil 3.'te verilmiştir.

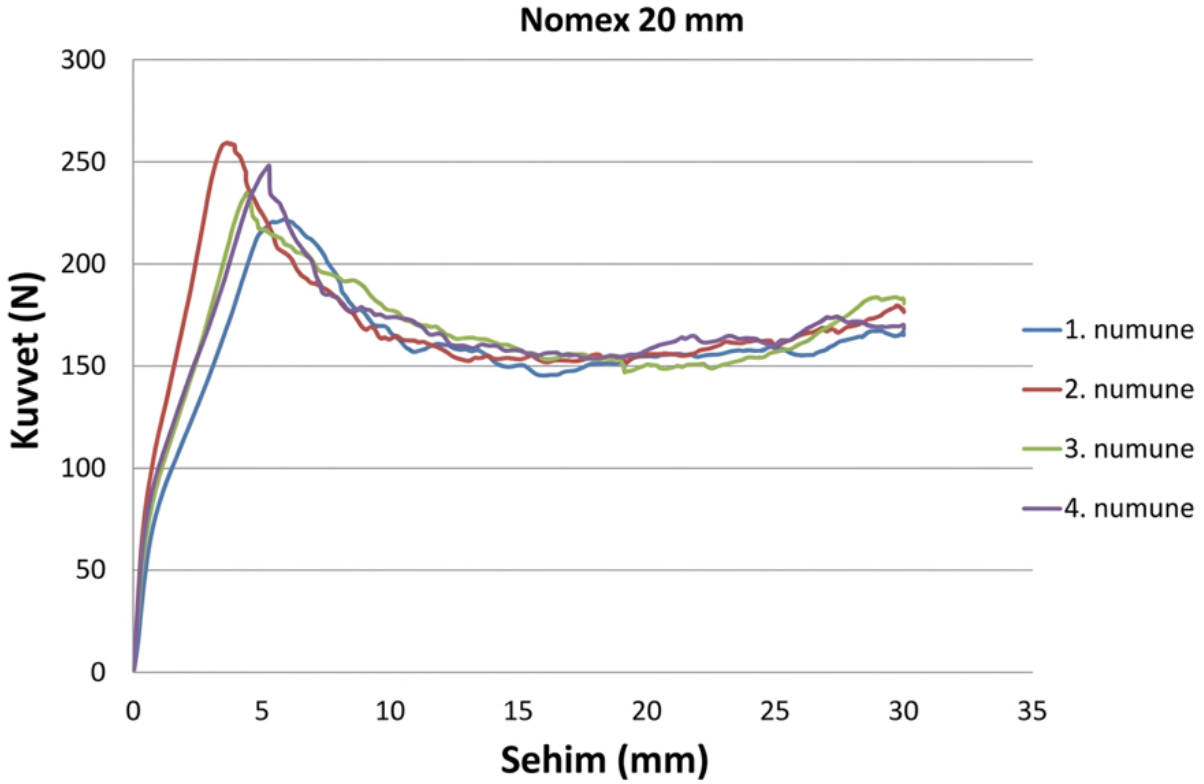
İncelenen dört numunenin elastik bölge sonuçları birbirine oldukça yakındır (Şekil 3). 25 mm sehimden sonra tamamen kırılan 1 numaralı numune dışında tüm örnekler süreklilik göstermiştir. Çalışmanın genel sonuçlarını temsil etmesi için, ortalama değerleri en iyi karakterize eden 3 numaralı numunenin verileri baz alınmıştır.



Şekil 3. Nomex çekirdekli 5 mm kalınlığındaki sandviç kompozitlerin, oda sıcaklığında gerçekleştirilen üç nokta eğilme testi sonucu ortaya çıkan kuvvet-sehim grafiği.

Şekil 3.'te gösterilen grafiğe göre 0-3mm arasında kuvvet hızla artıyor. Bu malzemenin ilk direnç gösterdiği kısımdır. Numunelerin taşıyabileceği maksimum yük 150N ile 185N arasında değişiyor. Maksimum değerden sonra kuvvet bir miktar düşüyor ve 100-120N bandında dalgalanarak devam ediyor. Bu malzemenin hücre duvarlarının katlanarak enerjiyi emdiği kısımdır.

20mm kalınlıklı nomex çekirdekli sandviç yapılara oda sıcaklığında uygulanan üç nokta eğme testine ait sonuçların grafiği aşağıdaki Şekil 4.' verilmiştir.



Şekil 4. Nomex çekirdekli 20 mm kalınlığındaki sandviç kompozitlerin, oda sıcaklığında gerçekleştirilen üç nokta eğilme testi sonucu ortaya çıkan kuvvet-sehim grafiği.

Şekil 4'te sunulan 20 mm Nomex çekirdekli numunelere ait deney verileri incelendiğinde, test edilen dört örneğin de birbiriyle tutarlı ve benzer karakteristikler sergilediği görülmektedir.

Dört numunenin deformasyon davranışları beklenen sonuçlarla örtüşmektedir. Bu doğrultuda, ortalama sonuçları en iyi şekilde karakterize ettiği görülen 4 numaralı numunenin eğrisi, analizler için baz alınmıştır.

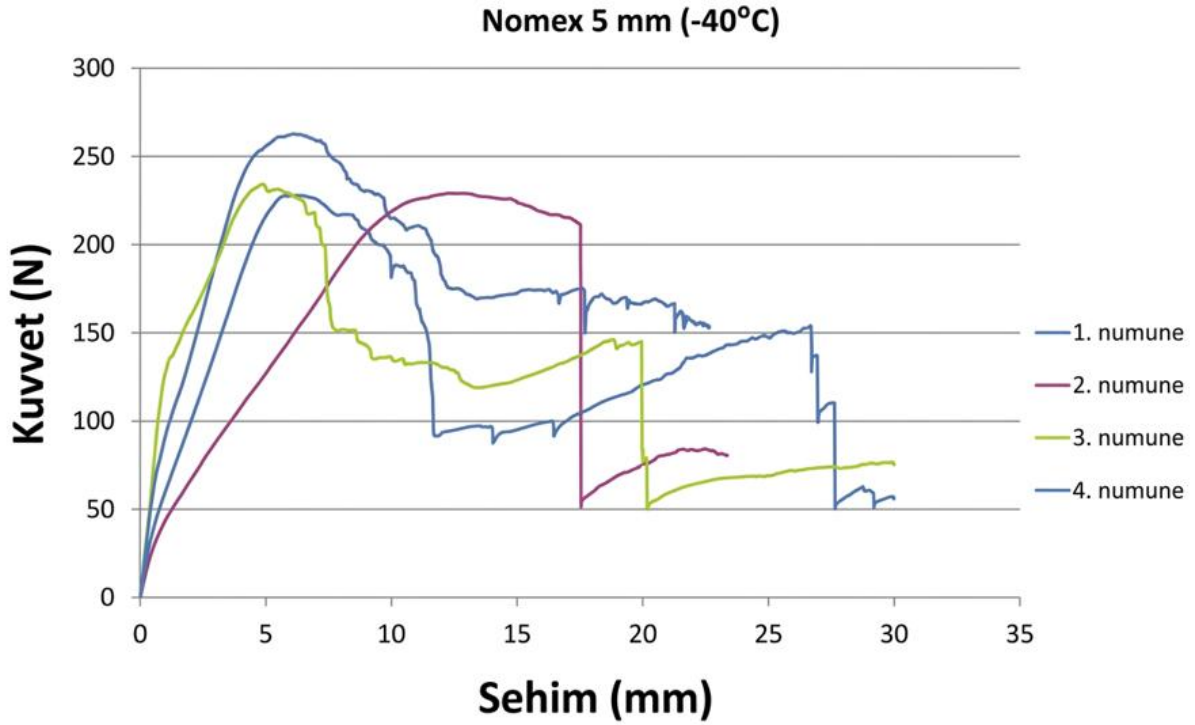
Numuneler, 220 N ile 260 N arasında değişen bir maksimum yük kapasitesine ulaşmıştır. 20 mm kalınlığındaki bu yapı, 5 mm'lik yapıya göre (maksimum ~180 N idi) belirgin şekilde daha fazla yük taşımaktadır. Grafiğin başlangıcındaki eğim (rijitlik), 5 mm'lik numunelere göre daha düşüktür. Bu, kalınlık arttığı için malzemenin ilk esneme aşamasında daha geniş bir sehim aralığında (yaklaşık 0-5 mm) enerji depoladığını gösterir. 10 mm sehinden sonra kuvvet 150 N-175 N bandında oldukça stabil bir seyir izlemektedir. Bu durum, kalın çekirdeğin ezilme sürecinin çok daha homojen ve uzun süreli olduğunu kanıtlar.

-40 °C'de Yapılan Deney Sonuçları

Farklı kalınlıklara sahip nomex çekirdekli sandviç yapılara 3 nokta eğme testleri daha sonra, sıvı nitrojen altında, şartlandırma odasında -40°C'de gerçekleştirilmiştir.

5mm kalınlıklı nomex çekirdekli sandviç yapılara -40°C sıcaklığında uygulanan üç nokta eğme testine ait sonuçların grafiği aşağıdaki Şekil 5.'te verilmiştir.

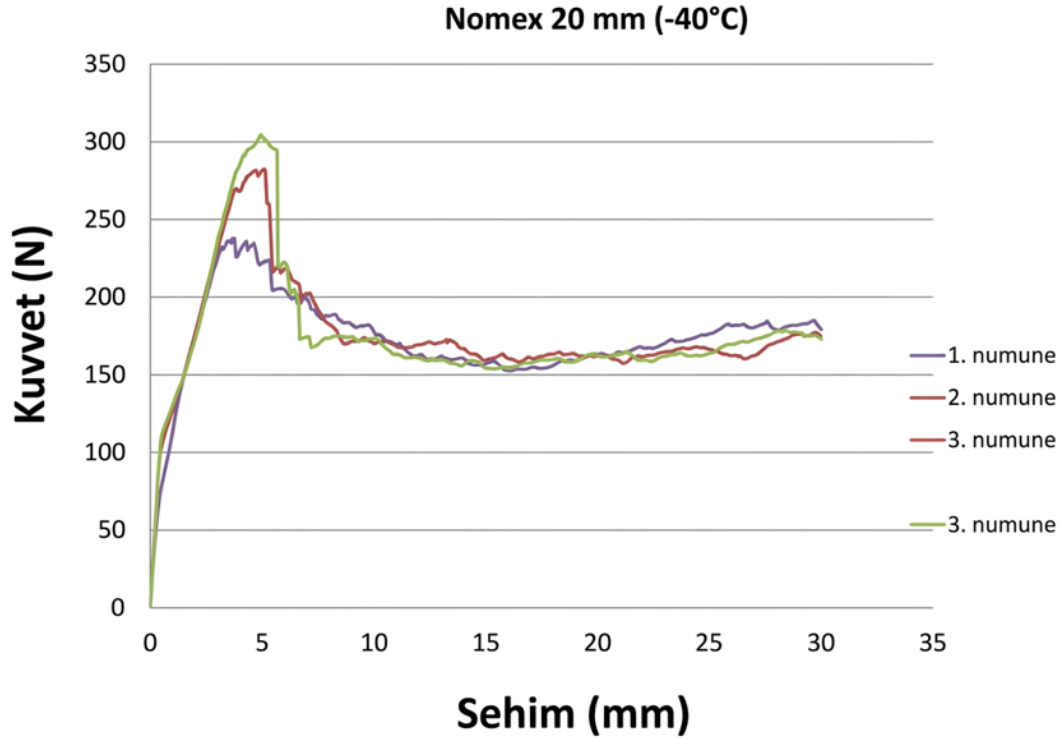
Numunelerin elastik bölgedeki davranışlarında belirli farklılıklar gözlemlense de, genel test karakteristiğini yansıtmak amacıyla 1 numaralı numuneye ait eğri temsili değer olarak belirlenmiştir.



Şekil 5. 5 mm kalınlığa sahip Nomex çekirdekli sandviç numunelerin, -40°C'deki üç nokta eğilme testi altındaki mekanik davranışını gösteren kuvvet-sehim grafiği.

Şekil 5.'te verilen grafiğe göre oda sıcaklığında 5 mm numuneler ~160-180 N bandındayken, -40°C'de numunelerin 230 N ile 260 N arasına çıktığını görüyoruz. Bunun nedeni düşük sıcaklıkta hem epoksi reçine hem de nomex lifleri daha rijit hale gelir. Bu durum malzemenin yük taşıma kapasitesini anlık olarak artırır. Grafiğin en dikkat çekici özelliği, stabil olması gereken bölgesinin oda sıcaklığına göre çok daha istikrarsız olmasıdır. Bunun nedeni ise soğuk etkisiyle malzeme esnekliğini kaybettiği için, bal peteği hücreleri kontrollü bir şekilde katlanmak yerine çatlayarak veya kırılarak yeniliyor. Düşük sıcaklık sandviç yapıyı daha güçlü ama daha dayanıksız hale getirmiş. Yani panel daha fazla yük kaldırabiliyor ancak limit değere ulaştığı an oda sıcaklığındaki gibi yavaşça ezilmiyor, aniden pes ediyor. Malzeme enerji sönümleme yeteneğinin bir kısmını soğuk nedeniyle kaybetmiştir.

20mm kalınlıklı nomex çekirdekli sandviç yapılara -40°C sıcaklığında uygulanan üç nokta eğme testine ait sonuçların grafiği aşağıdaki Şekil 6.'da verilmiştir.



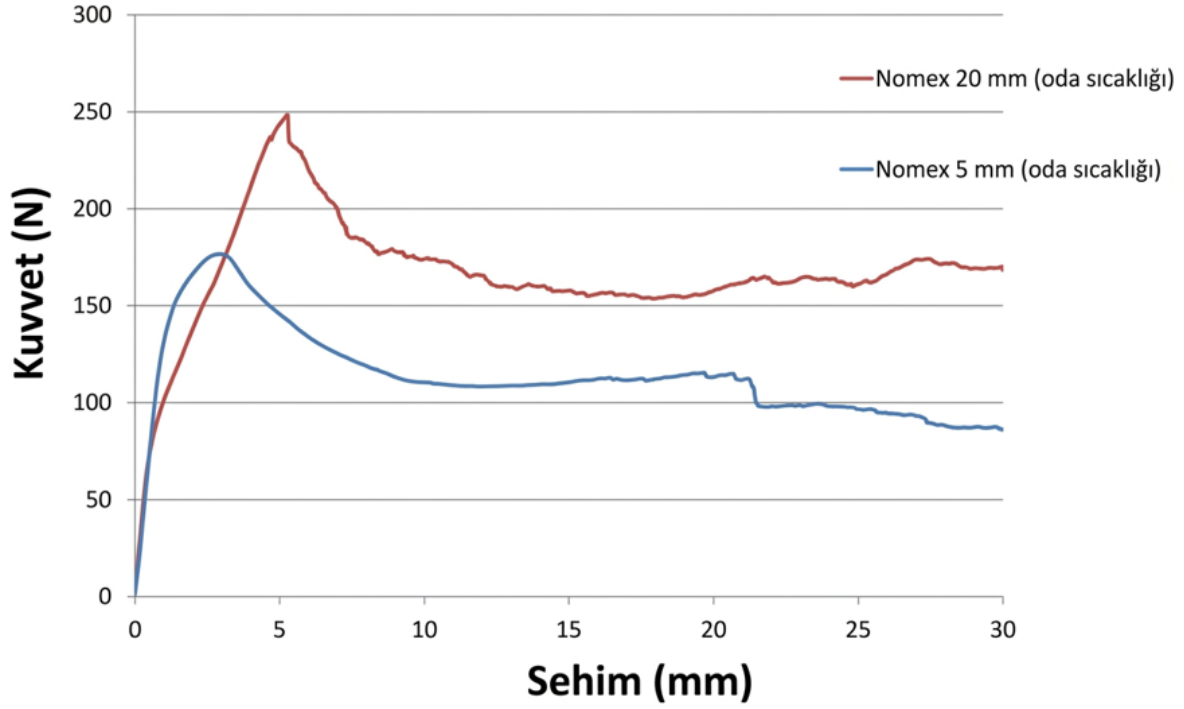
Şekil 6. 20 mm kalınlığa sahip Nomex çekirdekli sandviç numunelerin, -40°C'deki üç nokta eğilme testi altındaki mekanik davranışını gösteren kuvvet-sehim grafiği.

Bu deney veri seti, hem kalınlık artışının hem de soğuk etkisinin birleştiği oldukça kritik bir noktayı temsil ediyor. 1 numaralı numunenin düşük dayanım göstermesine rağmen, sonuçların genel bütünlüğü korunmaktadır. Çalışmanın devamında, tüm örnekleri temsilen 2 numaralı numuneye ait veriler baz alınmıştır.

Şekil 6.'daki grafiğe göre maksimum kuvvete yaklaşık 5 mm sehimde ulaşıyor. Bu, dondurucu soğukun malzemeyi çok daha gergin ve yük karşılamaya hazır rijit hale getirdiğini kanıtlar. Eğriler 150 N-175 N bandında stabilite ile devam ediyor. 20 mm çekirdek kalınlığı burada bir emniyet görevi görüyor. 5 mm'lik soğuk testindeki zikzaklı yapı gibi dağılmak yerine, kalın yapı sayesinde malzeme enerjiyi yutmaya devam ediyor. 20 mm'lik kalın nomex yapı, düşük sıcaklığın getirdiği gevreklik dezavantajını geometrisi sayesinde yenmiş görünüyor.

Deney Sonuçlarının Çekirdek Malzeme Kalınlığına Göre Karşılaştırılması

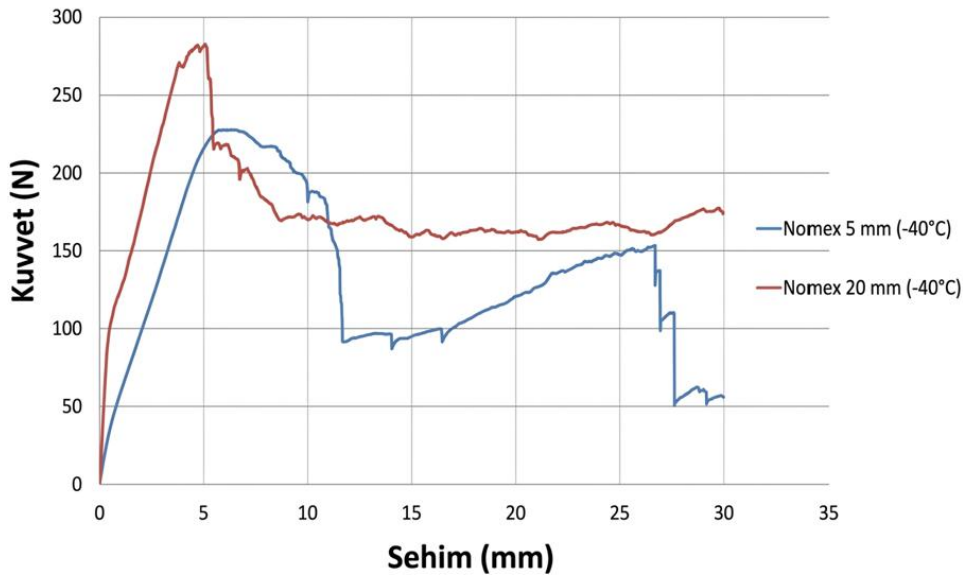
Farklı kalınlıklı nomex çekirdekli sandviç yapılara oda sıcaklığında yapılan üç nokta eğme test sonuçları karşılaştırması aşağıda Şekil 7.'de gösterilmektedir.



Şekil 7. Farklı çekirdek kalınlıklarının Nomex sandviç numuneler üzerindeki etkisini gösteren, oda sıcaklığında gerçekleştirilmiş üç nokta eğilme testi kuvvet-sehim grafiği.

Şekil 7.'deki grafiğe göre 20 mm nomex çekirdek kullanımı, yapıyı sadece daha güçlü yapmamış, aynı zamanda hasar toleransını önemli derecede artırmıştır. 5 mm'lik çekirdek düşük yüklerde pes ederken, 20 mm'lik çekirdek bal peteği hücrelerinin uzun boyu sayesinde yükü sönmölemek için çok daha fazla alana sahiptir.

Farklı kalınlıklı nomex çekirdekli sandviç yapılara -40°C sıcaklığında yapılan üç nokta eğme test sonuçları karşılaştırması aşağıda Şekil 8.'de gösterilmektedir.

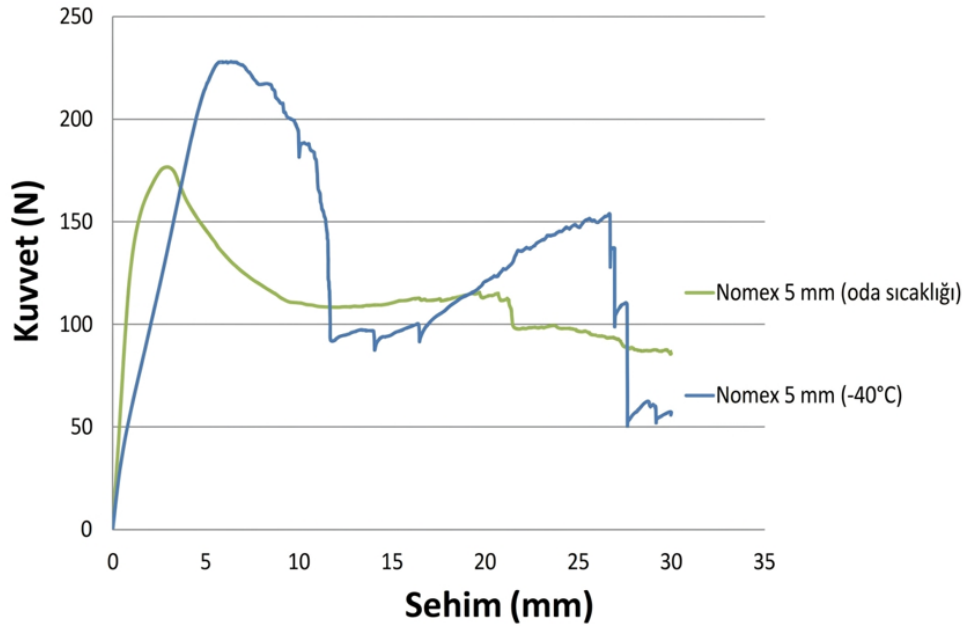


Şekil 8. Farklı çekirdek kalınlıklarının Nomex sandviç numuneler üzerindeki etkisini gösteren, -40°C'de gerçekleştirilmiş üç nokta eğilme testi kuvvet-sehim grafiği.

Şekil 8.'de grafiğe göre düşük sıcaklık testi, kalınlığın önemini iki katına çıkarmıştır. 5 mm'lik yapı soğukta kırılğan bir tepki verirken, 20 mm'lik yapı hem daha fazla yük taşımış hem de bu yükü uzun süre muhafaza etmiştir.

Deney Sonuçlarının Sıcaklık Farkına Göre Karşılaştırılması

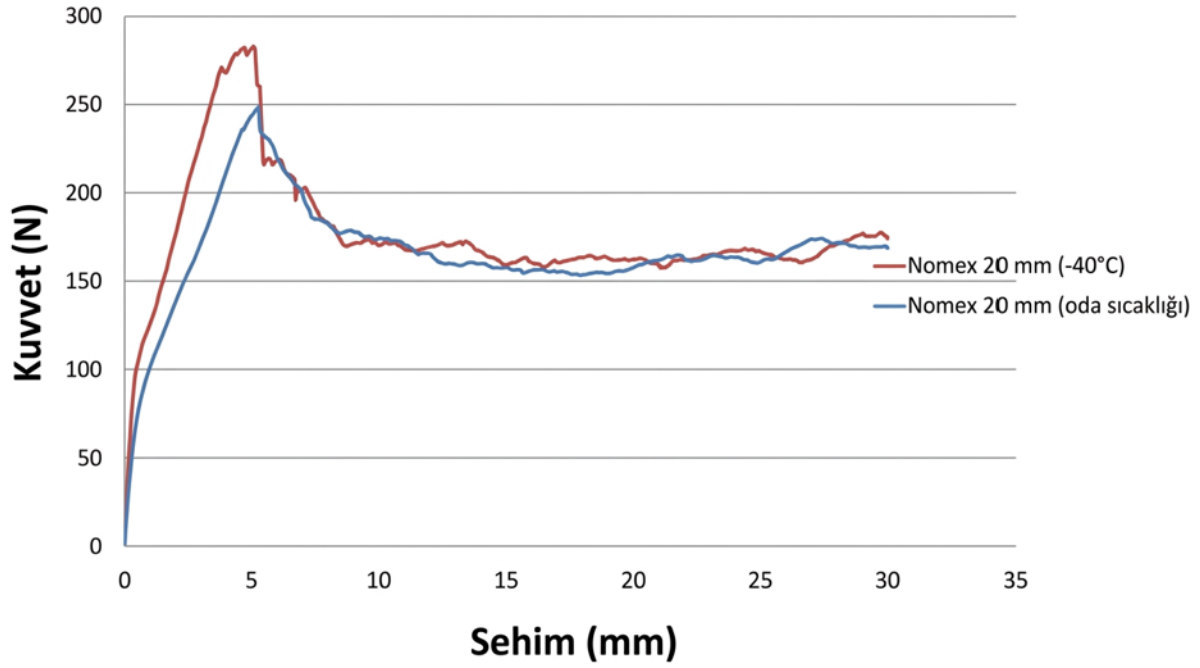
5mm kalınlığa sahip Nomex çekirdekli sandviç yapılara oda sıcaklığı ve -40°C sıcaklıkta yapılan üç nokta eğme testi deneysel sonuçlarının karşılaştırma grafiği aşağıda Şekil 9.'da gösterilmektedir.



Şekil 9. 5 mm kalınlığındaki Nomex çekirdekli sandviç yapıların, farklı sıcaklık koşulları altında gerçekleştirilen üç nokta eğilme deneylerinden elde edilen karşılaştırmalı kuvvet-sehim grafiği.

Şekil 9.'da verilen karşılaştırma grafiğine göre, sıcaklığın nomex 5 mm sandviç paneller üzerindeki etkisini çok net bir şekilde görülmüyor. Düşük sıcaklık, malzemeyi daha mukavemetli ama aynı zamanda daha gevrek bir yapıya dönüştürmüştür. Soğukta malzeme sünekliğini kaybetmiştir. Hücre duvarları katlanmak yerine kırılıyor. Her bir keskin düşüş, bir hücre duvarının gevrek bir şekilde kırıldığını temsil eder. -40°C'de malzeme daha yüksek yük taşısa da, hasar toleransı çok düşüktür. Ani kırılmalar yapısal güvenlik açısından risk teşkil eder.

20mm kalınlığa sahip Nomex çekirdekli sandviç yapılara oda sıcaklığı ve -40°C sıcaklıkta yapılan üç nokta eğme testi deneysel sonuçlarının karşılaştırma grafiği aşağıda Şekil 10.'da gösterilmektedir.

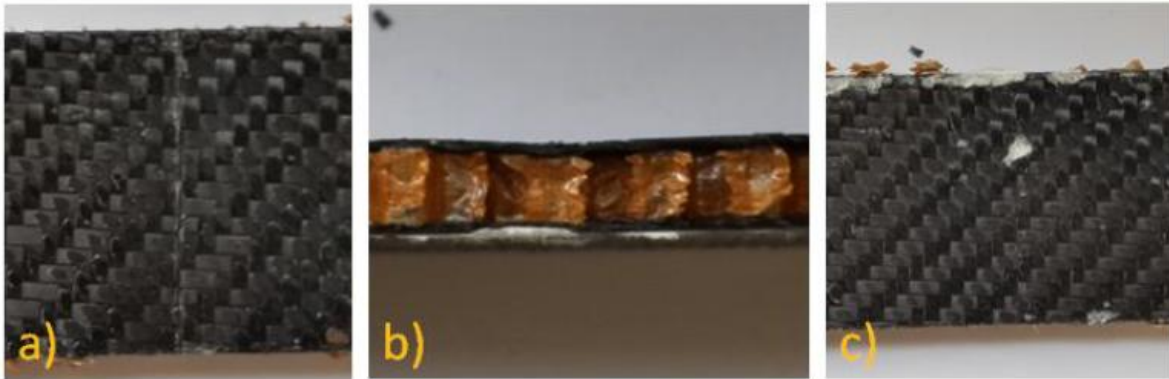


Şekil 10. 20 mm kalınlığındaki Nomex çekirdekli sandviç yapıların, farklı sıcaklık koşulları altında gerçekleştirilen üç nokta eğilme deneylerinden elde edilen karşılaştırmalı kuvvet-sehim grafiği.

Şekil 10.'da verilen grafiğe göre 20 mm çekirdek yüksekliği, hücrelerin soğuktan dolayı gevreyip aniden kırılmasını (5 mm'lik numunelerde gördüğümüz o ani düşüşleri) engellemiş. Çekirdek, her iki sıcaklıkta da enerjiyi emmek için başarıyla katlanmaya devam etmiş. -40°C sıcaklıktaki eğrinin başlangıç ivmesi oda sıcaklığındaki eğriye göre daha diktir. Bu da malzemenin soğukta daha az esnediğini ve daha yüksek bir eğilme modülüne sahip olduğunu gösterir. Bu grafik, 20 mm kalınlığın koruyucu etkisini kanıtlar niteliktedir. 5 mm'lik numunelerde sıcaklık düştüğünde yapı aniden düşerken (kuvvetin 50 N'a kadar düşmesi), 20 mm'lik yapıda sıcaklık farkı sadece maksimum yükü değiştirmiş, yapının enerji emme kapasitesini bozmamıştır.

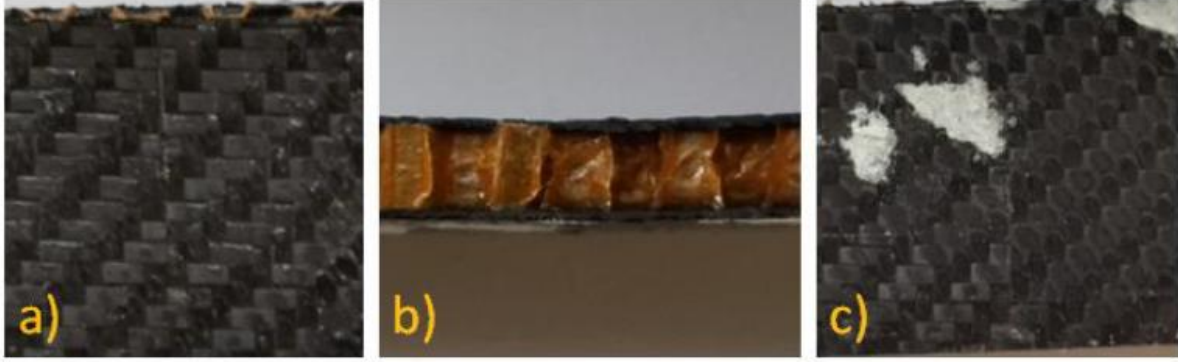
Testler Sonucunda Numunelerin Hasar Görüntüleri

Test sonrası numunelerde oluşan hasar karakteristikleri; basma, yan ve gerilme yüzeylerini kapsayacak şekilde hazırlanan görsellerle bu bölüm dahilinde analiz edilmektedir. Nomex çekirdekli numuneler ile yapılan testler sonrası numune görüntüleri Şekil 11., Şekil 12., Şekil13. ve Şekil 14.'te paylaşılmıştır.



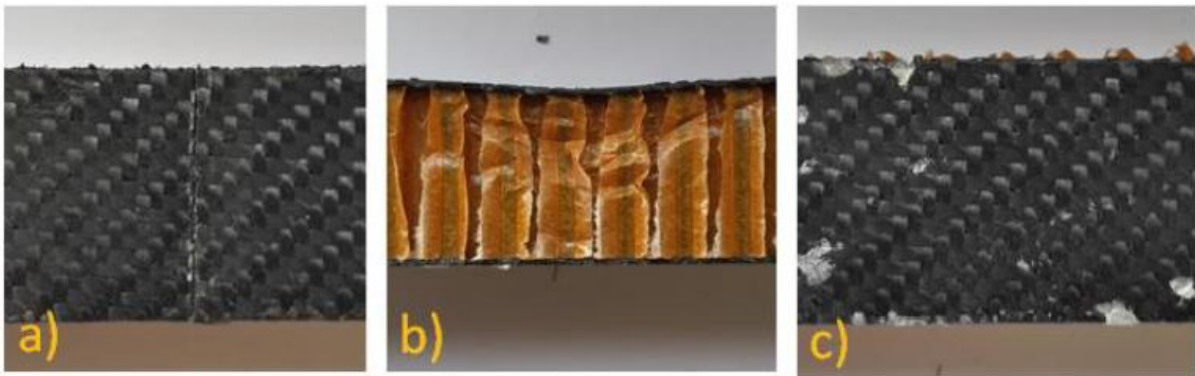
Şekil 11. Oda sıcaklığında 5 mm Nomex çekirdekli numunenin yükleme bölgesi yakın çekim görüntüleri; a) basma yüzeyi b) yan yüzey c) gerilim yüzeyi

Şekil 11.'de gösterilen numune 3'tür. Bu numunenin grafiğe de Şekil 3.'te gösterilmiştir. Üst yüzeyde karbon fiber dokusunda yer yer beyazlaşmalar stres izleri görülüyor. Görüntüde büyük bir yarıлма olmaması, yükün yüzeye başarılı bir şekilde yayıldığını ve basma kuvvetinin hücelere iletildiğini gösteriyor. Yan yüzey görüntüsünde ise nomex bal peteği hücrelerinde bariz bir katlanma (buckling) ve ezilme görülüyor. Hücrelerin bu düzenli ezilme biçimi, enerjinin ani bir kıvrılma yerine kontrollü bir şekilde yutulduğunu kanıtlıyor. Bal peteği yapısı tam olarak görevini yerine getirmiş.



Şekil 12. -40°C'de 5 mm Nomex çekirdekli numunenin yükleme bölgesi yakın çekim görüntüleri; a) basma yüzeyi b) yan yüzey c) gerilim yüzeyi

Şekil 12.'de gösterilen numune 1'dir. Bu numunenin grafiğinde Şekil 5.'te gösterilmiştir. Nomex çekirdeğin basma yüzeyindeki görüntüsünde karbon fiber doku üzerinde oda sıcaklığına göre çok daha keskin, dikey bir basma izi görülüyor. Epoksi matrisin beyazlaşması daha yerel ve yoğun. Grafikte numunenin yaklaşık 230 N değerine kadar hızla tırmanması bu yüzeyin sertleştiğini gösterir. Ancak bu sertlik, malzemenin darbeyi dağıtma yeteneğini azaltmış, yükü dar bir hatta hapsetmiş olduğunu açıklar. Yan yüzey görüntüsünde ise hücre duvarları oda sıcaklığındaki gibi akordeon şeklinde düzenli katlanmamış; bunun yerine gevrek kırılma emaresi olarak hücre duvarlarında dikey yarılmalar ve düzensiz ezilmeler görülüyor. Grafikteki ani düşüşlerin (örneğin 8 mm ve 12 mm sehimlerdeki keskin inişler) ana sebebi budur. Oda sıcaklığında hücre duvarları eğilerek yük taşımaya devam ederken, -40°C'de soğuktan dolayı gevreyen hücre duvarları yük altında aniden kırılıyor. Her kırılma anı, grafikte aşağı yönlü sert bir düşüş oluşturuyor.



Şekil 13. Oda sıcaklığında 20 mm Nomex çekirdekli numunenin yükleme bölgesi yakın çekim görüntüleri; a) basma yüzeyi b) yan yüzey c) gerilim yüzeyi

Şekil 13.'de gösterilen 3 nokta eğme testi sonrası seçilen 4 numaralı numunenin test sonrası görüntüsüdür. Bu numunenin grafiği Şekil 4.'te gösterilmiştir. Basma yüzeyinde karbon fiber yüzeyde yükün tam uygulandığı dikey hat boyunca belirgin bir iz ve matris çatlakları görülüyor. Liflerin dokusu hala bütünlüğünü koruyor ancak beyazlaşma dediğimiz stres bölgeleri yoğun. Grafikte eğrinin yaklaşık 250 N seviyesine kadar dik bir ivmeyle çıkması, bu üst yüzeyin yükü başlangıçta çok rijit bir şekilde karşıladığını gösterir. Yüzeydeki bu

izler, malzemenin elastik sınırdan çıkıp plastik deformasyona geçtiği maksimum yük anının fiziksel kanıtıdır. Yan yüzey görüntüsünde 5 mm'lik numuneye kıyasla burada çok daha fazla bir hücre duvarı burkulması görülüyor. Bal peteği hücreleri boylu boyunca katlanmış ve yer yer ezilme çizgileri (beyaz yatay hatlar) oluşmuş. Bu durum grafiğe göre, grafikteki 150 N-175 N arasındaki uzun ve stabil bölgenin nedenidir. 20 mm'lik derinlik, hücrelerin katlanmak için daha fazla mesafeye sahip olmasını sağlar. Eğrinin 10 mm'den 30 mm sehime kadar hiç kopmadan devam etmesi, çekirdeğin bu katlanma yoluyla enerjiyi sönümlediğini doğrular.



Şekil 14. -40°C’de 20 mm Nomex çekirdekli numunenin yükleme bölgesi yakın çekim görüntüleri; a) basma yüzeyi b) yan yüzey c) gerilim yüzeyi

Şekil 14.’te gösterilen 3 nokta eğme testi sonrası seçilen 2 numaralı numunenin test sonrası görüntüsüdür. Bu numunenin grafiği Şekil 6.’da gösterilmiştir. Şekil 14.’teki yan yüzey görüntüsüne göre 20 mm’lik derinlikte hücre duvarlarının sadece orta kısımlarda burkulduğunu, alt ve üst kısımların ise nispeten dik kaldığını görüyoruz. Ancak burkulmalar oda sıcaklığındaki gibi yumuşak değil; daha çok kırılma ve yarıлма şeklinde (beyazımsı, parlak çizgiler). Bu durum, grafikte maksimum noktadan sonra yaşanan sert düşüşü açıklar. Oda sıcaklığında hücreler yavaşça katlanırken, -40°C’de hücre duvarları gevredikleri için aniden kırılıyor. Ancak 20 mm kalınlık sayesinde bu hasar tüm gövdeye yayılmıyor, bu da grafiğin 10 mm’den sonra neden tekrar stabilize olup 150-175 N bandında kaldığını gösteriyor.

TARTIŞMA VE SONUÇ

Bu çalışma kapsamında, farklı kalınlıktaki (5 mm ve 20 mm) Nomex petek çekirdekli karbon fiber takviyeli sandviç kompozitlerin oda sıcaklığı ve -40°C düşük sıcaklık koşullarındaki eğilme davranışları incelenmiştir. Yapılan deneysel çalışmalar sonucunda elde edilen veriler ışığında aşağıdaki temel çıkarımlara varılmıştır:

- Nomex çekirdek kalınlığının 5 mm’den 20 mm’ye çıkarılması, yapıların taşıyabildiği maksimum kuvvet kapasitesini belirgin şekilde artırmıştır. Oda sıcaklığında 5 mm numuneler ortalama 175 N civarında maksimum değere ulaşırken, 20 mm numunelerde bu değer 250 N seviyelerine çıkmıştır.
- Düşük sıcaklık (-40°C) koşulları, malzemenin gevrek karakterini artırarak daha yüksek maksimum kuvvet değerlerine ulaşmasını sağlamıştır. Özellikle 20 mm kalınlığındaki numunelerde -40°C’deki maksimum kuvvet, oda sıcaklığına kıyasla yaklaşık %20 oranında bir artış göstererek 300 N seviyelerine yaklaşmıştır. Düşük sıcaklıkta numunelerin daha ani (gevrek) kırılmalar yaşadığı, ancak genel yük taşıma kapasitesinin arttığı tespit edilmiştir.
- Deney sonrası numuneler görsel olarak incelendiğinde, yapıların ana hasar mekanizmalarının çekirdek ezilmesi, yüzey tabakası ayrılması ve petek hücre duvarlarının burkulması olduğunu göstermektedir. 20 mm kalınlıktaki numunelerde, çekirdeğin daha geniş bir alanda enerji sönümleme kapasitesine sahip olduğu ve hasarın daha kademeli ilerlediği gözlemlenmiştir.

Sonuç olarak, Nomex sandviç yapılar hem düşük sıcaklık hem de artan kalınlık ile daha yüksek yük taşıma kapasitesi sergilemektedir. Bu durum, malzemenin havacılık ve savunma sanayii gibi değişken termal koşullara maruz kalan alanlarda kullanım potansiyelini doğrulamaktadır.

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**SURVEILLANCE PERFORMANCE ANALYSIS OF MINI UNMANNED AERIAL VEHICLES
USING THE ANALYTICAL HIERARCHY PROCESS**

Ünal YILMAZ

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ABSTRACT

In this study, the surveillance performance of unmanned aerial vehicles (UAVs) belonging to the Mini series was systematically analyzed using the Analytical Hierarchy Process (AHP), a multi-criteria decision-making method. The evaluation criteria were defined as weight, flight time, camera performance, range, obstacle detection, and return-to-home (RTH) capabilities. Qualitative data were quantified using appropriate scoring systems, and a decision matrix was created. Pairwise comparisons were made between the criteria to calculate weights, and the consistency ratio was verified to be within acceptable limits. During the analysis process, the criteria were normalized to obtain a weighted decision matrix, and the performance of four different UAV models (Mini 4K, Mini 2 SE, Mini 3, and Mini 4 Pro) was compared. The results showed that the Mini 4 Pro model achieved the highest overall performance score, surpassing other alternatives in range, obstacle detection, and camera performance criteria. The Mini 3 model ranked second, while the Mini 4K and Mini 2 SE models obtained lower scores due to their more limited technical specifications. The study's findings reveal that, particularly in the upper segment, technical specifications and criteria related to flight safety and autonomy are decisive in the multi-criteria decision-making process. This indicates that UAV selections are evaluated not only in terms of performance but also in terms of safety and operational continuity. Consequently, the AHP method offers an objective, repeatable, and practical evaluation approach to UAV selection, providing a guiding reference for both academic literature and practitioners.

Keywords: Multi-criteria decision making, Drone performance analysis, Surveillance performance, Unmanned aerial vehicle, Decision matrix

**ANALİTİK HİYERARŞİ SÜRECİ KULLANILARAK MİNİ İNSANSIZ HAVA ARAÇLARININ
GÖZETLEME PERFORMANS ANALİZİ**

ÖZET

Bu çalışmada, mini serisine ait insansız hava araçlarının (İHA) gözetleme performansları, çok kriterli karar verme yöntemlerinden Analitik Hiyerarşi Süreci (AHP) kullanılarak sistematik bir şekilde analiz edilmiştir. Değerlendirme kriterleri olarak ağırlık, uçuş süresi, kamera performansı, menzil, engel algılama ve eve dönüş (RTH) özellikleri belirlenmiştir. Nitel veriler uygun puanlama sistemleri ile sayısallaştırılmış ve karar matrisi oluşturulmuştur. Kriterler arasında ikili karşılaştırmalar yapılarak ağırlıklar hesaplanmış ve tutarlılık oranının kabul edilebilir sınırlar içerisinde olduğu doğrulanmıştır. Analiz sürecinde, kriterler normalize edilerek ağırlıklı karar matrisi elde edilmiş ve dört farklı İHA modeli (Mini 4K, Mini 2 SE, Mini 3 ve Mini 4 Pro) performansları açısından karşılaştırılmıştır. Elde edilen sonuçlar, Mini 4 Pro modelinin menzil, engel algılama ve kamera performansı kriterlerinde diğer alternatiflerin önüne geçerek en yüksek toplam performans skoruna ulaştığını göstermiştir. Mini 3 modeli ikinci sırada yer alırken, Mini 4K ve Mini 2 SE modelleri daha sınırlı teknik özellikler nedeniyle daha düşük skor elde etmiştir. Çalışmanın bulguları, özellikle üst segment teknik özelliklerin ve uçuş güvenliği ile otonomiye yönelik kriterlerin, çok kriterli karar sürecinde belirleyici olduğunu ortaya koymaktadır. Bu durum, İHA seçimlerinin yalnızca performans değil, aynı zamanda güvenlik ve operasyonel süreklilik açısından da değerlendirildiğini göstermektedir. Sonuç olarak, AHP yöntemi, İHA seçiminde nesnel, tekrarlanabilir ve uygulamaya dönük bir değerlendirme yaklaşımı sunmakta olup hem akademik literatüre hem de uygulayıcılara yol gösterici bir referans sağlamaktadır.

Anahtar Kelimeler: Çok kriterli karar verme, Drone performans analizi, Gözetleme performansı, İnsansız hava aracı, Karar matrisi

GİRİŞ

İHA'lar, teknolojik gelişmelerle birlikte son yıllarda önemli bir dönüşüm geçirerek askeri kullanım alanlarının ötesine taşınmış ve sivil, ticari ve endüstriyel uygulamalarda yaygın olarak kullanılmaya başlanmıştır [1-3]. Özellikle görüntüleme, haritalama, tarım, lojistik ve afet yönetimi gibi alanlarda sağladıkları esneklik, düşük maliyet ve erişilebilirlik avantajları, İHA'ların kullanım alanlarını giderek artırmaktadır [4-6]. Bu gelişmeler doğrultusunda, aynı amaçlı kullanım için farklı firmalar tarafından farklı teknik özelliklere sahip çok sayıda İHA modeli piyasaya sunulmuş ve kullanıcılar için en uygun alternatifin seçimi karmaşık bir karar problemi haline gelmiştir [7].

İHA larla ilgili özelliklerin değerlendirilmesi için literatürde birçok araştırma mevcuttur [8-10]. Bazıları aşağıda sunulmuştur.

Oliveira ve diğerleri, eriyik filament imalatı kullanılarak insansız hava araçlarının çerçeve yapılarında ABS üretimini araştırmışlar ve özellikleri analiz etmek için çeşitli geometriler tasarlamışlardır. Tasarımın taşıdığı gerilimleri, sonlu eleman analizi ANSYS ile hesaplamışlar ve kafes dolgu yapıların orijinal yapılardan daha iyi özellikler sağladığını rapor etmişlerdir [11]. Mohanavel ve diğerleri, eklemeli imalatın havacılık ve otomotiv endüstrisindeki rolünü açıklayarak bir CAD modelinin 3 boyutlu yazdırılmış bir ürüne dönüştürülmesi sürecini 3 boyutlu yazdırılmış organlar, mekanik aletler, prototipler, askeri bileşenler ve yedek parçaların yerinde özelleştirilmesi gibi uygulamalar da tartışmıştır. 3 boyutlu baskı, maliyet etkin, yerden tasarruf sağlayan ve atık azaltan bir yöntem olduğunu kanıtlayarak dezavantajlarını belirtmişlerdir [12]. Abdujabarov ve diğerleri, İHA'ların imalatında kullanılan mevcut ve gelecekteki teknolojileri ve malzemeleri tanımlamıştır. Transgenik biyopolimerler, karbon nanotüpler ve şekil değiştiren ve kendi kendini onaran malzemeler gibi modern malzemelerin İHA özelliklerini geliştirmeye etkilerini araştırmışlardır. Modern bilgisayar teknolojilerini, görüntü işleme teknolojilerini ve navigasyon sistemlerini geliştirerek İHA'ların kalitelerinin ne kadar artırabileceğini araştırmışlardır. Çalışmalarında ayrıca kompozit malzemelerin İHA yapılarının ağırlığını %30-40 oranında azaltabileceği de belirtmişlerdir [13]. Höche ve diğerleri, İHA yapımında magnezyum kullanımına ilişkin bir inceleme önermiştir ve insanlı ve insansız araçlar için farklı özelliklerle geliştirilmiş gelecekteki uygulamaları tanıtmıştır. Magnezyumun kullanılabileceği tartışılan bileşenler, hafifliği ve çarpışmalara dayanma yeteneği nedeniyle çalışmada ön plana çıkarılmıştır. Magnezyum, titanyum, alüminyum alaşımları ve kompozitler arasında ASHBY grafikleri kullanılarak bir karşılaştırma yapılmıştır. Son olarak, magnezyum bazlı bileşenlerin elektrolizle üretildiğinde alüminyumdan daha ekonomik, geri dönüştürülebilir ve daha iyi bir karbon ayak izine sahip olduğu belirtilmiştir [14]. Mitridiset, bir VTOL'ün dikeyden yatay uçuşa geçiş mekanizmasını araştırmıştır. Amaç, hem sabit kanatlı konfigürasyonun hem de çok rotorlu sistemin avantajlarını birleştiren küçük, taşınabilir bir insansız hava sistemi geliştirmektir. Kanatçığın son tasarımı için karbon fiber takviyeli plastik kullanılmıştır. Eğilme yükleri dikkate alındığında, İHA'nın dış yüzeyi olarak 6061-T6 alüminyum alaşımı kullanılmıştır. Ana yapısal elemanlar, kapağı yerinde tutmak için çelik çubuklar olarak seçilmiştir. Kanatçık mili yüksek gerilimli bir alan olduğundan ilgili kısımda alüminyum kullanarak özelliklerin geliştirilmesine etkisini araştırmıştır [15]. Xiang ve diğerleri, enerji cihazlarında kullanılan grafen bazlı nanokompozitlerin uygulamalarını araştırmıştır. Bunlar arasında yakıt hücreleri, lityum iyon piller, güneş pilleri ve termoelektrik dönüşüm uygulamaları yer almaktadır. Grafenin yüksek taşıyıcı hareketliliğine, yüksek güç yoğunluğuna, düşük direnç ve yüksek verimli termoelektrik enerji dönüşümüne sahip olduğu gösterilmiştir [16].

İHA seçim sürecinde belirlenen amaç doğrultusunda ağırlık, uçuş süresi, kamera kapasitesi, menzil ve otonom sistemler gibi birçok kriterin aynı anda değerlendirilmesi gerekmektedir [17]. Ancak bu kriterlerin farklı ölçü birimlerine sahip olması ve bazı parametrelerin nitel özellikler içermesi, karar verme sürecini zorlaştırmaktadır. Bu nedenle, çok kriterli karar verme (ÇKKV) yöntemleri, bu tür problemlerin çözümünde etkin bir araç olarak öne çıkmaktadır.

Bu çalışmada, yaygın olarak kullanılan ÇKKV yöntemlerinden biri olan Analitik Hiyerarşi Süreci (AHP) tercih edilmiştir. AHP yöntemi, karar problemini hiyerarşik bir yapıya dönüştürerek kriterler ve alternatifler arasında sistematik karşılaştırmalar yapılmasına olanak tanımaktadır. Ayrıca yöntemin tutarlılık kontrolü içermesi, elde edilen sonuçların güvenilirliğini artırmaktadır.

Çalışma kapsamında, Mini serisine ait dört farklı model (Mini 4K, Mini 2 SE, Mini 3 ve Mini 4 Pro) analiz edilmiştir. Bu modeller, taşınabilirlik, kullanım kolaylığı ve teknik yeterlilik açısından geniş bir kullanıcı kitlesine hitap etmekte ve farklı firma üretimi olmalarına karşın yakın teknik özellikler içermektedir. Analizde kullanılan kriterler literatür ve teknik özellikler dikkate alınarak belirlenmiş, nitel veriler uygun şekilde sayısallaştırılmış ve karar matrisi oluşturulmuştur. Daha sonra kriter ağırlıkları hesaplanmış, normalize edilmiş ve ağırlıklı karar matrisleri elde edilerek alternatiflerin performansları karşılaştırılmıştır.

Bu çalışmanın temel amacı, İHA seçim problemine sistematik, objektif ve tekrarlanabilir bir yaklaşım sunmaktır. Aynı zamanda çalışma, tüketici odaklı drone seçiminden mühendislik tabanlı performans analizine kadar geniş bir uygulama alanı için referans niteliği taşımaktadır. Elde edilen bulguların, hem akademik literatüre katkı sağlaması hem de uygulayıcılar için yol gösterici olması beklenmektedir.

Gözetleme Amaçlı İHA Alternatifleri

Bu çalışmada kullanılan farklı firmalara ait gözetleme amacı daha ön planda tutulan ve özellikleri birbirine yakın İHA modelleri, piyasada yaygın olarak bulunan ve amatör kullanıcılar tarafından tercih edilen insansız hava araçları arasından kataloğlardan seçilmiştir. Araştırılan mini serisi insansız hava araçları Analitik Hiyerarşi Süreci (AHP) yöntemi kullanılarak değerlendirilmiştir. Teknik özellikler sayısallaştırılarak karar matrisi oluşturulmuştur. Karar matrisi Tablo 1’de sunulmuştur. Nitel veriler (kamera kalitesi, engel algılama ve RTH özellikleri) uygun puanlama sistemi ile nicel hale getirilmiştir. Ağırlık kriteri maliyet yönlü değerlendirilirken, diğer kriterler fayda yönlü olarak ele alınmıştır. Bu yapı, alternatiflerin çok kriterli karar verme yaklaşımıyla karşılaştırılmasına olanak sağlamıştır.

Tablo 1. Karar Matrisi

Alternatif	Ağırlık (g)	Uçuş Süresi (dk)	Kamera Skoru	Menzil (km)	Engel Algılama Skoru	RTH Skoru
DJI Mini 4K	249	31	4	10	1	2
DJI Mini 2 SE	249	31	3	10	1	2
DJI Mini 3	249	45	5	10	1	2
DJI Mini 4 Pro	249	45	6	20	3	3

Çalışmada, uçuş süresi ve menzil, operasyonel performansı temsil ederken; kamera skoru veri kalitesini, engel algılama ve RTH özellikleri ise uçuş güvenliği ve otonomi düzeyini ifade etmektedir. Bu kriterler, İHA’ların hem gözetleme hem de çok boyutlu performans değerlendirmesini mümkün kılmaktadır.

Tablo 2. Çalışmada Kullanılan Değerlendirme Kriterleri ve Açıklamaları

Kriter	Amaç (Optimizasyon Yönü)	Açıklama
Ağırlık (g)	Minimize (Maliyet)	İHA’nın toplam kütlesini ifade eder. Daha düşük ağırlık, taşınabilirlik, enerji verimliliği ve yasal sınırlamalar açısından avantaj sağlar.
Uçuş Süresi (dk)	Maksimize (Fayda)	İHA’nın tek bir batarya ile havada kalabildiği süreyi gösterir. Daha uzun uçuş süresi, operasyonel verimliliği artırır.

Kamera Skoru	Maksimize (Fayda)	Kamera çözünürlüğü, görüntü kalitesi ve video performansını temsil eden sayısallaştırılmış kriterdir. Yüksek skor, daha kaliteli veri elde edilmesini sağlar.
Menzil (km)	Maksimize (Fayda)	İHA'nın kontrol cihazı ile maksimum iletişim mesafesini ifade eder. Daha yüksek menzil, geniş alanlarda kullanım avantajı sağlar.
Engel Algılama Skoru	Maksimize (Fayda)	İHA'nın çevresel engelleri algılama kapasitesini temsil eder. Gelişmiş algılama sistemleri uçuş güvenliğini artırır.
RTH Skoru	Maksimize (Fayda)	"Return to Home" (Eve Dönüş) özelliğinin gelişmişlik seviyesini ifade eder. Daha yüksek skor, otonom ve güvenli geri dönüş kabiliyeti sağlar.

Analitik Hiyerarşi Süreci

Bu çalışmada, insansız hava araçlarının performanslarının çok boyutlu bir çerçevede değerlendirilmesi amacıyla Analitik Hiyerarşi Süreci kullanılmıştır. AHP, karmaşık karar problemlerini hiyerarşik bir yapıya dönüştürerek, karar vericilere birden fazla kriteri sistematik ve tutarlı bir şekilde değerlendirme imkânı sunan güçlü bir çok kriterli karar verme yöntemidir. Yöntemin temelinde, karar probleminin amaç, kriterler ve alternatifler olmak üzere üç ana seviyede yapılandırılması yer almaktadır. Bu kapsamda öncelikle problem tanımlanmış, ardından literatür ve teknik özellikler doğrultusunda değerlendirme kriterleri belirlenmiştir. Çalışmada ele alınan kriterler; ağırlık, uçuş süresi, kamera performansı, menzil, engel algılama ve eve dönüş (RTH) yetenekleri olarak seçilmiş ve her bir kriterin karar sürecine olan katkısı dikkate alınmıştır. Nitel özellikler uygun puanlama yaklaşımları ile nicel verilere dönüştürülerek analiz edilebilir hale getirilmiştir.

Tablo 3. İkili Karşılaştırma Matrisi (Kriterler)

	K1	K2	K3	K4	K5	K6
K1 Ağırlık (Cost)	1	1/3	1/5	1/5	1/7	1/7
K2 Uçuş Süresi (Benefit)	3	1	1/3	1/3	1/5	1/5
K3 Kamera (Benefit)	5	3	1	1	1/3	1/3
K4 Menzil (Benefit)	5	3	1	1	1/3	1/3
K5 Engel Algılama (Benefit)	7	5	3	3	1	1
K6 RTH (Benefit)	7	5	3	3	1	1

AHP yönteminin uygulanmasında, kriterler arasında ikili karşılaştırmalar yapılmış ve bu karşılaştırmalar karar vericinin uzman görüşleri doğrultusunda Saaty'nin 1–9 ölçeği kullanılarak sayısallaştırılmıştır. Elde edilen karşılaştırma matrisi normalize edilerek kriter ağırlıkları hesaplanmış ve her bir kriterin göreceli önemi belirlenmiştir. Yöntemin güvenilirliğini sağlamak amacıyla tutarlılık analizi gerçekleştirilmiş ve tutarlılık oranının kabul edilebilir sınırlar içerisinde olduğu doğrulanmıştır. Daha sonra oluşturulan karar matrisi normalize edilmiş, kriter ağırlıkları ile çarpılarak ağırlıklı karar matrisi elde edilmiştir. Bu matris üzerinden alternatiflerin toplam performans skorları hesaplanmış ve sıralama yapılmıştır. Böylece, farklı teknik özelliklere sahip İHA modellerinin objektif, sistematik ve karşılaştırılabilir bir şekilde değerlendirilmesi sağlanmıştır.

Bu yaklaşım sayesinde, karar verme sürecinde öznel yargıların etkisi minimize edilerek daha rasyonel sonuçlara ulaşılmış ve elde edilen bulguların hem akademik hem de uygulamaya yönelik katkı sağlaması hedeflenmiştir. İkili karşılaştırma matrisi (Kriterler) ve kriter ağırlıkları sırasıyla Tablo 3 ve Tablo 4’de verilmiştir.

Tablo 4. Kriter Ağırlıkları

Kriter	Ağırlık
Ağırlık	0.05
Uçuş Süresi	0.10
Kamera	0.20
Menzil	0.20
Engel Algılama	0.225
RTH	0.225

Karar matrisi normalize edilerek kriterler arasında ölçek birliği sağlanmıştır. Ağırlık kriteri maliyet yönlü olduğu için ters normalizasyon uygulanırken, diğer kriterler fayda yönlü olarak değerlendirilmiştir. Bu işlem, farklı birimlere sahip kriterlerin karşılaştırılabilir hale getirilmesini sağlamıştır. Normalize edilmiş karar matrisi Tablo 5’de sunulmuştur.

Tablo 5. Normalize Edilmiş Karar Matrisi

Alternatif	Ağırlık	Uçuş Süresi	Kamera	Menzil	Engel Algılama	RTH
Mini 4K	0.25	0.20	0.22	0.20	0.17	0.22
Mini 2 SE	0.25	0.20	0.17	0.20	0.17	0.22
Mini 3	0.25	0.29	0.28	0.20	0.17	0.22
Mini 4 Pro	0.25	0.29	0.33	0.40	0.50	0.33

Normalize edilmiş karar matrisi, kriter ağırlıkları ile çarpılarak ağırlıklı normalize matris elde edilmiştir. Ağırlıklı normalize edilmiş karar matrisi Tablo 6’da verilmiştir. Bu matris üzerinden alternatiflerin toplam performans skorları hesaplanmıştır. Sonuçlara göre Mini 4 Pro modeli en yüksek skoru elde ederek en iyi alternatif olarak belirlenmiştir. Bu durum, modelin özellikle menzil, engel algılama ve kamera performansı açısından üstün olmasından kaynaklanmaktadır.

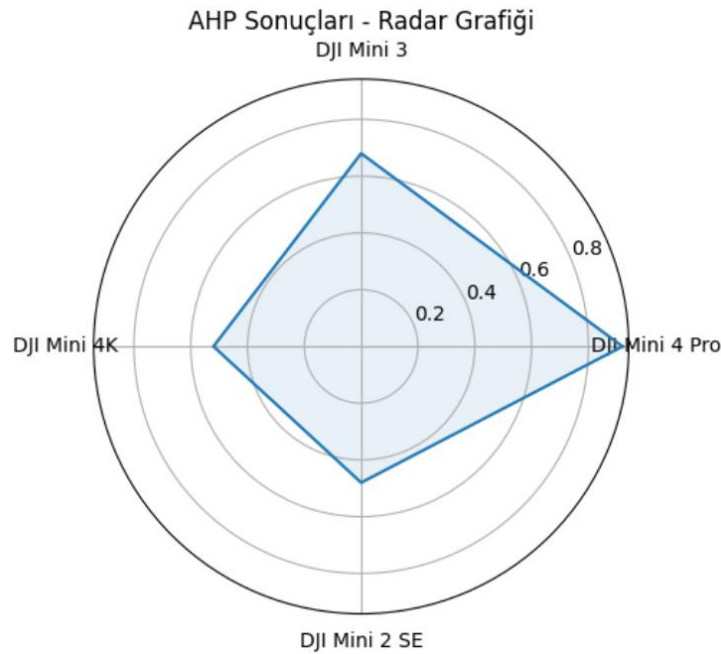
Tablo 6. Ağırlıklı Normalize Edilmiş Karar Matrisi

Alternatif	Ağırlık (0.05)	Uçuş Süresi (0.10)	Kamera (0.20)	Menzil (0.20)	Engel Algılama (0.225)	RTH (0.225)	Toplam Skor
Mini 4K	0.0125	0.020	0.044	0.040	0.038	0.050	0.204
Mini 2 SE	0.0125	0.020	0.034	0.040	0.038	0.050	0.194
Mini 3	0.0125	0.029	0.056	0.040	0.038	0.050	0.225
Mini 4 Pro	0.0125	0.029	0.066	0.080	0.113	0.075	0.375

Tablo 7. Nihai Skorlar ve Sıralama

Alternatif	Skor	Sıralama
DJI Mini 4 Pro	0.92	1
DJI Mini 3	0.68	2
DJI Mini 4K	0.52	3
DJI Mini 2 SE	0.48	4

Nihai Skorlar ve Sıralama Tablo 7’de gösterilmiştir.



Şekil 1. AHP Sonuçlarının Radar Grafiği

Şekil 1’deki Radar grafiği, alternatiflerin görel performanslarını görsel olarak karşılaştırmak amacıyla sunulmuştur. Mini 4 Pro modelinin tüm kriterler açısından daha geniş bir performans alanı kapsadığı görülmektedir. Bu durum, modelin çok kriterli karar verme analizinde en dengeli ve üstün alternatif olduğunu göstermektedir.

AHP analizi sonuçlarına göre, Mini 4 Pro modeli en yüksek performansı göstermiştir. Bu sonuç, özellikle gelişmiş engel algılama sistemi, yüksek menzil kapasitesi ve üstün kamera özelliklerinden kaynaklanmaktadır. Mini 3 modeli ikinci sırada yer alırken, temel özelliklere sahip olan Mini 4K ve Mini 2 SE modelleri daha düşük performans göstermiştir. Tutarlılık oranının 0.10’dan küçük olması, yapılan karşılaştırmaların güvenilir olduğunu göstermektedir.

TARTIŞMA VE SONUÇ

Bu çalışmada, insansız hava araçlarının performanslarının çok kriterli bir bakış açısıyla değerlendirilmesi amacıyla Analitik Hiyerarşi Süreci kullanılmıştır. Mini serilerine ait farklı modeller, ağırlık, uçuş süresi, kamera performansı, menzil, engel algılama ve eve dönüş (RTH) özellikleri dikkate alınarak sistematik bir şekilde analiz edilmiştir. Çalışmada hem nicel hem de nitel kriterlerin birlikte ele alınması, karar verme sürecinin daha gerçekçi ve kapsamlı bir şekilde yürütülmesini sağlamıştır.

Elde edilen bulgular, Mini 4 Pro modelinin diğer alternatiflere kıyasla belirgin bir performans üstünlüğüne sahip olduğunu ortaya koymuştur. Bu üstünlük, özellikle gelişmiş engel algılama sistemi, daha yüksek iletim menzili ve üstün kamera özelliklerinden kaynaklanmaktadır. Mini 3 modeli, yüksek uçuş süresi ve dengeli teknik özellikleri ile ikinci sırada yer alırken, Mini 4K ve Mini 2 SE modelleri daha sınırlı teknik kapasitelere sahip olmaları nedeniyle daha düşük performans skorları elde etmiştir. Bu sonuçlar, üst segment teknolojik özelliklerin çok kriterli değerlendirme süreçlerinde belirleyici olduğunu açıkça göstermektedir.

Kriter ağırlıklarının incelenmesi, uçuş güvenliği ve otonom sistemlerle ilişkili parametrelerin (engel algılama ve RTH) karar sürecinde en yüksek etkiye sahip olduğunu göstermiştir. Bu durum, günümüzde İHA kullanımının yalnızca performans odaklı değil, aynı zamanda güvenlik ve operasyonel süreklilik açısından da değerlendirildiğini ortaya koymaktadır. Ayrıca menzil ve kamera performansı gibi teknik kriterlerin de önemli katkılar sunduğu belirlenmiştir. Buna karşın ağırlık kriterinin daha düşük bir etkiye sahip olması, Mini serisi gibi hafif sınıf İHA’larda bu parametrenin ayırt edici bir faktör olmaktan kısmen uzaklaştığını göstermektedir.

Çalışmada elde edilen tutarlılık oranının kabul edilebilir sınırlar içerisinde olması, yapılan değerlendirmelerin güvenilirliğini desteklemektedir. Bu bağlamda, uygulanan AHP yöntemi, İHA seçim problemi gibi çok kriterli ve karmaşık karar yapılarında etkin ve uygulanabilir bir araç olduğunu bir kez daha ortaya koymuştur. Yöntemin sistematik yapısı sayesinde, farklı özelliklere sahip alternatiflerin karşılaştırılması nesnel bir temele oturtulmuş ve karar vericilere açık ve anlaşılır sonuçlar sunulmuştur.

Bununla birlikte, çalışmanın bazı sınırlılıkları bulunmaktadır. Kullanılan kriterler belirli teknik parametrelerle sınırlandırılmış olup, maliyet, kullanıcı deneyimi, bakım gereksinimleri ve çevresel faktörler gibi ek değişkenler analiz kapsamına dahil edilmemiştir. Gelecek çalışmalarda, farklı çok kriterli karar verme yöntemlerinin entegrasyonu ile sonuçların karşılaştırılması, modelin doğrulanabilirliğini artıracaktır. Ayrıca, bulanık AHP gibi gelişmiş yaklaşımlar kullanılarak belirsizliklerin daha etkin bir şekilde modellenmesi mümkündür.

Sonuç olarak, bu çalışma İHA seçim problemine yönelik sistematik, şeffaf ve tekrarlanabilir bir değerlendirme yaklaşımı sunmakta ve hem akademik literatüre hem de uygulayıcılara önemli katkılar sağlamaktadır. Elde edilen bulgular, özellikle kullanıcı ihtiyaçlarına göre en uygun İHA modelinin belirlenmesinde yol gösterici niteliktedir ve gelecekte yapılacak çok kriterli karar verme çalışmalarına bir örnek oluşturmaktadır.

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**LOCKING MECHANISM SELECTION IN UNMANNED AERIAL VEHICLES: RELIABILITY
AND COST-ORIENTED DECISION-MAKING APPLICATION**

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ABSTRACT

This study systematically evaluates the selection of latching mechanisms used in unmanned aerial vehicles (UAVs), based on reliability and cost criteria. Latching mechanisms are critical for the mission success, operational safety, and system integrity of UAVs. In this context, three different alternatives—electrical counter-lock, magnetic latching, and electromechanical solenoid—were analyzed. Each mechanism was evaluated considering engineering-specific factors such as system integration, in-mission performance, and maintenance requirements. Using the Analytical Hierarchy Process (AHP), a multi-criteria decision-making method, the relative importance of the criteria was numerically determined, and the alternatives were compared under these criteria. Reliability was prioritized in terms of system performance and mission success, while cost was considered a crucial parameter for economic sustainability, especially in small and micro UAV applications. Additionally, factors such as energy consumption, ease of installation, and size/weight contributed to a comprehensive analysis of the alternatives' performance. The analysis results showed that electric counter-lock and magnetic latching exhibited high performance in terms of reliability. Although electromechanical solenoids offer a low-cost advantage, they have demonstrated limited reliability. Consequently, the electric counter-lock mechanism has been identified as the solution that best balances reliability and cost. This study provides UAV designers with a systematic, numerical, and reliable reference for selecting locking mechanisms, and allows for more comprehensive and multi-dimensional decision analyses in the future by including additional criteria.

Keywords: Unmanned aerial vehicle, Locking Mechanism, Performance Evaluation, Reliability, Cost

**İNSANSIZ HAVA ARAÇLARINDA KİLİTLEME MEKANİZMASI SEÇİMİ: GÜVENİLİRLİK VE
MALİYET ODAKLI KARAR UYGULAMASI**

ÖZET

Bu çalışmada, insansız hava araçlarında (İHA) kullanılan kilitleme mekanizmalarının seçiminde güvenilirlik ve maliyet kriterleri temel alınarak sistematik bir değerlendirme gerçekleştirilmiştir. Kilitleme mekanizmaları, İHA'ların görev başarısı, operasyonel güvenliği ve sistem bütünlüğü açısından kritik öneme sahiptir. Bu kapsamda, elektrikli karşılık kilidi, manyetik kilit ve elektromekanik solenoid olmak üzere üç farklı alternatif analiz edilmiştir. Her bir mekanizma, sistem entegrasyonu, görev sırasında performans ve bakım gereksinimleri gibi mühendislik açıdan belirleyici faktörler göz önünde bulundurularak değerlendirilmiştir. Çalışmada çok kriterli karar verme yöntemlerinden Analitik Hiyerarşi Süreci (AHP) kullanılarak kriterlerin göreceli önemi sayısal olarak belirlenmiş ve alternatifler bu kriterler altında karşılaştırılmıştır. Güvenilirlik kriteri, sistem performansı ve görev başarısı açısından öncelikli olarak ele alınırken, maliyet kriteri özellikle küçük ve mikro İHA uygulamalarında ekonomik sürdürülebilirlik açısından önemli bir parametre olarak değerlendirilmiştir. Ayrıca enerji tüketimi, kurulum kolaylığı ve boyut/ağırlık gibi ek faktörler de alternatiflerin performansının kapsamlı bir şekilde analiz edilmesine katkı sağlamıştır. Analiz sonuçları, elektrikli karşılık kilidi ve manyetik kilidin güvenilirlik açısından yüksek performans sergilediğini göstermiştir. Elektromekanik solenoid, düşük maliyet avantajına sahip olmasına rağmen güvenilirlik açısından sınırlı performans göstermiştir. Sonuç olarak, elektrikli karşılık kilidi, güvenilirlik ve maliyet dengesini en iyi sağlayan çözüm olarak belirlenmiştir. Bu çalışma, İHA tasarımcılarına kilitleme mekanizması seçiminde

sistematik, sayısal ve güvenilir bir referans sunmakta olup, gelecekte ek kriterlerin dahil edilmesiyle daha kapsamlı ve çok boyutlu karar analizlerine olanak tanımaktadır.

Anahtar Kelimeler: İnsansız hava aracı, Kilitleme Mekanizması, Performans Değerlendirmesi, Güvenilirlik, Maliyet

GİRİŞ

İnsansız hava araçları (İHA), son yıllarda askeri, sivil ve ticari uygulamalarda yaygın olarak kullanılan önemli teknolojik sistemler haline gelmiştir. Keşif, gözetleme, haritalama, lojistik ve afet yönetimi gibi birçok alanda etkin şekilde kullanılan bu sistemlerin performansı, yalnızca uçuş kabiliyetlerine değil, aynı zamanda alt sistemlerinin güvenilirliğine de doğrudan bağlıdır. Bu alt sistemlerden biri olan kilitleme mekanizmaları, özellikle faydalı yük taşıma, bırakma ve güvenli sabitleme görevlerinde kritik bir rol oynamaktadır [1-3].

Kilitleme mekanizması, uçuş sırasında yük yerleştirme sırasında kapağın açılıp kapanmasını sağlamak için otomatik çalışma sunmalı ve ayrıca arıza emniyetli bir işlevselliğe sahip olmalıdır. Bu, sistem için kritik bir gereksinimdir ve sistem arızaları veya elektrik kesintileri durumunda bile kapağın her zaman güvenli bir şekilde kilitli kalmasını, kazara açılmayı önlemeyi ve uçuş operasyonları sırasında yükü korumayı sağlaması açısından önemlidir. Mekanizmanın yüksek güvenilirlik göstermesi, değişik çevresel koşullar ve operasyonel senaryolar altında tutarlı performans sağlaması kritiktir. Çünkü normal bir uçuşta düzenli olarak farklı kritik senaryolar ortaya çıkabilmektedir.

Örneğin, kargo bölmesinin genel tasarımına entegrasyon kolaylığı için kilitleme mekanizmasının genel sistem mimarisi aerodinamik ve kargo alanı üzerinde minimum etki sağlayacak şekilde düzenlenmelidir. Sistem özellikle zorlu uçuş ortamlarında dayanıklı ve aşınmaya karşı dirençli olmalıdır ve bu, kilitleme sisteminin ömrünü ve performansını artırmak için yüksek kaliteli malzemeler ve sağlam yapı teknikleri kullanılarak elde edilebilir [4-6].

İHA’larda kullanılan kilitleme mekanizmaları, görev sırasında meydana gelebilecek titreşim, ani manevra ve çevresel etkiler altında stabil çalışmak zorundadır. Bu nedenle seçilecek mekanizmanın güvenilir olması, sistem bütünlüğü ve görev başarısı açısından hayati önem taşımaktadır. Öte yandan, özellikle küçük ve mikro İHA platformlarında maliyet faktörü de önemli bir tasarım kriteri olarak öne çıkmaktadır. Düşük maliyetli çözümler, geniş ölçekli üretim ve uygulama açısından avantaj sağlarken, bu durum çoğu zaman performans ve güvenilirlik ile bir denge kurulmasını gerektirmektedir [7-9].

Literatürde mekanik sistem seçimi problemleri genellikle çok kriterli karar verme (ÇKKV) yöntemleri kullanılarak ele alınmaktadır. Bu yöntemler, birden fazla ve çoğu zaman birbiriyle çelişen kriterlerin birlikte değerlendirilmesine olanak tanıyarak daha rasyonel ve sistematik kararlar alınmasını sağlamaktadır. Analitik Hiyerarşi Süreci (AHP), bu yöntemler arasında yaygın olarak kullanılan ve karar vericilerin öznel değerlendirmelerini sayısal hale dönüştüren güçlü bir yaklaşımdır.

Bu çalışmada, İHA’larda kullanılabilecek üç farklı kilitleme mekanizması (elektrikli karşılık kilidi, manyetik kilit ve elektromekanik solenoid), güvenilirlik ve maliyet kriterleri çerçevesinde değerlendirilmiştir. AHP yöntemi kullanılarak kriterlerin göreceli önem düzeyleri belirlenmiş ve alternatifler bu kriterler altında karşılaştırılarak en uygun mekanizma tespit edilmiştir. Çalışmanın amacı, İHA tasarım sürecinde kilitleme mekanizması seçiminde karar vericilere sistematik ve uygulanabilir bir yaklaşım sunmaktır.

Alternatif Kilitleme Sistemleri

İHA kilitleme mekanizması alternatiflerine ait temel özelliklerin karşılaştırılması Tablo 1’de verilmiştir. Bu tabloda değerlendirilen kilitleme mekanizmaları, insansız hava araçlarının operasyonel gereksinimleri doğrultusunda belirlenen temel mühendislik kriterlerine göre karşılaştırılmıştır. Nitel ifadeler, ilgili mekanizmaların literatürde bildirilen performans özellikleri ve mühendislik değerlendirmeleri dikkate alınarak oluşturulmuştur.

Tablo 1. İHA Kilitleme Mekanizması Alternatiflerine Ait Temel Özelliklerin Karşılaştırılması [10]

Özellik	Elektrikli Karşılık Kilidi (Electric Strike Lock)	Manyetik Kilit (Magnetic Lock)	Elektromekanik Solenoid
Emniyetli Arıza (Fail-Safe) Çalışma	Var	Var	Var

Güvenilirlik	Yüksek	Yüksek	Orta
Güvenlik	Yüksek	Yüksek	Orta
Hassas Kontrol	Yüksek	Orta	Orta
Enerji Tüketimi	Düşük	Düşük	Orta
Kurulum Kolaylığı	Orta	Orta	Yüksek
Boyut ve Ağırlık	Orta	Orta	Düşük
Maliyet	Orta	Orta	Düşük

Solenoid kilit sistemi, tuzak kapısının kilitlenmesini ve açılmasını kontrol etmek için elektromekanik bir solenoid kullanır ve elektromanyetik indüksiyon prensiplerine göre çalışır; burada bir tel bobininden geçen elektrik akımı bir manyetik alan oluşturur ve solenoid, silindirik bir gövde içinde ileri geri hareket edebilen bir pistonun etrafına sarılmış bir tel bobininden oluşur. Solenoid, elektrik akımı uygulanarak enerjilendirildiğinde, bobin manyetik bir alan oluşturur; bu alan, tasarımına bağlı olarak pistonun solenoid gövdesine çekilmesine veya itilmesine neden olur ve piston hareket ettikçe, kapak üzerindeki karşılık gelen bir kilitleme mekanizmasıyla temas ederek kapağı güvenli bir şekilde yerine kilitler. Piston tamamen uzatıldığında veya geri çekildiğinde, kilitleme mekanizmasını yerinde tutarak kapağın açılmasını engeller, kargo bölmesi için güvenli bir kilitleme mekanizması sağlar ve yükün güvenli bir şekilde içeride kalmasını garanti eder. Kapağı açmak için, solenoidin bobinden geçen elektrik akımı kesilerek devre dışı bırakılması gerekir; bu, solenoid tarafından oluşturulan manyetik alanı keser ve pistonun nötr konumuna dönmesine izin vererek kilitleme mekanizmasını serbest bırakır ve kapağın açılmasını sağlar. Bu sistem otomatik kilitleme ve kilit açma özelliği sunarak otomatik sistemler ve uçuş sırasındaki operasyonlar için uygundur ve düzgün bir şekilde bakımı yapıldığında, solenoid kilitler güvenilir performans sunarak yapının tutarlı bir şekilde kilitlenmesini ve kilidinin açılmasını sağlar. Öte yandan, solenoid kilitler, kilitli veya kilitsiz durumu korumak için sürekli güce ihtiyaç duyar; bu da elektrik kesintisi durumunda endişe kaynağı olabilir ve bu kilitlerin İHA sistemine entegre edilmesi ek kablolama ve kontrol devreleri gerektirebilir, bu da tüm projenin karmaşıklığını artırabilir.

Manyetik kilit sistemi, kapıları güvenli hale getirmek için tasarlanmış elektromanyetik bir kilitleme cihazıdır ve elektromanyetizma prensibine göre çalışır. Elektromıknatısa elektrik enerjisi uygulandığında, armatür plakasını çeken bir manyetik alan oluşturur ve bu da kapıyı yerinde kilitleyen güçlü bir bağ oluşturur. Kilitlendiğinde, manyetik kilit güvenli bir kilitleme mekanizması sağlar ve kapının istem dışı açılmasını önler, çünkü manyetik kuvvetin gücü, kapının dış kuvvetler veya titreşimler altında bile sıkıca kilitli kalmasını sağlar. Kapıyı açmak için, elektromıknatısa giden elektrik enerjisinin kesilmesi gerekir, çünkü güç kesildiğinde, manyetik alan dağılır ve armatür plakasını elektromıknatıstan ayırarak kapının serbestçe açılmasına izin verir. Bu sistem güçlü bir kilitleme mekanizması sağlar, ancak kilitli durumu korumak için sürekli elektrik enerjisine bağlıdır ve elektrik kesintisi veya arıza durumunda kilit açılabilir ve bölmenin içindeki kargoyu tehlikeye atabilir. Bu kilit ayrıca karmaşık kablolama ve mekanik bağlantılar gerektirir ve kontrol sistemleri veya güç kaynağı üniteleri gibi diğer bileşenlerle yüksek uyumluluk gerektirir.

Elektrikli kilit sistemi, elektrikle kontrol edilen bir kilit mekanizması kullanarak tuzak kapısını yerinde sabitlemek üzere tasarlanmıştır; kilitleme mekanizmasının devreye girmesi ve devre dışı bırakılması için elektrik aktivasyonuna dayanır. Elektrik gücü elektrikli kilide uygulandığında, kilit mekanizması devreye girer, kapı çerçevesine doğru uzar veya geri çekilir ve tuzak kapısı üzerindeki karşılık gelen bir mandal veya sürgü mekanizmasıyla etkileşime girerek onu yerinde kilitler ve açılmasını engeller. Tuzak kapısını açmak için, elektrikli kilide giden elektrik gücü kesilmelidir; bu da kilit mekanizmasını devre dışı bırakır ve ardından tuzak kapısı üzerindeki mandal mekanizmasından ayrılır, böylece havada yük bırakma işlemi mümkün hale gelir. Elektrikli kilitler, çeşitli malzeme türleriyle yapılandırılabilirler ve ayarlanabilir mandal konumlandırması ve farklı kilit plakası konfigürasyonları seçenekleriyle belirli güvenlik gereksinimlerini karşılayacak şekilde özelleştirilebilirler için kurulum seçeneklerinde çok yönlülük sunar. Ayrıca, genellikle takıldıktan sonra minimum bakım gerektirirler, dayanıklı bileşenlere ve uzun süreler boyunca güvenilir çalışmaya sahiptirler, ancak kurulumları kapı çerçevesinde veya kilit karşılığı plakasında değişiklikler

gerektirebilir ve ek bileşenleri ve kurulum gereksinimleri nedeniyle diğer kilitleme mekanizmalarından daha pahalı olabilirler [10]. Analiz için kullanılan değerlendirme kriterleri Tablo 2’de verilmiştir.

Tablo 2. Değerlendirme kriterleri

Özellik	Amaç	Açıklama
Emniyetli Arıza (Fail-Safe) Çalışma	Sistem arızası durumunda mekanizmanın güvenli bir şekilde çalışmaya devam etmesi veya güvenli konuma geçmesi	İHA’larda kontrol kaybı veya enerji kesintisi durumlarında görev güvenliği ve sistem bütünlüğünü sağlamak kritik öneme sahiptir
Güvenilirlik	Mekanizmanın uzun süreli ve kararlı çalışma performansı	Görev başarısının doğrudan mekanizmanın arızasız çalışmasına bağlı olması nedeniyle en kritik kriterlerden biridir
Güvenlik	Mekanizmanın istenmeyen açılma veya kapanma durumlarına karşı dayanıklılığı	Faydalı yükün kontrolsüz bırakılması veya sistem hasarı riskini minimize etmek için önemlidir
Hassas Kontrol	Mekanizmanın doğru ve istenilen zamanda tepki verebilme kabiliyeti	Özellikle hassas görevlerde (yük bırakma vb.) operasyonel doğruluğu artırmak için gereklidir
Enerji Tüketimi	Mekanizmanın çalışması için gerekli enerji miktarı	İHA’larda sınırlı enerji kapasitesi nedeniyle uçuş süresini doğrudan etkileyen bir faktördür
Kurulum Kolaylığı	Mekanizmanın sisteme entegrasyonunun kolaylığı	Tasarım ve bakım süreçlerini kolaylaştırarak operasyonel verimliliği artırır
Boyut ve Ağırlık	Mekanizmanın fiziksel hacmi ve kütlesi	İHA’larda taşıma kapasitesi sınırlı olduğundan ağırlık ve hacim kritik tasarım parametreleridir
Maliyet	Mekanizmanın üretim ve temin maliyeti	Özellikle düşük bütçeli ve seri üretim uygulamalarında ekonomik sürdürülebilirlik açısından önemlidir

Bu çalışmada kullanılan değerlendirme kriterleri, insansız hava araçlarının operasyonel gereksinimleri ve mühendislik tasarım kısıtları dikkate alınarak belirlenmiştir. Emniyetli arıza (fail-safe) çalışma, güvenilirlik ve güvenlik kriterleri, sistemin görev sırasında hatasız ve güvenli bir şekilde çalışmasını sağlamak amacıyla öncelikli olarak ele alınmıştır. Hassas kontrol, özellikle faydalı yük bırakma gibi zamanlama gerektiren operasyonlarda doğruluğu artıran önemli bir parametredir.

Enerji tüketimi, İHA’ların sınırlı enerji kapasitesi nedeniyle uçuş süresi üzerinde doğrudan etkili olup, sistem performansını belirleyen temel faktörlerden biridir. Kurulum kolaylığı, sistem entegrasyon sürecini ve bakım faaliyetlerini etkileyerek operasyonel verimlilik açısından değerlendirilmiştir. Boyut ve ağırlık kriterleri ise İHA’ların taşıma kapasitesi ve aerodinamik performansı üzerinde belirleyici rol oynamaktadır.

Son olarak, maliyet kriteri, özellikle düşük bütçeli ve yaygın kullanım hedeflenen uygulamalarda ekonomik sürdürülebilirliği sağlamak amacıyla değerlendirmeye dahil edilmiştir. Bu kriterlerin birlikte ele alınması, kilitleme mekanizması seçiminin hem teknik hem de ekonomik açıdan dengeli bir şekilde gerçekleştirilmesine olanak sağlamaktadır.

Analitik Hiyerarşi Uygulaması

Bu çalışmada, İHA’larda kullanılacak en uygun kilitleme mekanizmasının belirlenmesi amacıyla çok kriterli karar verme yöntemlerinden Analitik Hiyerarşi Süreci (AHP) uygulanmıştır. AHP yöntemi, karmaşık karar problemlerinde kriterler ve alternatifler arasında ikili karşılaştırmalar yaparak öncelik sıralaması belirlemeye olanak sağlamaktadır [11].

Çalışmada iki temel kriter (güvenilirlik ve maliyet) ve üç alternatif (elektrikli karşılık kilidi, manyetik kilit ve elektromekanik solenoid) değerlendirilmiştir.

Kriterler Arası Karşılaştırma ve Ağırlıkların Belirlenmesi

Kriterler arası karşılaştırma matrisi Saaty'nin 1–9 ölçeğine göre oluşturulmuştur. Güvenilirlik kriterinin, İHA sistemlerinde görev başarısı açısından daha kritik olması nedeniyle maliyet kriterine göre daha önemli olduğu kabul edilmiştir. Kriterler arası karşılaştırma matrisi Tablo 3'de verilmiştir.

Tablo 3. Kriterler Arası Karşılaştırma Matrisi

Kriter	Güvenilirlik	Maliyet
Güvenilirlik	1	5
Maliyet	1/5	1

AHP yönteminde normalizasyon aşağıdaki formül ile hesaplanmıştır:

$$r_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}}$$

Burada:

a_{ij} : karşılaştırma matrisi elemanı

r_{ij} : normalize edilmiş değer

Normalize edilmiş kriter matrisi ve ağırlıklar Tablo 4'de gösterilmiştir.

Tablo 4. Normalize Edilmiş Kriter Matrisi ve Ağırlıklar

Kriter	Güvenilirlik	Maliyet	Ortalama (Ağırlık)
Güvenilirlik	0.833	0.833	0.833
Maliyet	0.167	0.167	0.167

İki kriterli yapıdan dolayı tutarlılık oranı (CR) sıfır olduğundan model tam tutarlıdır.

Alternatiflerin Kriterlere Göre Değerlendirilmesi

Güvenilirlik Kriterine Göre Karşılaştırma

Güvenlik kriteri için matris ve **normalize matris** Tablo 5 ve Tablo 6'da gösterilmiştir.

Tablo 5. Güvenlik kriteri için Matris

Alternatif	EKK	MK	ES
EKK	1	1	5
MK	1	1	5
ES	1/5	1/5	1

Tablo 6. Normalize Matris (Güvenilirlik)

Alternatif	EKK	MK	ES	Ortalama
EKK	0.455	0.455	0.455	0.455
MK	0.455	0.455	0.455	0.455

ES	0.091	0.091	0.091	0.090

Maliyet Kriterine Göre Karşılaştırma

Maliyet kriteri için matris ve normalize matris Tablo 7 ve Tablo 8’de gösterilmiştir.

Tablo 7. Maliyet kriteri için matris

Alternatif	EKK	MK	ES
EKK	1	1	1/5
MK	1	1	1/5
ES	5	5	1

Tablo 8. Normalize Matris (Maliyet)

Alternatif	EKK	MK	ES	Ortalama
EKK	0.143	0.143	0.143	0.143
MK	0.143	0.143	0.143	0.143
ES	0.714	0.714	0.714	0.714

Genel Skorların Hesaplanması

Genel skorlar aşağıdaki formül ile hesaplanmıştır:

$$S_i = \sum_{j=1}^n w_j \cdot p_{ij}$$

Burada:

w_j : kriter ağırlığı

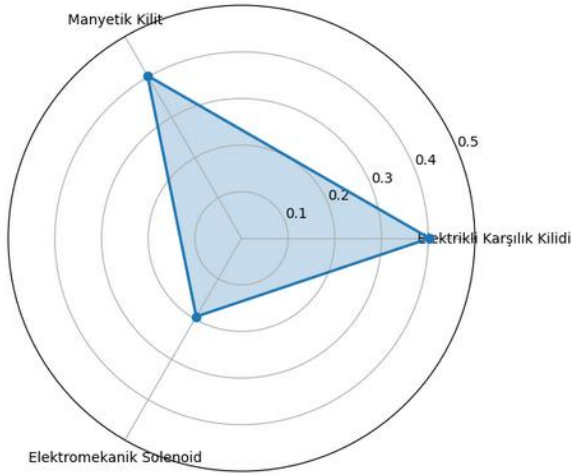
p_{ij} : alternatifin kriter altındaki ağırlığıdır

Tablo 9. Nihai Skorlar ve Sıralama

Alternatif	Skor	Sıralama
Elektrikli Karşılık Kilidi	0.403	1
Manyetik Kilit	0.403	1
Elektromekanik Solenoid	0.194	3

Elde edilen sonuçlara göre, elektrikli karşılık kilidi ve manyetik kilit alternatifleri eşit skor ile en uygun seçenekler olarak belirlenmiştir. Elektromekanik solenoid ise düşük güvenilirlik performansı nedeniyle daha düşük bir skor elde etmiştir.

Bu sonuçlar, güvenilirlik kriterinin yüksek ağırlığa sahip olmasının karar üzerinde belirleyici olduğunu göstermektedir. Maliyet açısından avantajlı olan elektromekanik solenoid, güvenilirlik açısından yetersiz kalması nedeniyle genel sıralamada geride kalmıştır. Kriterler bazında skor dağılımı Şekil 1’de görselleştirilmiştir.



Şekil 1. Kriterler bazında skor dağılımı

TARTIŞMA VE SONUÇ

Bu çalışmada, insansız hava araçlarında (İHA) kullanılacak kilitleme mekanizmasının seçiminde güvenilirlik ve maliyet kriterleri temel alınarak Analitik Hiyerarşi Süreci (AHP) uygulanmıştır. Elektrikli karşılık kilidi, manyetik kilit ve elektromekanik solenoid olmak üzere üç alternatif, kriter ağırlıkları dikkate alınarak değerlendirilmiştir.

AHP sonuçları, güvenilirlik kriterinin yüksek ağırlığının karar sürecinde belirleyici olduğunu göstermektedir. Elde edilen genel skorlar, elektrikli karşılık kilidi ve manyetik kilit için 0.403, elektromekanik solenoid için ise 0.194 olarak hesaplanmıştır. Bu sonuçlar, elektrikli karşılık kilidi ve manyetik kilidin güvenilirlik açısından yüksek performans sergilediğini ve maliyet farkına rağmen güvenilirlik öncelikli seçimde öne çıktığını ortaya koymaktadır. Elektromekanik solenoid ise maliyet avantajına sahip olmasına rağmen, güvenilirlik açısından sınırlı performans göstermesi nedeniyle genel sıralamada geride kalmıştır. Grafiksel analizler de bulguları desteklemektedir. Radar grafiği ile kriter bazında performans farklılıkları görselleştirmiştir.

Bu çalışma, İHA sistem tasarımında kilitleme mekanizması seçimi için güvenilirlik ve maliyet odaklı sistematik bir yaklaşım sunmaktadır. Özellikle, görev başarısının kritik olduğu operasyonel senaryolarda güvenilirliğin öncelikli kriter olarak değerlendirilmesi gerektiği vurgulanmıştır. Ayrıca, maliyetin düşük öncelikli olduğu durumlarda elektromekanik solenoid alternatifinin sınırlı fakat ekonomik bir çözüm sunduğu gözlemlenmiştir.

Gelecekteki çalışmalar, kriter setinin genişletilmesi ve farklı görev senaryolarının değerlendirilmesiyle karar sürecini daha kapsamlı hale getirebilir. Örneğin enerji tüketimi, kurulum kolaylığı, titreşim dayanımı veya çevresel dayanıklılık gibi ek kriterler, AHP yöntemi ile birlikte dikkate alınarak alternatiflerin çok boyutlu performansı daha detaylı analiz edilebilir.

Sonuç olarak, AHP ile yapılan bu çalışma, İHA tasarımcıları ve mühendisleri için kilitleme mekanizması seçimi sürecinde bilimsel ve sayısal bir referans oluşturmaktadır.

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**THE DEVELOPMENT AND FUTURE OF PODCAST BROADCASTING IN TURKEY: COULD
PODCAST BROADCASTING BE AN ALTERNATIVE TO RADIO IN TURKEY?**

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ABSTRACT

Podcasting emerged in the early 2000s with the spread of RSS technology and portable devices such as the iPod and MP3 players and has since become one of the most dynamic publishing tools in the global media industry. Originally a niche format dominated by amateur producers, podcasting has undergone a major transformation due to the widespread adoption of smartphones and streaming platforms, the rise of professional content production, and the growing interest of advertisers and investors. In Turkey, podcasting emerged in the mid-2000s but gained significant momentum by the late 2010s. Podcasting in Turkey has experienced rapid growth, particularly during the pandemic. Today, Turkey ranks among the world's fastest-growing podcast markets, standing out as a media format preferred by young, educated listeners from the middle-to-upper income bracket. The first section of this study conducts a conceptual analysis of podcasting, comprehensively examining its global and Turkey-specific development, growth dynamics, and listener profiles. In the second section of the study, the current state of podcasting in Turkey was described using an online survey to 611 people. The following questions were examined: Can podcasting completely replace radio broadcasting? What business models can podcasting utilize? And what are the advantages and disadvantages of podcasting for both listeners and content creators? The data obtained from the research revealed that participants agreed that podcasting has increased in popularity in Turkey and that it is a medium well-suited to replace radio in the future.

Keywords: Podcast, Radio, Podcasting, Podcast Business Models

**TÜRKİYE'DE PODCAST YAYINCILIĞININ GELİŞİMİ VE GELECEĞİ: PODCAST
YAYINCILIĞI TÜRKİYE'DE RADYO MECRASININ ALTERNATİFİ OLABİLİR Mİ?**

ÖZET

Podcast yayıncılığı, 2000'li yılların başından itibaren RSS teknolojisi ve iPod , mp3 çalar gibi taşınabilir cihazların yaygınlaşmasıyla ortaya çıkmış, zamanla küresel medya endüstrisinin en dinamik yayın araçlarından biri haline gelmiştir. Başlangıçta amatör üreticilerin hakimiyetindeki niş bir yayın biçimi olan podcast, akıllı telefonların ve akış platformlarının yaygınlaşması, profesyonel içerik üretiminin artması ve reklam verenler ile yatırımcıların ilgisinin yoğunlaşmasıyla büyük bir dönüşüm geçirmiştir. Türkiye'de podcast, 2000'lerin ortalarında ortaya çıkmış ancak asıl ivmesini 2010'ların sonunda kazanmıştır. Podcast yayıncılığı Türkiye'de özellikle pandemi dönemiyle birlikte hızlı bir büyüme kaydetmiştir. Günümüzde Türkiye, dünya genelinde en hızlı büyüyen podcast pazarları arasında yer almakta, genç, eğitilmiş ve orta-üst gelir grubuna mensup dinleyicilerin tercih ettiği bir medya formatı olarak öne çıkmaktadır. Bu çalışmanın birinci bölümünde podcast yayıncılığı hakkında kavramsal bir araştırma yapılmış ve podcast yayıncılığının küresel ve Türkiye özelindeki gelişimi, büyüme dinamiklerini ve dinleyici profillerini kapsamlı bir şekilde araştırılmıştır. Çalışmanın ikinci bölümünde çevrim içi uygulanan bir anketle 611 kişiye podcast yayıncılığının Türkiye'deki durumu betimlenmiştir. Rassal olarak seçilen katılımcılara podcast yayıncılığı tamamen radyo yayıncılığının yerini alabilir mi, podcast yayıncılığının kullanabileceği iş modelleri nelerdir ve podcast yayıncılığının dinleyici ve içerik üreticisine olan avantaj ve dezavantajları nedir soruları sorgulanmıştır. Araştırma sonucunda elde edilen verilerde araştırmaya katılanların Türkiye'de podcast yayıncılığının popülerliğini arttırdığını ve podcastin gelecekte radyo mecrasının yerini almaya uygun bir mecra olduğu konusunda hem fikir olduğu görülmüştür

Anahtar Kelimeler: Podcast, Radyo, Podcast Yayıncılığı, Podcast İş Modelleri.

GİRİŞ

Dijital medya teknolojilerinin hızla geliştiği ve geleneksel medya tüketim alışkanlıklarının köklü bir dönüşüme uğradığı günümüzde, podcast yayıncılığı hem üretim hem de tüketim pratikleri açısından dikkat çeken bir medya formatı olarak öne çıkmaktadır. 2000'li yılların başında RSS teknolojisinin ses dosyalarının dağıtımına olanak tanınmasıyla temelleri atılan podcast formatı, yirmi yılı aşkın bir sürede amatör bir uğraştan profesyonel bir medya endüstrisine evrilmiştir. Bu çalışma, podcast yayıncılığının tarihsel gelişimini, formatın büyümesini tetikleyen teknolojik, ekonomik ve sosyokültürel faktörleri ve Türkiye'ye özgü dinamiklerini ele almayı amaçlamaktadır. Çalışmanın temel amacı, podcast ekosisteminin küresel ölçekte nasıl şekillendiğini ortaya koymak, Türkiye'deki gelişim sürecinin uluslararası alandaki yerini konumlandırmak ve Türk dinleyicilerinin demografik özellikleri ile tüketim alışkanlıklarını incelemektir. Bu doğrultuda çalışma, podcast kavramının tanımlanması ve kapsamının belirlenmesiyle başlamakta, ardından formatın büyümesini sağlayan platform dinamiklerini, profesyonelleşme süreçlerini ve gelir modellerini irdelemekte, son olarak Türkiye özelinde podcast yayıncılığının gelişim aşamalarını ve mevcut durumu değerlendirmektedir.

PODCAST KAVRAMI VE KAPSAMI

Podcast formatının tarihsel ve teknolojik gelişimi, 1990'ların başında internet tabanlı ses dağıtımının temellerini atan RSS (Really Simple Syndication) teknolojisinin ortaya çıkışıyla başlamıştır. Bu teknolojik altyapı, kullanıcıların ses dosyaları da dahil olmak üzere seri web içeriklerine abone olmalarına ve bu içerikleri otomatik olarak cihazlarına indirmelerine olanak tanımıştır (Story, 2022). Başlangıçta “sesli bloglar” veya rafine edilmemiş sohbet kayıtları olarak nitelendirilen bu içerikler, zamanla blog yazarlarının hakimiyetinden çıkarak teknoloji yazarları, komedyenler ve kamu yayıncılarını da içine alan geniş bir üretim sahasına yayılmıştır. Ben Hammersly, 2004 yılında Apple'ın taşınabilir müzik çaları “iPod” ile “yayın” (broadcast) kelimelerini birleştirerek “podcast” terimini literatüre kazandırmış ve bu formatın ana akım bir medyaya dönüşüm sürecini isimlendirmiştir (Story, 2022). Menduni (2007), bu süreci dijital müziğin yaygınlaşması, web radyosunun ortaya çıkışı, ücretsiz müzik paylaşımı ve son olarak iPod ile podcasting'in yükselişi şeklinde dört temel evreye ayırmaktadır. Bu evrim, radyonun mekansal ve zamansal sınırlarını aşan ancak başlangıçta beklendiği gibi radyo ortamını tamamen dönüştürmekten ziyade niş bir uygulama olarak kalan internet radyosundan, kullanıcının kendi içeriğini seçebildiği ve kişisel tercihlerin ön planda olduğu daha etkileşimli bir yapıya geçişi temsil etmektedir.

Podcasting ekosisteminin ilk yılları, özellikle 2004 ve 2005 döneminde, teknik zorluklar ve merkezi bir dağıtım ağının eksikliği nedeniyle sınırlı bir amatör topluluk tarafından sürdürülmüştür. Örneğin İspanya'da bu dönem “pijama radyosu” olarak adlandırılan, bilgi paylaşımı ve iş birliği kültürüne dayalı, kâr amacı gütmeyen amatör yaratıcıların hakim olduğu bir yapı sergilemiştir (García-Marín, 2019). García-Marín (2019), bu erken dönemin ardından akıllı telefonların ve mobil teknolojilerin gelişmesiyle birlikte 2006'dan itibaren geleneksel medyanın da alana ilgi duymaya başladığını ve podcasting'in marjinal bir uğraştan sağlam bir medya ekosistemine evrildiğini belirtmektedir. Bu dönüşümde sadece teknomerkezci faktörler değil, aynı zamanda içerik oluşturucular arasında kurulan güçlü topluluk bağları ve ulusal dernekleşme gibi sosyosentrik faktörler de belirleyici olmuştur. Başlangıçta sadece ses formatına odaklanan bu yapı, zamanla farklı platformlara yayılmıştır.

Geleneksel radyo yayıncılığı ile podcasting arasındaki etkileşim, formatın tarihsel gelişiminde bir diğer önemli kırılma noktasını oluşturmuştur. Radyo ve internet teknolojilerinin yakınsaması, medya tüketim alışkanlıklarını köklü bir biçimde değiştirmiş ve “zaman kaydırmalı” (time-shifted) dinleme pratiklerini yaygınlaştırmıştır (Ribeiro, 2021). Alonso-Fernández, Rodríguez-Luque ve Legorburu Hortelano (2022), özellikle 2015 yılından sonra ivme kazanan bu süreçte, konuşma tabanlı radyo istasyonlarının podcast formatını isteğe bağlı bir dağıtım kanalı olarak stratejik biçimde kullandıklarını vurgulamaktadır. Radyo yayıncıları, canlı yayın içeriklerini podcast olarak yeniden paketleyerek hem geleneksel dinleyici kitlesini korumayı hem de dijital yerlilerden oluşan daha genç bir kitleye ulaşmayı hedeflemiştir. Bu entegrasyon süreci, yayıncıların organizasyonel yapılarında değişikliğe gitmelerine, dijital ve programlama departmanları arasında hibrit yönetim modelleri geliştirmelerine ve izleyici ölçüm tekniklerinde daha sistematik yaklaşımlar benimsemelerine yol açmıştır (Alonso-Fernández vd., 2022). Böylece podcasting, radyonun dijital çağda hayatta kalmasını sağlayan ve içeriğin yeniden değerlendirilmesine olanak tanıyan bir araç olarak konumlanmıştır.

İçerik ve anlatı yapısı açısından incelendiğinde, podcast formatı sadece teknolojik bir dağıtım aracı olmanın ötesine geçerek hikaye anlatıcılığında (storytelling) kendine özgü bir dil geliştirmiştir. Aujla-Sidhu (2023),

sesin samimiyeti ve anlatı gücünün, dinleyicilerle derin bir bağ kurulmasını sağladığını ve bu durumun podcasting'i diğer medya türlerinden ayırdığını ifade etmektedir. Bu anlatı gücü, kurgusal içeriklerin ve görsel-işitsel yapımların genişletilmesinde de etkili bir şekilde kullanılmaktadır. Pedrero-Esteban, Terol-Bolínches ve Arense-Gómez (2023), televizyon dizilerinin anlatı evrenini genişletmek amacıyla üretilen transmedya podcast'lerin, izleyici sadakatini artırdığını ve kurgusal evrenle süreklilik sağladığını tespit etmiştir. Benzer şekilde, Martínez-Otón, Rodríguez-Luque ve Alcudia-Borreguero (2019), hayat hikayelerine dayalı raporlar ve docudrama gibi formatların podcasting ortamında yeniden hayat bulduğunu, ancak her formatın kendine has üretim ve anlatı tekniklerine sahip olduğunu belirtmektedir. Bu durum, podcasting'in hem gazetecilik hem de kurgu alanında hibrit formların ortaya çıkmasına zemin hazırladığını göstermektedir.

Günümüzde podcasting, bağımsız üreticilerin domine ettiği bir alandan çıkarak yerel ve küresel medya pazarlarında önemli bir sektör haline gelmiştir. Ancak bu hızlı büyüme, formatın tanımlanması ve sınıflandırılması konusunda bazı belirsizlikleri de beraberinde getirmiştir. Rime, Pike ve Collins (2022), podcast'in "üretilmesi ve deneyimlenmesi kolay epizodik ses" olarak tanımlanabileceğini öne sürerken, formatın temel özelliklerini koruyarak yeniliklere açık olunması gerektiğini savunmaktadır. Öte yandan Tennant (2024), mevcut tür kategorilerinin (örneğin "Gerçek Suç" dışında kalanlar) yetersiz kaldığını ve binlerce verinin analiz edilmesi sonucunda daha esnek ve spesifik bir sınıflandırma sistemine ihtiyaç duyulduğunu ortaya koymuştur. Sonuç olarak podcasting, teknolojik kökenlerinden bugüne kadar geçirdiği evrimle hem amatör ruhu barındıran hem de profesyonel medya endüstrisiyle bütünleşen, sınıflandırılması giderek zorlaşan ancak etkisi sürekli artan dinamik bir medya ortamı olarak varlığını sürdürmektedir.

PODCAST EKOSİSTEMİNİN BÜYÜMESİNİ TETİKLEYEN FAKTÖRLER

Podcast yayıncılığının büyümesi, dağıtım mimarisindeki dönüşüm ve platformlaşma dinamikleriyle birlikte ele alındığında daha iyi açıklanmaktadır. Açık RSS mantığına dayalı dolaşımdan, merkezî akış ve uygulama ekosistemlerine doğru yaşanan kayma, dinleme ve keşif sürecindeki sürtünmeleri azaltmakta ve pazarın ölçeklenmesini hızlandırmaktadır (Sullivan, 2019). Akıllı telefonların yaygınlaşması ve uygulama arayüzlerinin "mobil-öncelikli" deneyimi güçlendirmesi, dinleyicinin zaman ve mekân kısıtlarını gevşetmekte, dinlemeyi gündelik rutinlere eklemekte ve süreklilik oluşturmaktadır (McGregor, 2022). Platformların katalog yönetimi, arama ve öneri sistemleri ile kullanıcı verisine dayalı kişiselleştirme pratikleri, hem arz tarafında görünürlük rekabetini keskinleştirmekte hem de tüketim tarafında keşif maliyetini düşürmektedir (Sullivan, 2024). Bu çerçevede büyüme, yalnızca içerik sayısındaki artışla değil, içeriklerin dolaşımının daha koordineli ve ticari açıdan daha öngörülebilir bir zemine taşınmasıyla da ilişkilendirilmektedir (Sullivan vd., 2020). Dolayısıyla podcast ekosistemi, teknolojik altyapının sağladığı erişim kolaylığını, platform stratejilerinin yarattığı pazarlama ivmesiyle birleştirerek genişlemektedir.

Platform aktörleri arasındaki rol farklılaşması, bölgesel örüntüleri belirginleştirmekte ve büyümenin biçimini pazardan pazara dönüştürmektedir. Müzik akış hizmetlerinin podcast'leri ürün paketine dâhil etmesi, özellikle düşük tüketim düzeyine sahip pazarlarda farkındalığı artırmakta ve "keşif" eşiğini düşürmektedir. Türkiye örneğinde Spotify üzerinden karşılaşma ve dinleme deneyiminin algılanan kullanım kolaylığını güçlendirdiği raporlanmıştır (Özel, 2022). Avrupa ve Latin Amerika bağlamında platform ağları ile barındırma şirketleri, kürasyon, katalog organizasyonu, gelir araçları ve pazarlama kapasitesiyle üretim pratiklerini yeniden düzenlemekte, böylece bağımsız üretimin operasyonel mantığı profesyonel standartlara yaklaşmaktadır (Pérez-Alaejos vd., 2022). Bu örnekler, platformların yalnızca dağıtım kanalı olarak konumlanmadığını, aynı zamanda reklam teknolojisi, veri yönetimi ve üretim hizmetleriyle sektörün kurumsal düzenini şekillendirdiğini düşündürmektedir (Sullivan, 2019). Bölgesel stratejiler bu nedenle tek tip bir büyüme hattı yaratmamakta, yerel ekosistemlerin kurumsal yoğunluğuna ve rekabet yapısına göre farklılaşan genişleme yolları üretmektedir (Pérez-Alaejos vd., 2022).

Üretim alanındaki profesyonelleşme, format inovasyonu ve yüksek bütçeli anlatı yatırımları, podcast'lerin kültürel ve ekonomik değerini yükseltmektedir. Geleneksel medya kuruluşları ile platform destekli stüdyoların sektöre sermaye ve iş süreçleri taşımış olması, seri anlatı, belgesel anlatıcılığı ve ağ-temelli üretim pratiklerini güçlendirmiştir (Sullivan vd., 2020). "Serial" gibi çıkış yapan yapımların, uzun soluklu hikâye anlatımı ve "true crime" başta olmak üzere belirli türlerin kalıcılılaşmasına ivme kazandırdığı, bunun da hem dinleyici beklentilerini hem de yatırım iştahını yeniden düzenlediği tartışılmıştır (Berry, 2015). Platformların video podcast'lere ve çapraz mecra uyarlamalarına yönelmesi, ses ürününü çoklu dağıtım pencerelerine uygun paketlemeyi teşvik etmekte ve üretim planlamasında görsel-işitsel bütünleşmeyi artırmaktadır (Pérez-Alaejos vd., 2022). Aynı dönemde sesli asistanlar, öneri motorları ve üretimde otomasyon olanakları, iş akışlarını

kısaltmakta ve içerik üretiminde verimlilik hedeflerini güçlendirmektedir (Bulakh & Kulykova, 2025; Singh & Neha, 2024). Bu eğilimler, yaratıcı emeğin yerini ortadan kaldırmamakta, fakat editoryal karar alma, montaj, dağıtım optimizasyonu ve hedefleme pratiklerinin daha veri-duyarlı biçimde kurgulanmasına zemin hazırlamaktadır (Sullivan, 2024).

Büyümenin sürdürülebilirliği, yalnızca “hit” yapımlara değil, mikro-topluluklara seslenen niş üretimin sürekliliğine ve dinleyiciyle kurulan yakın ilişkiye de dayanmaktadır. Podcast çalışmalarında, üreticilerin dar ilgi alanlarını hedefleyerek ekonomik olarak sürdürülebilir bir dinleyici tabanı kurabildiği ve bu süreçte parasosyal yakınlığın önemli bir bağ kurucu işlev gördüğü vurgulanmıştır (McGregor, 2022). Kullanıcı ve üretici deneyimlerine dayanan bulgular, etkileşimi belirleyen unsurlar arasında sunucunun üslubu, konu yetkinliği, topluluk ölçeği, katılımcı kültürün yoğunluğu ve dinleyicinin geri bildirim kanallarına erişimi gibi değişkenleri öne çıkarmıştır (García-Marín, 2020). Bu tür etkileşim düzenleri, üretimin “genel kitle” mantığından ziyade belirli bir topluluk için süreklilik ve aidiyet üretmesiyle güçlenmektedir (García-Marín, 2020). Temsil ve kimlik temelli üretimler de bu bağlamda önem kazanmakta, dışarıda bırakılmış grupların kendi deneyimlerini merkeze alan yayınlarının sadakat ve üretim motivasyonunu artırdığı belirtilmektedir (McGregor, 2022). Böylece podcast ekosistemi, bir yandan kurumsal ölçeklenmeyi yaşarken, diğer yandan topluluk-temelli üretimin değerini dinleyici sadakati üzerinden yeniden üretmektedir.

Dinleyici tarafında benimseme, “zaman kaydırma” ve çoklu görev pratikleriyle yakından bağlantılı biçimde ilerlemiştir. Erken dönem çözümlemelerde podcast’lerin, dinleyicinin uygun gördüğü anda erişebileceği bölümlü yapısıyla yayın akışına bağımlılığı azalttığı ve kişiselleştirilmiş medya tüketimini güçlendirdiği belirtilmiştir (Crofts vd., 2005). Pandemi sonrasında yürütülen anket temelli çalışmalar, motivasyonların eğlence, dikkat, rahatlama, kaçış, sosyal etkileşim ve bilgi/öğrenme eksenlerinde kümелendiğini, ayrıca bilgi/öğrenme ve sosyal etkileşim değişkenlerinin kullanım üzerinde anlamlı yordayıcılar ürettiğini göstermiştir (Werner & Rennhak, 2024). Büyük akış uygulamalarında yer alma, keşfi kolaylaştırdığı ölçüde benimsemeyi artırmakta ve özellikle Türkiye gibi pazarlarda “platform üzerinden ilk karşılaşma” deneyimi kritik bir eşik oluşturmaktadır (Özel, 2022). Bununla birlikte katalog bolluğu, dikkat ekonomisinde rekabeti sertleştirmekte ve üreticiler açısından görünürlük maliyetini yükseltmektedir (Bulakh & Kulykova, 2025). Dolayısıyla benimseme, kullanım kolaylığıyla başlamakta, devamlılık ise içerik kalitesi, ilişki kurma kapasitesi ve keşif mekanizmalarının sürekliliğiyle pekişmektedir (García-Marín, 2020; Werner & Rennhak, 2024).

Gelir üretimi ve sektörleşme, reklamcılık, abonelik, platform anlaşmaları ve hizmet temelli modellerin birlikte var olduğu çok kanallı bir zeminde ilerlemektedir. Podcast reklamcılığında sunucu tarafından okunan reklamların güven düzeyi yüksek algılandığı için reklam veren yatırımlarının bu forma yöneldiği, böylece sponsorlu modellerin önemli bir gelir omurgası oluşturduğu tartışılmaktadır (Bulakh & Kulykova, 2025). Platformlar ve ağlar, premium abonelik, seçili içerik anlaşmaları ve katalog kürasyonu üzerinden ek gelir rejimleri kurmakta ve üreticileri daha istikrarlı nakit akışlarına bağlamayı hedeflemektedir (Pérez-Alaejos vd., 2022; Sullivan, 2024). Latin Amerika’daki yerli podcast girişimlerinde ise danışmanlık, markalı içerik üretimi ve müşteri için prodüksiyon gibi hizmet temelli gelir stratejilerinin öne çıktığı ve ölçek sınırlamalarını bu yolla aşmaya çalıştıkları gösterilmiştir (Rojas-Torrijos vd., 2020). Endüstri metriklerinin standardizasyonu ve ölçüm rejimlerinin olgunlaşması, reklam pazarında şeffaflık beklentisini güçlendirmekte ve daha büyük bütçelerin sektöre yönelmesini kolaylaştırmaktadır (Sullivan vd., 2020). Bununla birlikte erken dönemden beri tartışılan telif, sorumluluk ve iş modeli belirsizlikleri tamamen ortadan kalkmamış, platform merkezli yapının güçlenmesiyle birlikte veri yönetimi ve dağıtım kontrolü gibi yeni pazarlık alanları oluşmuştur (Crofts vd., 2005; Sullivan, 2019). Kamu ve özel radyo kuruluşlarının podcast’e yönelmesi, mevcut yayıncılık kurumlarını yeni dağıtım mantığına uyarlamakta ve yatay-dikey kitle genişlemesi hedefleriyle daha sistematik stratejiler üretmektedir (Prigent, 2025). Önümüzdeki evrede, yapay zekâ destekli üretim ve keşif sistemleri ile video ve transmedya biçimlerinin yaygınlaşması hızlanmakta, fakat bu dönüşümün pazarlara göre farklı yoğunluklarda gerçekleşmesi beklenmektedir (Bulakh & Kulykova, 2025; Sullivan, 2024).

TÜRKİYE’DE PODCASTİN GELİŞİMİ VE GÜNÜMÜZDEKİ DURUMU

Küresel ölçekte medya ekonomisinin en dinamik dikeylerinden biri haline gelen podcast pazarı, Türkiye’de de kendine has kültürel kodlar, teknolojik altyapı ve ekonomik değişkenlerle şekillenen özgün bir büyüme yörüngesine oturmuştur. Marketing Türkiye platformunun verilerine göre 2023 yılı itibarıyla 2,37 milyar ABD doları büyüklüğe ulaşan küresel podcast reklam platformu pazarının, 2024-2030 yılları arasında %28.4’lük bir bileşik yıllık büyüme oranıyla (CAGR) genişleyerek 2030 yılında 7.13 milyar dolarlık bir hacme ulaşması

öngörülmektedir (Alimoğlu, 2024). Bu artışta şüphesiz artan dinleyici kitlesinin rolü büyüktür. 2024 verilerine göre Türkiye’de podcast dinleyici sayısında bir önceki yıla kıyasla %26’lık bir artış kaydedilmiş, toplam dinleme süreleri ise %15 oranında yükselmiştir (Alimoğlu, 2024). Dolayısıyla tüm dünyada olduğu gibi Türkiye özelinde de podcastin artık bir “erken benimseyenler” hobisi olmaktan çıkıp, ana akım medyanın bir bileşeni haline geldiğini söylemek mümkündür.

Türkiye’de podcastin bir format olarak benimsenmesi, Batı ülkelerindeki teknolojik yayılım sürecinden farklı olarak, toplumun halihazırda var olan güçlü “işitsel hafızası” üzerine inşa edilmiştir. Türkiye Radyo Televizyon Kurumu’nun (TRT) on yıllar boyunca sürdürdüğü “Radyo Tiyatrosu” ve “Arkası Yarın” kuşakları, Türk dinleyicisinin sesi sadece bir arka plan gürültüsü olarak değil, bir “öyküleme” (storytelling) aracı olarak kodlamasını sağlamıştır (Sancar, 2024). Bu da Türk dinleyicisinde podcast’in benimsenmesinin kolaylaştırmıştır.

Podcast kavramı küresel olarak ortaya çıktıktan kısa bir süre sonra Türkiye’de de yankı bulmaya başlamıştır. 2004 yılı şubat ayında dünyada ilk kez bahsi geçen kavram, aynı yılın ekim ayında teknoloji yazarı Serdar Kuzuloğlu tarafından Radikal gazetesindeki köşe yazısında ilk defa anılmıştır (Kuzuloğlu, 2004). Türkiye’de literatürde kayda geçen ilk podcast yayını ise yine aynı isim tarafından radyoda yapılan “Sanal Alem” isimli radyo programının 2005 yılında dijital ortamda podcast formatında yayınlanmasıyla gerçekleşmiştir. Ancak bu erken denemeye rağmen 2000’lerin sonunda podcastler ülke genelinde yaygın bir mecraya dönüşmemiş ve sadece sınırlı sayıda meraklı deneme olarak kalmıştır.

2010’lu yılların başı, Türkiye’de podcast yayıncılığının kitlesel ölçekte filizlenmeye başladığı dönem oldu. 2011 yılında, yıllarca geleneksel medyada çalışmış deneyimli spor yorumcusu Kaan Kural, NBA’deki lokavt döneminde Orkun Çolakoğlu ile Türkiye’nin ilk geniş kitleli podcast serilerinden *Potacast*’i başlatmış (Saygın, 2025), yine 2011’de kurulan teknoloji portalı *TeknoSeyir*, haftalık teknoloji gündemi değerlendirmelerini her Cuma podcast olarak paylaşmaya başlamıştır. Bu iki seri, Türkiye’de podcast formatının ilk sürekli ve tanınan örnekleri olarak kabul edilmektedir.

2010’ların ortalarında, podcast ekosistemi yavaş da olsa büyümeyi sürdürmüştür. 2016 yılında radyoda başlayan mizahi sohbet programı “*O Tarz Mı?*” kısa süre içinde podcast mecrasına geçiş yapmış ve özellikle 18-27 yaş arası gençler arasında podcast farkındalığını önemli ölçüde artırmıştır (Kaynar, 2021). Bu dönemde podcast yayıncılarının sayısı artmaya başlarken, aynı zamanda podcast toplulukları oluşmaya ve sektörel etkinlikler düzenlenmeye başlamıştır. Mayıs 2019’da Kadir Has Üniversitesi’nde Friedrich Ebert Stiftung desteğiyle Türkiye’nin ilk Podcast Zirvesi 2019 gerçekleştirilerek 40’tan fazla podcast yapımcısı bir araya gelmiştir ki bu etkinlik, podcastlerin artan popülerliğinin ve sektörel iletişimin gelişmeye başladığının bir göstergesi olmuştur (Medyapod, 2019).

Türkiye’de podcastin modern anlamda bir RSS beslemesi üzerinden dağıtılan, epizodik dijital ses dosyası olarak popülerleşmesi 2010’ların sonuna denk gelmektedir. Bu dönemin en belirleyici kırılma noktası, teknoloji yazarı ve trend analisti Serdar Kuzuloğlu’nun “Nasıl Olunur” serisidir. Kuzuloğlu’nun girişimi, Türkiye’de podcast formatını “niş teknoloji sohbetleri” alanından çıkarıp, geniş kitlelerin ilgisini çeken “entelektüel biyografi” formatına dönüştürmüştür. “Nasıl Olunur”, sadece dinlenme sayılarıyla değil, aynı zamanda markalara bu mecra da yer almanın “prestijli” ve “güvenli” olduğunu göstermesi bakımından da sektörün kurucu metni sayılabilir. Zira Kuzuloğlu’nun podcast yayını sırasında arka planda bölüm sponsoru bir beyaz eşya firmasına ait çamaşır makinesinin ekstra sessiz modda çalışması, markaları podcast yayınlarına sponsor olmak konusunda cesaretlendirmiştir (Ernek Alan vd., 2025).

Kuzuloğlu’nun ardından, özellikle 2019-2020 yıllarında pandemi sürecinin getirdiği eve kapanma dönemleri, Türkiye’de podcast üretimi ve tüketiminde patlama etkisi yaratmıştır. İnsanların ekran yorgunluğu yaşaması, gözlerini dinlendirirken zihinlerini besleyebilecekleri sesli içeriklere yönelmelerine neden olmuştur. Ipsos ve Podbee Media’nın yürüttüğü çalışmaya göre podcast bilinirliği ülke genelinde %11 düzeyinde kalmakla birlikte, 45 yaş altı bireylerde %16’ya ve İstanbul’da %19’a ulaşmaktadır. Aktif dinleyici sayısı ise yaklaşık 650 bin kişidir. Bununla birlikte, 2020 yılında cihaz başına podcast indirme oranında 5,2 katlık artışla Türkiye dünya çapında en hızlı büyüyen pazar konumuna gelmiş, Türkçe podcast sayısı aynı dönemde 3,5 kat artmıştır. 2025 itibarıyla 20 binden fazla Türkçe podcast kanalı ve 400 binden fazla bölüm üretilmiş olup, bu durum Türkiye’yi küresel ölçekte en çok içerik üretilen 15. dil arasına taşımıştır. Dinleyicilerin motivasyonları arasında öğrenme (%43) ve eğlenme (%41) öne çıkarken, vakitsizlik (%35) dinlememe nedenlerinin başında gelmektedir (IPSOS, 2025).

TÜRKİYE'DE PODCAST DİNLEME ALIŞKANLIKLARINA YÖNELİK YAPILAN ARAŞTIRMALAR

Türkiye’de podcast dinleyicilerinin demografik profilleri ve içerik tüketim alışkanlıkları üzerine yapılan araştırmalarda, dinleyici kitlesinin belirgin sosyo-ekonomik ve kültürel özellikler etrafında şekillendiği görülmektedir. Bu kapsamda elde edilen bulgular, Türkiye’deki podcast dinleyicilerinin ağırlıklı olarak orta ve üst sosyo-ekonomik sınıfa mensup, eğitim seviyesi yüksek ve genç bireylerden oluştuğu, dinleyicilerin eğitim seviyeleri yükseldikçe podcast dinleme motivasyonlarının sadece zaman geçirme veya eğlence arayışından sıyrılarak kişisel ve sosyal kimlik inşasına, arkadaşlık kurma arzusuna ve entelektüel tatmine doğru evrildiği gözlemlenmektedir (Çil, 2023). Aynı çalışmada cinsiyet değişkeni de tüketim motivasyonları üzerinde ayırt edici bir rol oynadığı tespit edilmiştir. Erkek dinleyicilerin kadınlara kıyasla daha yüksek bir tüketim motivasyonu sergilediği saptanmıştır. Genç dinleyiciler ise işitsel platformların sunduğu teknik avantajlara ve kullanım kolaylığına öncelik vermektedir. Bu demografik yapı, podcast mecrasının Türkiye’de belirli bir entelektüel sermayeye sahip kitle tarafından, geleneksel medyada bulunamayan niş içeriklere erişim aracı olarak konumlandırıldığını göstermektedir.

Dinleyicilerin içerik tercihleri ve tüketim motivasyonları incelendiğinde, bilgilendirici ve öğretici niteliğe sahip yayınların ön plana çıktığı görülmektedir. Kullanıcılar, toplum, kültür, bilim, sanat ve eğitim gibi konularda derinlemesine bilgi sunan içerikleri ana akım medyaya alternatif bir bilgi kaynağı olarak değerlendirmektedir (Kurt, 2023). Dinleyiciler bu içerikleri genellikle ev ortamında ve akıllı telefonları aracılığıyla tüketmekte, dinleme eylemini ise sıklıkla başka işlerle meşgul oldukları esnada, yani çoklu görev (multitasking) bağlamında gerçekleştirmektedir (Çil, 2023). Dolayısıyla, içeriğin niteliği kadar, bu içeriğin gündelik yaşamın akışı içine entegre edilebilir olması da tercihleri şekillendiren temel unsurlardan biridir.

Teknolojik kabul ve platform erişilebilirliği, Türkiye’deki podcast dinleyicilerinin davranış kalıplarını belirleyen bir diğer kritik faktördür. Podcast formatının Türkiye pazarındaki yayılımı, içeriğin benzersizliğinden ziyade, algılanan kullanım kolaylığı ve istenilen içeriğe zaman ve mekân kısıtlaması olmaksızın erişebilme imkânı ile doğrudan ilişkilidir (Özel, 2022). Spotify’nın varlığı, Türkiye’de ilginin artmasında tetikleyici bir rol oynamıştır. Kullanıcılar, RSS tabanlı dağıtım sistemlerden ziyade halihazırda kullandıkları müzik platformları üzerinden podcastlere erişmeyi tercih etmektedir (Özel, 2022). Bu platformların sağladığı algılanan fayda, kullanıcıların dinleme motivasyonlarını ve tutumlarını olumlu yönde etkilemektedir. Erişim kolaylığı, dinleyicilerin yeni içerikleri keşfetme bariyerini düşürmekte ve podcast dinleme alışkanlığının daha geniş kitlelere yayılmasına zemin hazırlamaktadır.

Genç kitleler ve özellikle üniversite öğrencileri özelinde yapılan çalışmalarda dinleme tercihlerine dair mevcut durum ortaya konmaya çalışılmıştır. Akgün Akan (2024), iletişim fakültesi öğrencileri ile gerçekleştirdiği çalışmada, katılımcıların büyük çoğunluğunun süresi otuz dakikayı aşmayan hem bilgilendirici hem de eğlendirici hibrit formatları tercih ettiğini ortaya koymuştur. Bu kitle, uzun soluklu ve tekdüze anlatımlardan ziyade, dikkat sürelerine uygun, dinamik ve yoğunlaştırılmış içeriklere yönelmektedir. Reklam toleransı açısından bakıldığında ise dinleyicilerin, programın akışını bozmayan ve içerikle bağlamsal uyum içinde olan reklamları kabul edilebilir bulduğu saptanmıştır (Akgün Akan, 2024). Özellikle programın dikkat yoğunluğunun en yüksek olduğu orta bölümlerinde yer alan ve içerik ile bütünleşmiş reklamlar, dinleyiciler tarafından mecranın sürdürülebilirliği açısından önemli görülmektedir. Bu bulgular, genç demografik profilin, pasif birer tüketici olmaktan öte, medyanın ekonomik dinamiklerinin farkında olan bilinçli bir kitle olduğuna işaret etmektedir.

Demografik özellikler ve dinleme alışkanlıkları, dinleyicilerin yayıncılarla kurdukları psikolojik bağı ve parasosyal etkileşim düzeylerini de şekillendirmektedir. Podcast ortamının sunduğu samimi ve sohbet dayalı atmosfer, dinleyicilerin medya kişilikleriyle bir tür “arkadaşlık yanılsaması” geliştirmesine olanak tanımaktadır (Özkan Sev & Vural, 2024). Yapılan araştırmalar, yaş, cinsiyet ve dinleme sıklığı gibi değişkenlerin, bu parasosyal etkileşimin yoğunluğunu belirlediğini göstermektedir. Yayıncının üslubu, ses tonu ve tavrı, dinleyicinin içerikle kurduğu duygusal bağın niteliğini etkilemektedir. Dinleyiciler, kendilerine doğrudan hitap edildiğini hissettikleri ve konuşma dilinin hâkim olduğu yayınlarda, sunucu ile daha güçlü bir bağ kurmaktadır (Özkan Sev & Vural, 2024).

Türkiye’deki podcast yayıncılığı, geçmiş yıllarda net bir dinleyici profilinin olmaması ve farkındalık eksikliği gibi sorunlarla mücadele etmiş olsa da güncel veriler bu belirsizliğin giderek azaldığını göstermektedir. Geçmiş dönem çalışmalarında, podcast haberciliğinin ve yayıncılığının önündeki en büyük engellerden biri olarak tanımlanmış dinleyici kitlesinin belirsizliği (Budak, 2022), son yıllarda yapılan araştırmalarla daha öngörülebilir bir yapıya kavuşmuştur. Özellikle pandemi süreci ve sonrasında artan ilgi, dinleyici profilinin

netleşmesini ve üreticilerin hedef kitle beklentilerine daha uygun içerikler üretmesini sağlamıştır (Özkan Sev, 2024). Geline nokta, Türkiye’deki podcast dinleyicisi, ne istediğini bilen, teknolojik araçları etkin kullanan ve entelektüel beklentileri yüksek bir profil çizmektedir.

ARAŞTIRMANIN ÖNEMİ VE YÖNTEMİ

Bu çalışmada podcast yayıncılığının geleceği ve radyo mecrasına kıyasla gelecekteki konumu hakkında bir araştırma yapılmıştır. Araştırmada İstanbul’da yaşayan rassal seçilen 611 kişiye bir anket uygulanmıştır. Anket 01-31 Mart 2026 tarihleri arasında daha hızlı sonuçlar alınması için çevrim içi uygulanmıştır. Sosyal Bilimler alanında ve özellikle nicel araştırmalarda internet anketleri hızlı bir şekilde yaygınlaşmaktadır (Frippiat ve Marquis, 2010:54). Anket soruları hem açık hem kapalı cevap şıkları içerebilir. Kapalı uçlu sorular, cevap şıklarının anket formunda belirtildiği sorulardır. Bu tür bir soru şekli ile araştırmacı belirlenen cevaplar arasından bir tanesini katılımcının tercih etmesini beklemektedir (Kasuniç,2005:32). Açık uçlu sorular belirli soru şıklarının olmadığı, katılımcıların sorulara kendi verdikleri cevapları gerektiren sorulardır (Akalin, 2018:64). Bu araştırmada kullanılan ankette üç tane kapalı uçlu demografik soru, beş tane açık uçlu soru yer almıştır. Sorular anketi uygulayan kişilerin sıkılmaması ve anketin sonuna kadar gelebilmesi için araştırmanın temel sorularını içeren sayıda olmasına özellikle dikkat edilmiştir. Çalışmada elde edilen bulgular analiz edilerek tablolştırılmıştır. Araştırmada yanıtı aranan sorular şöyledir:

- Podcast Dinleme Oranı nedir?
- Gelecek beş yılda podcast yayıncılığı radyo yayıncılığından daha popüler olabilir mi?
- Gelecek on yılda podcast yayıncılığı radyo yayıncılığından daha popüler olabilir mi?
- Podcast yayıncılığında hangi gelir iş modelleri uygulanabilir?
- Podcast yayıncılığının avantajları nelerdir?
- Podcast yayıncılığının dezavantajları nelerdir?

BULGULAR

Araştırma da elde edilen bulgular ve analizleri aşağıdaki gibi olmuştur:

Tablo 1. Son Bir Yılda Podcast Dinleme Oranı

Son bir yılda herhangi bir Podcast yayını dinlediğiniz mi?		(n)	(%)
	Evet	541	88,54
	Hayır	70	11,46
	Toplam	611	100

Araştırmaya katılan katılımcıların yüzde 88,54’ü son bir yılda podcast dinlediğini belirtirken yüzde 11,46’sı podcast dinlemediğini belirtmiştir.

Tablo 2. Podcast Yayıncılığının Önümüzdeki Beş Yılda Popülerliği Hakkındaki Öngörüler

Sizce gelecek BEŞ yılda Podcast Yayıncılığı Radyo yayıncılığından daha popüler olabilir mi?		(n)	(%)
	Evet	527	86,36
	Hayır	84	13,64
	Toplam	611	100

Araştırmada katılımcıların podcast yayıncılığının gelecek beş ve on yıldaki konumu hakkında fikirlerini söylemeleri istenmiştir. Buna göre podcast yayıncılığının gelecek beş yılda popülerliğini arttıracak ve radyo yayıncılığının önüne geçeceğine inandıklarını söyleyen katılımcıların oranı yüzde 86,36 iken gelecek on yılda podcast yayıncılığının radyo yayıncılığının önüne geçeceğini düşünenlerin oranı yüzde 100 olmuştur.

Tablo 3. Podcast Yayıncılığının Önümüzdeki On Yılda Popülerliği Hakkındaki Öngörüler

Sizce gelecek ON yılda Podcast Yayıncılığı Radyo yayıncılığından daha popüler olabilir mi?		(n)	(%)
	Evet	611	100
	Hayır	0	0
	Toplam	611	100

Araştırmada Podcast yayıncılığında kullanılabilecek gelir modelleri hakkındaki görüşler sorgulanmıştır. Buna göre podcast yayıncılığında kullanılabilecek gelir modelleri tablo 4’de gibi derlenmiştir.

Tablo 4. Podcast Yayıncılığında Kullanılabilecek Gelir Modelleri

Podcast yayıncıları sponsorluk, reklam, dinleyici bağışı ve abonelik sisteminden gelir modeli geliştirebilirler.
Patreon platformunun yaptığı gibi kullanıcılardan direkt bağış alarak gelir elde edebilirler
Radyo ve TV mecralarına göre direkt olarak reklam verenin hizmet ve ürünlerini kendi anlattıkları bireysel reklamlardan gelir elde edilebilir
YouTube ve Instagram’da hesapları olanların yaptığı gibi belirli içeriklere özel erişim sağlayacak özel / bireysel üyelik modeliyle gelir elde edilebilir
Etkinlikler düzenleyerek çeşitli organizasyonlar düzenleyerek gelir elde edilebilir
T-shirt, kitap ve benzeri kişileştirilmiş marka adlarının yer aldığı ürün satışı ile gelir elde edilebilir.
Spotify, Apple Music gibi abonelik modelleriyle gelir elde edilebilir

Araştırmada katılımcılara Podcast yayıncılığının geleneksel medyaya göre olan avantajları ve dezavantajları sorulmuş ve en çok tekrarlanan yargılar (n>50) tablo 5 ve tablo 6'da derlenmiştir.

Tablo 5. Podcast Yayıncılığının Diğer Medyalara Göre Avantajları

Bir akıllı telefonu ve internet bağlantısı olan herkes dinleyebilir bu nedenle kolay ulaşılabilir bir mecra
Podcastin en büyük avantajı ulaşılabilirlik. Yürüyerek, spor yaparak her konum ve şartta dinlenebilmektedir.
Küresel ölçekte dinleyicilere ulaşılabilir
Özgür ve sansüresiz bir içerik üretim fırsatı vermektedir
Zamansız bir formattır. Dinleyici dilediği zaman podcast yayınlarına erişebilir.
Dinlemesi kolay ve düşük maliyetli veya maliyetsizdir
Konu çeşitliliği vardır. Aranana hemen hemen her konuda bir podcast içeriği bulunabilir.
Eğitim kurumları tarafından eğitim amaçlı kullanılabilir.
Eğitim, pazarlama, tanıtım gibi alanlarda bir reklam mecrası olarak kullanılabilir.
Üretilmesi ve dağıtımı diğer mecralara göre daha hızlı ve pratiktir.
Konu çeşitliliğinden dolayı entelektüel bir mecra özelliği de taşımaktadır.
Belirli meslek grubu veya belirli düşüncelere sahip kişilerin ortak bir paydada buluşmasına katkıda bulunabilir. Niş bir ürün özelliği taşımaktadır.
Radyo ve TV mecraları gibi belirli gün ve saatlerde bir içerik üretme veya dinleme zorunluluğunu yoktur. Podcast yayıncılığı özgür bir yayıncılıktır.

Tablo 6. Podcast Yayıncılığının Diğer Medyalara Göre Dezavantajları

Geleneksel medyanın aksine podcast yayıncılığında da dezenformasyon yaşanabilir
Podcast yayıncılığı kalabalık bir piyasa olduğu için fark edilmek zor olabilir
Görsellik içermemesi
Sürekli içerik üretimi zorluk yaratabilir. Süreklilik bir podcast yayını için önemlidir.
Dinleyici ile limitli etkileşim kurulamaktadır
İçerik üretirken Müzik ve diğer dış seslerin kullanımından kaynaklanan telif sorunları yaşanabilir.
Sadık bir dinleyici kitlesi yakalamak sosyal medyaya göre daha fazla zaman alabilir.
İçerik üreticisi için podcast yayınlarının tanıtılması için dijital pazarlama bilgisine ihtiyaç duyulabilir.
Podcast yayıncılığı her geçen gün artmaktadır buda pazarda olan podcastlerin sayısını arttırmaktadır. Bu durumda podcast yayıncılarının geniş kitlelere ulaşması zor olacaktır.

İçerik üreticileri için podcastin üretiminde teknik alt yapı bilgisi gerektirebilir. Kayıt-kurgu vb. gibi bilgilere sahip olmayanlar için pazara giriş zor olabilir.

Uzun süren ses içeriği dinleyicide konsantrasyon kaybı yaşatabilir.

SONUÇ

Podcast yayıncılığının 2000'li yılların başından günümüze kadar geçirdiği evrim, bir medya formatının teknolojik altyapı, platform dinamikleri, üretim pratikleri ve dinleyici davranışlarının karmaşık etkileşimi sonucunda nasıl dönüştüğünü gösteren çarpıcı bir örnek sunmaktadır. RSS teknolojisinin temellerini attığı bu format, iPod ve akıllı telefonların yaygınlaşmasıyla erişilebilir hale gelmiş, Spotify gibi büyük dijital müzik akış platformlarının ekosisteme dahil olmasıyla merkezi bir yapıya kavuşmuş ve profesyonel içerik üreticilerinin, geleneksel medya kuruluşlarının ve reklam endüstrisinin yatırımlarıyla ekonomik açıdan sürdürülebilir bir sektöre dönüşmüştür. Küresel ölçekte podcast pazarının 2030 yılına kadar 7 milyar doları aşması beklenen bir büyüklüğe ulaşacağı öngörüldürken, bu genişlemenin ardında sadece teknolojik kolaylıklar değil, aynı zamanda formatın sunduğu samimi anlatı dili, zaman ve mekan esnekliği, çoklu görev yapabilme imkanı ve niş içeriklere erişim fırsatı gibi kullanıcı merkezli avantajlar yatmaktadır.

Türkiye özelinde ise podcast, 2000'lerin ortalarında Serdar Kuzuloğlu gibi öncü isimlerin girişimleriyle tanınmaya başlamış, 2010'lu yılların sonunda “Nasıl Olunur?” gibi serilerle popülerlik kazanmış ve pandemi döneminde patlama yaşamıştır. Bu süreçte Türkiye, dünya genelinde en hızlı büyüyen podcast pazarı konumuna yükselmiş, 20 binden fazla Türkçe podcast kanalı ve 400 bini aşkın bölümle küresel dil sıralamasında 15. sıraya yerleşmiştir. Türk dinleyicilerinin demografik profili incelendiğinde ağırlıklı olarak genç, eğitilmiş, orta ve üst sosyo-ekonomik sınıflara mensup, bilgi edinme ve entelektüel tatmin arayışında olan, teknolojik araçları etkin kullanan ve içerikleri çoklu görev yapma bağlamında tüketen bir kitle ortaya çıkmaktadır. Bu kitle, ana akım medyaya alternatif, derinlemesine ve niş bilgi kaynaklarına yönelirken, aynı zamanda platformların sunduğu kullanım kolaylığını ve erişilebilirliği temel tercih faktörleri olarak benimsemektedir. Dinleyicilerin özellikle otuz dakikayı aşmayan hem bilgilendirici hem eğlendirici hibrit formatları tercih etmeleri, reklam konusunda içerikle bütünleşmiş ve bağlamsal uyum içindeki sponsorluklara tolerans göstermeleri ve podcast yayıncılarıyla parasosyal bağlar kurmaları, formatın gelecekteki gelişimini şekillendirecek önemli davranışsal eğilimler olarak değerlendirilmektedir.

Yapılan bu araştırmada da katılımcılar podcast yayıncılığının Türkiye’de geleceğini parlak görmektedir. Bunun en büyük nedeni ise dijitalleşmede yaşanan artış ve dijital dönüşümün tüm medyayı etkilemesi olarak açıklanmıştır. Dijital tabanlı bir mecra olan podcast dijitalleşmenin tüm avantajlarını da barındırmaktadır. Araştırmada podcast yayıncılığının popülerliğini arttıracak ve radyo mecrasının önüne geçeceğine dair görüşler yüzde 86 ‘dır. Bu oran gelecek on yıl ile ilgili görüşlerde yüzde 100’e çıkmaktadır. Araştırmaya katılanların tamamı podcast yayıncılığının gelecek on yıl içinde radyo yayıncılığından daha popüler olacağına inanmaktadır.

Araştırmada podcast yayıncılığının avantaj ve dezavantajları da irdelenmiştir. Podcast yayıncılığının avantajlarını dile getiren katılımcılar mecranın bir akıllı telefon ve internet sayesinde tüm dünyadan dinlenebileceğine vurgu yaparak podcast yayıncılığının küresel erişimine ve pratikliğine değinmiştir. Podcast yayıncılığında geleneksel medyaya göre daha fazla konunun işlenebildiğini ve konu çeşitliliğinin büyük bir renk olduğunu belirten katılımcılar ayrıca podcast içeriklerinde bir sansürün olmamasının da özgür yayıncılık adına bir avantaj olduğunu dile getirmişlerdir. Araştırmada Podcast yayıncılığının sadece bireysel içerik üretmek isteyenler için değil kurumsal içeriklerde ve reklam & tanıtım içeriklerinde de özel bir mecra olduğuna vurgu yapılmıştır.

Podcast yayıncılığının avantajları olduğu gibi dezavantajları da bulunmaktadır. Bu dezavantajlar arasında en çok diğer dijital medya mecraları gibi podcast yayıncılığında da dezenformasyon olabileceği konusu ön plana gelmiştir. Podcast yayıncılığının bir diğer büyük avantajı sadece işitsel bir mecra olması ve görsellik içermemesidir. Yaşanabilecek üçüncü dezavantaj ise telif sorunlarıdır. Podcast içeriklerinde kullanılabilecek müzik ve diğer üçüncü şahıslara ait içeriklerden dolayı telif ihlalleri yaşanabilir.

Bugün geldiğimiz noktada her ne kadar birtakım dezavantajları olsa da daha çok sayıda avantaja sahip olması ve dijital medyanın tüm olanaklarını barındırması nedeniyle podcast yayıncılığı hem küresel hem yerel ölçekte sürekli genişleyen, çeşitlenen ve kurumsallaşan bir medya ekosistemi olarak geleneksel radyonun sınırlarını

aşmaya devam etmektedir. Tüm bunların sonucunda Podcast yayıncılığı topluluk temelli üretim ve niş içerik yaratımını başka bir boyuta ulaştırarak büyümesini sürdürmekte ve geleceğin en popüler dijital medya mecralarından biri olacağını göstermektedir.

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DEVELOPING A MULTIDIMENSIONAL RESEARCH COMPETENCE FRAMEWORK FOR UNDERGRADUATE STUDENTS

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ABSTRACT

Research competence has become a central outcome of higher education, contributing to students' critical thinking, problem-solving, and lifelong learning capacities. However, its conceptualization remains fragmented, as existing studies often emphasize isolated research skills rather than providing an integrated and theoretically grounded framework. This limitation constrains the ability of higher education institutions to design coherent curricula and develop systematic approaches to competence assessment, particularly in emerging contexts.

This study aims to develop a multidimensional research competence framework for undergraduate students. The framework is constructed through a qualitative synthesis of recent literature and theoretical perspectives, combined with contextual analysis of higher education practices.

The proposed framework conceptualizes research competence as a structured system of eight interrelated dimensions, including research cognition, research methodology, data analysis, academic communication, research ethics, collaboration, research management, and research technology. These dimensions integrate cognitive, methodological, behavioral, and technological aspects of research competence, providing a more comprehensive representation than existing skill-based models. Each dimension is further operationalized through observable indicators, enabling its application in competence assessment and curriculum design.

The study contributes to the literature by proposing an integrated and theoretically grounded framework that addresses the fragmentation of prior approaches. It also offers a practical model to support curriculum development, student assessment, and research-oriented learning in higher education, while establishing a foundation for future empirical validation and multi-source competence measurement.

Keywords: Competency framework; Higher education; Research competence; Research skills; Undergraduate students.

INTRODUCTION

Research competence has become a key outcome of higher education in the 21st century, as universities increasingly emphasize the development of students' critical thinking, problem-solving abilities, and capacity for independent inquiry. It plays a fundamental role in enabling students to engage in knowledge creation, contribute to academic discourse, and adapt to rapidly changing professional environments (Vlachopoulos, 2024; Zamir et al., 2025).

Research competence is generally understood as a multidimensional construct that encompasses knowledge, skills, attitudes, and behaviors required to conduct research effectively. It includes the ability to formulate research questions, apply appropriate methodologies, analyze and interpret data, and communicate findings in academic contexts. In addition, it involves ethical awareness, collaboration, and research management capabilities, which are increasingly recognized as essential components of research performance (Bearman et al., 2022).

Despite its recognized importance, the conceptualization of research competence remains fragmented in the existing literature. Many studies tend to focus on specific research skills, such as data analysis or academic writing, without providing a comprehensive framework that captures the complexity and interrelated nature of

research competence. This fragmentation limits the ability of higher education institutions to design coherent curricula and implement systematic approaches to competence development and assessment.

Recent research in higher education has highlighted the need for integrated and multidimensional frameworks that can better represent complex competencies. In particular, competence-based education requires structured models that define key dimensions and provide measurable indicators for teaching and assessment (Vlachopoulos, 2024). However, there remains a lack of theoretically grounded frameworks that comprehensively conceptualize research competence, especially at the undergraduate level.

This gap is particularly evident in emerging higher education contexts, where research training is still developing and often lacks systematic frameworks. Without a clear and integrated model, it becomes difficult to align curriculum design, teaching strategies, and assessment practices to effectively support the development of research competence.

In response to these challenges, this study aims to develop a multidimensional research competence framework for undergraduate students. The framework is constructed through a qualitative synthesis of recent literature and theoretical perspectives, combined with contextual analysis of higher education practices. It conceptualizes research competence as a structured system of interrelated dimensions, integrating cognitive, methodological, behavioral, and organizational aspects.

Specifically, this study addresses the following research questions:

- (1) What are the core dimensions of research competence for undergraduate students?
- (2) How can these dimensions be structured into a coherent and integrated framework?
- (3) How can the framework be operationalized for competence development and assessment in higher education?

The study contributes to the literature by proposing an integrated and theoretically grounded framework that addresses the fragmentation of existing approaches. It also provides a practical foundation for curriculum development, student assessment, and research-oriented learning in higher education.

METHODOLOGY

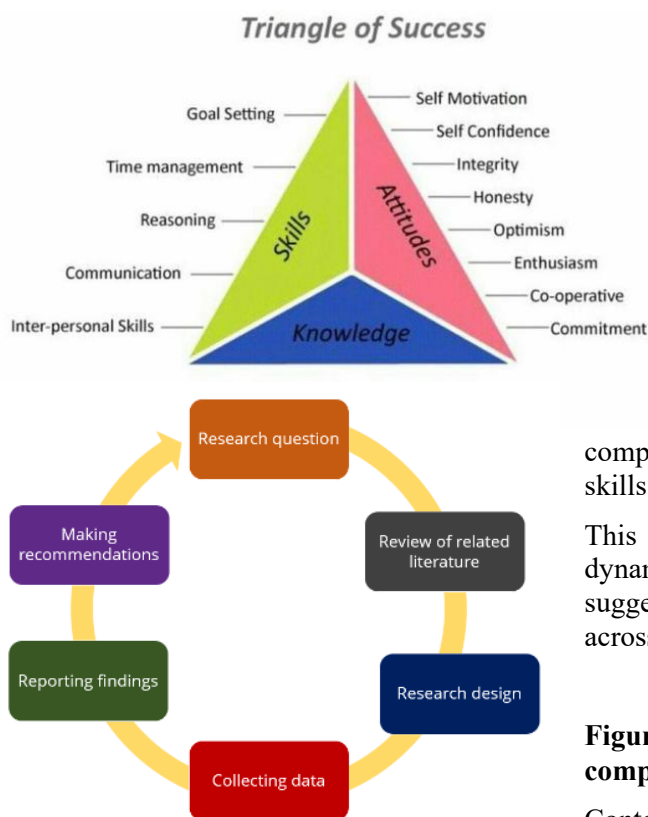
A qualitative approach was employed to develop a multidimensional research competence framework for undergraduate students. The framework was constructed through a systematic synthesis of recent literature combined with contextual analysis of higher education practices.

The literature was analyzed using a thematic approach to identify recurring concepts and key dimensions of research competence. Similar constructs were compared and grouped into broader categories, reflecting the cognitive, methodological, behavioral, and technological aspects of research competence.

Based on this synthesis, a multidimensional framework was developed by organizing the identified components into interrelated dimensions. Each dimension was conceptually defined and supported by representative indicators to ensure theoretical coherence and practical applicability in higher education contexts.

LITERATURE REVIEW

Research competence is commonly conceptualised as a multidimensional construct integrating knowledge, skills, and attitudes. This perspective, widely adopted in competency-based education, emphasises that effective performance requires not only cognitive understanding but also behavioural and affective components (Mulder, 2017; Le Deist & Winterton, 2005; OECD, 2018).



Such models (Figure 1) provide a foundational structure for operationalising research competence into measurable dimensions, supporting both assessment and curriculum design in higher education.

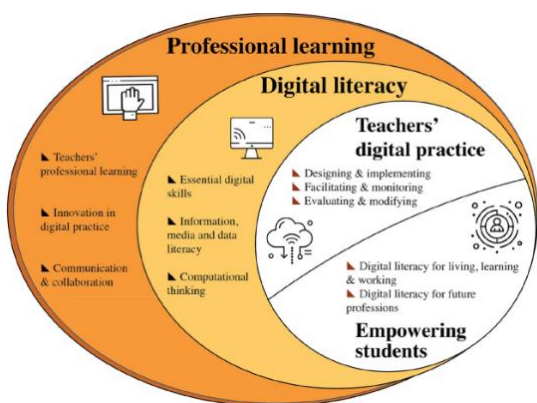
Figure 8. Multidimensional model of competence (knowledge–skills–attitudes)

Research competence can also be understood through the lens of the research process, which includes stages such as problem identification, research design, data collection, analysis, and dissemination. Each stage requires specific competencies, including critical thinking, methodological skills, and communication abilities (Weng & Chiu, 2024).

This process-oriented model (Figure 2) highlights the dynamic and iterative nature of research competence, suggesting that competencies are developed and applied across different stages of the research cycle.

Figure 9. Research process model of research competence

Contemporary research further emphasises the integration of cognitive, social, and technological competencies in higher education. Integrated competence frameworks highlight that research competence involves not only individual capabilities but also collaboration, digital literacy, and engagement with broader academic and societal contexts (Vlachopoulos, 2024; Bearman et al., 2022).



As shown in Figure 3, these models reflect the evolving nature of research competence in the digital age, where interdisciplinary collaboration and knowledge dissemination play increasingly important roles.

Figure 10. Integrated framework of research competence in higher education

Drawing on these theoretical models, research competence can be understood as a multidimensional and process-oriented construct that integrates knowledge, skills, and behavioural attributes across different stages of the research process.

While existing models provide valuable insights, they often lack a structured framework tailored to undergraduate students.

Therefore, we have developed an eight-dimensional research competence framework that synthesises prior theoretical perspectives and adapts them to the context of higher education, ensuring both theoretical coherence and practical applicability.

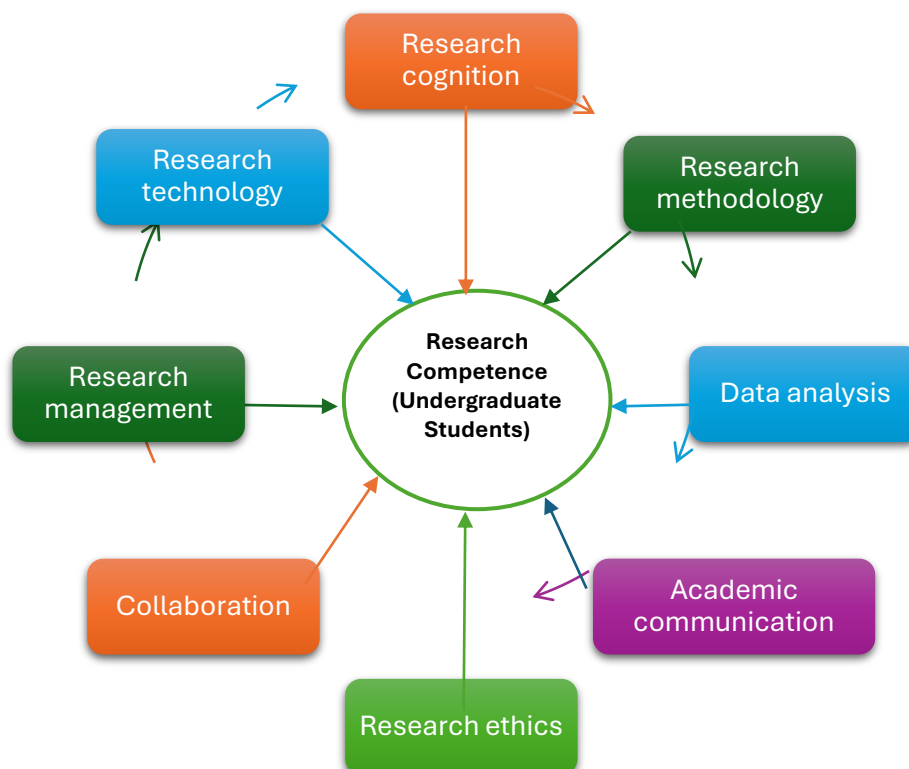
RESULTS

The qualitative synthesis of the literature revealed that research competence cannot be understood as a single skill or a narrow methodological ability. Instead, it emerged as a multidimensional construct formed by several recurring and interconnected domains consistently emphasized across previous studies. Through thematic

analysis, the reviewed literature showed that undergraduate research competence includes not only technical knowledge of research methods, but also cognitive, communicative, ethical, managerial, collaborative, and technological capacities.

Figure 11. A multidimensional research competence framework for undergraduate students

Figure 4 illustrates the proposed multidimensional research competence framework, which consists of eight interrelated dimensions: research cognition, research methodology, data analysis, academic communication,



research ethics, collaboration, research management, and research technology.

The circular structure of the model reflects the interconnected and dynamic relationships among the dimensions, suggesting that research competence is developed through the integration of cognitive, methodological, behavioural, and technological aspects.

Rather than functioning independently, these dimensions interact continuously to support effective research performance in higher education contexts.

The analysis resulted in the identification of eight major dimensions of research competence. These dimensions were derived from recurring concepts in the literature and then organized into a coherent framework. Although each dimension represents a distinct aspect of competence, they are closely interrelated and together form a comprehensive structure for understanding research competence in higher education.

Research cognition

The first recurring theme identified in the literature relates to the cognitive foundation of research. Many studies emphasize that research competence begins with the ability to understand the nature and purpose of research, identify problems, raise questions, and think critically about knowledge and evidence. This dimension was categorized as research cognition because it reflects the intellectual and conceptual basis that enables students to approach research in a meaningful and analytical way. Without this cognitive foundation, research activities may become mechanical rather than inquiry-driven.

Research methodology

A second prominent theme concerns methodological competence. The reviewed studies consistently highlight the importance of understanding research designs, selecting appropriate methods, constructing research procedures, and ensuring rigor in data collection. These elements were grouped into the dimension of research methodology, which represents students' ability to apply appropriate research approaches and procedures. This

dimension forms the procedural core of the framework, as it translates research ideas into feasible and systematic investigation.

Data analysis

Another major theme emerging from the literature is the ability to work with data. Across studies, competence in data analysis is represented through activities such as organizing data, applying analytical techniques, interpreting findings, and drawing evidence-based conclusions. This theme was identified as a separate dimension because it goes beyond methodological planning and relates specifically to how evidence is processed and transformed into knowledge. Therefore, data analysis was established as an independent dimension within the framework.

Academic communication

The literature also repeatedly points to the importance of communicating research outcomes effectively. This includes academic writing, oral presentation, argumentation, citation practices, and the ability to report research in ways that are clear, logical, and academically appropriate. These recurring indicators were synthesized into the dimension of academic communication. The emergence of this dimension suggests that research competence is not limited to conducting research, but also includes the ability to disseminate findings and participate in scholarly dialogue.

Research ethics

Ethical issues appeared as a consistent and indispensable theme in the reviewed studies. The literature emphasizes academic honesty, avoidance of plagiarism, respect for participants, informed consent, confidentiality, and responsible use of data. These elements were grouped into the dimension of research ethics, reflecting the understanding that competent research practice must be guided by ethical principles. This dimension is especially important because it ensures the credibility, responsibility, and social legitimacy of research activities.

Collaboration

A further theme identified in the synthesis concerns the social nature of research. Research is increasingly conducted through teamwork, peer interaction, and interdisciplinary cooperation. The literature highlights the value of sharing responsibilities, exchanging ideas, providing feedback, and working productively with others. These indicators were combined into the dimension of collaboration. Its inclusion in the framework reflects the recognition that research competence in higher education should not be viewed solely as an individual ability, but also as a capacity developed and exercised in collaborative environments.

Research management

The analysis also revealed a set of indicators related to the organization and regulation of research activities. These include planning tasks, managing time, monitoring progress, using resources efficiently, and completing research according to schedule. Such elements were synthesized into the dimension of research management. This dimension demonstrates that competence in research is not only about knowledge and analysis, but also about the ability to manage the research process effectively from beginning to end.

Research technology

The final recurring theme concerns the role of digital tools and technologies in contemporary research practice. The literature increasingly highlights the use of software for data analysis, reference management tools, digital search platforms, and online environments for collaboration and dissemination. These elements were grouped into the dimension of research technology. Its emergence as a distinct dimension reflects the growing importance of technological literacy in supporting efficient, accurate, and up-to-date research practice in higher education.

Integrated structure of the framework

Taken together, the eight dimensions indicate that research competence is a holistic and integrated construct. Research cognition, research methodology, and data analysis represent the intellectual and technical core of the research process. Academic communication and research ethics ensure that research is reported responsibly and in accordance with academic standards. Collaboration and research management reflect the interpersonal and organizational capacities needed to sustain research activity, while research technology supports the effective use of digital tools throughout the process.

The relationship among these dimensions suggests that undergraduate research competence should be understood as an interconnected system rather than a collection of isolated skills. The framework therefore provides a more comprehensive representation of research competence and offers a foundation for developing assessment indicators, curriculum design, and research-oriented learning activities in higher education.

DISCUSSION

The findings of this study contribute to the growing body of research on research competence by providing a comprehensive and integrated framework that addresses the fragmentation identified in previous studies. While earlier research has conceptualised competence as a combination of knowledge, skills, and attitudes (Mulder, 2017; Le Deist & Winterton, 2005), and has highlighted the importance of structured competency models in higher education (OECD, 2018), these approaches often lack a detailed representation of how research competence is organised into interrelated dimensions.

The proposed eight-dimensional framework extends prior conceptualisations by integrating cognitive, methodological, behavioural, and technological aspects into a unified structure. In particular, the identification of research cognition, research methodology, and data analysis as core dimensions aligns with process-oriented models of research competence, which emphasise the sequential and analytical nature of research activities (Weng & Chiu, 2024). However, this study goes beyond process-based approaches by incorporating additional dimensions such as academic communication and research ethics, which ensure the quality and integrity of research outcomes.

Furthermore, the inclusion of collaboration and research management highlights the social and organisational dimensions of research competence, which have been increasingly recognised in recent higher education research (Bearman et al., 2022). These dimensions reflect the reality that research is not only an individual cognitive activity but also a collaborative and managed process that requires coordination, communication, and responsibility.

Another important contribution of this study is the integration of research technology as a distinct dimension. In contrast to traditional frameworks, which often treat technology as a supporting tool, this study conceptualises technological competence as an essential component that underpins all stages of the research process. This perspective is consistent with recent trends in higher education, where digital tools and platforms play a central role in data analysis, knowledge dissemination, and academic collaboration (Vlachopoulos, 2024).

Overall, the proposed framework provides a more holistic representation of research competence by demonstrating that its dimensions are not isolated but interconnected. This finding reinforces the view that competence development requires the integration of multiple capabilities rather than the acquisition of discrete skills.

Implications for higher education

The findings of this study have several important implications for higher education. First, the framework provides a structured basis for curriculum design, enabling educators to systematically integrate research competence into teaching and learning activities. By clearly identifying key dimensions, institutions can develop targeted learning outcomes and align them with appropriate teaching strategies and assessment methods.

Second, the framework supports the development of assessment tools for measuring research competence. The identification of distinct yet interconnected dimensions allows for the creation of multidimensional assessment instruments, which can capture the complexity of students' research capabilities more effectively than traditional single-skill assessments.

Third, the framework can contribute to enhancing research-oriented learning environments by promoting active learning, collaboration, and the use of digital technologies. This is particularly relevant in emerging higher education contexts, where the development of research competence remains a key challenge.

Limitations and future research

Despite its contributions, this study has several limitations. First, the framework is developed based on qualitative synthesis of existing literature and has not yet been empirically validated. Future studies should apply quantitative methods, such as exploratory and confirmatory factor analysis, to test the validity and reliability of the proposed dimensions.

Second, the study focuses on undergraduate students in general higher education contexts and does not account for disciplinary differences. Research competence may vary across fields, and future research should examine how the framework can be adapted to specific disciplines.

Finally, further research is needed to develop measurement scales and practical tools for assessing research competence based on the proposed framework. This would enhance its applicability in educational practice and support evidence-based curriculum development.

CONCLUSION

This study developed a multidimensional research competence framework for undergraduate students by synthesising existing literature and theoretical perspectives in higher education. The proposed framework identifies eight interrelated dimensions, including research cognition, research methodology, data analysis, academic communication, research ethics, collaboration, research management, and research technology, providing a comprehensive and structured representation of research competence.

By addressing the fragmentation of prior studies, the framework contributes to both theory and practice. It offers a coherent model that can support curriculum design, competence assessment, and research-oriented learning in higher education. In addition, the study highlights the importance of integrating cognitive, methodological, behavioural, and technological aspects to develop students' research capabilities.

Future research should focus on empirically validating the proposed framework and developing measurement instruments to enhance its applicability across different educational contexts and disciplines.

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**COMMUNITY COMPOSITION AND GUILD STRUCTURE OF SPIDER ASSEMBLAGES IN
RELATION TO THE DRY DECIDUOUS FOREST OF BARMKELA, CHHATTISGARH, INDIA**

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ABSTRACT

The tropical, dry deciduous forests of Barmkela Tahsil support diverse natural ecosystems that contribute to spider species diversity and abundance. Spiders can be categorized into ecological guilds based on foraging behavior, including orb weavers, space web builders, sheet web builders, ambushers, ground runners, foliage runners, stalkers, and other hunters. The present investigation employs an interdisciplinary approach to comprehensively study spider diversity in conjunction with plant diversity. Established sampling protocols were implemented in selected sampling plots within Barmkela tahsil. This study documents the presence of 11 distinct families, 21 genera, and 29 species. The surveyed spider population consists of approximately 28% orb weavers, 24% ambushers, 20% foliage runners, 17 ground runners, and 10% other hunters. The high abundance of Araneae may be attributed to the heterogeneous vegetation within the forest, which offers ample space for web construction of varying sizes and provides refuge from predators. The dry deciduous forest, characterized by a shrub-rich understory, supports a greater number of Salticidae and Philodromidae. The moderate population of Thomisidae in this region is likely due to the presence of flowering plants and dense vegetation within the forest area.

Key words-Spider, Community composition, Guild structure, Barmkela forest.

This study aims to:

1. Develop a comprehensive checklist of spider species identified in the Barmkela forest.
2. Assess the guild structure and species composition within the Barmkela forest.

1. INTRODUCTION-

Spiders are recognized as one of the most diverse and abundant faunal groups within the animal kingdom. They play a critical role in maintaining ecological balance in ecosystems. Vegetation structure influences microclimates, thereby impacting invertebrate community composition. As of World Spider Catalogue (version 27 2026), 53,760 spider species belong to 139 families within 4,507 genera have been documented globally. In India, Caleb & Sankaran (2021) report 1,875 species belonging to 478 genera across 61 families. Spiders exhibit diverse population attributes, distribution patterns, and microhabitat preferences. They play a significant role in numerous ecosystems (Branco and Cardoso, 2020). Habitat-specific species are particularly vulnerable and can rapidly disappear even with minor habitat alterations (Argañaraz et al., 2020). The impact of habitat heterogeneity on spider density and diversity is evident in both natural and agroecosystems (Hore and Uniyal, 2008). Deshmukh (2018) conducted a study on the spider diversity of Salbardi Forest and Upper Wardha Dam in Amravati, India. Spiders were systematically surveyed in habitats including the forest floor, undergrowth, rocks, firewood piles, and beneath stones. This investigation documented 142 spider species, representing 62 genera within 21 families. The Araneidae family demonstrated the greatest species richness, with a total of 33 species identified.

Spider guilds are assemblages of spider species that utilize comparable resources or inhabit analogous ecological niches within a given habitat. The term "guild," as it is currently used, was formally defined in a study by Root (1967) on how birds use their environment. He described it as "a group of species that exploit the same class of environmental resources in a similar way." Root later applied this concept to the arthropod fauna of collards (Root 1973). Uetz (99) identified 8 guilds, a similar observation to Riechert & Lockley (1984), who also identified 8 guilds. Young & Edwards (1990) identified 5 guilds, while Nyffeler (1982) identified 3 guilds. Sumesh and Sudhikumar (2020) reported that spider guilds specific to microhabitats such as bark, foliage, and ground exhibited strong association levels, suggesting their potential to indicate changes in these microhabitats.

Several recent studies have investigated the variety of spider species (spider diversity) and how it relates to the structure of vegetation structure. Examples of this research include Cardoso et al. (2011), Štokmane and Spunġis (2016), Griotti et al. (2017), Dragan and Schuldt (2021), Dimitar and Gustavo (2021), Hu et al. (2022), Lia and Hindayana (2022), and Munevar et al. (2022).

3.MATERIAL AND METHODS:

3.1. Study area- Barmkela Forest situated on the periphery of the Sarangarh- Bilaigarh district in Chhattisgarh and bordering Odisha, lies between North Latitude 21° 33' 57.5316" N and East Longitude 83° 15' 54.7128" E. Encompassing a total area of 11,443 sq. km, Barmkela Forest possesses 421 km² of dry deciduous forest, characterized by significant biodiversity and a diverse array of flora and fauna.

3.2. Vegetations- Spiders were documented from various selected areas within the Barmkela forest. These areas encompassed riparian habitats, grasslands, dry deciduous forests, and mixed forests characterized by tall trees, shrubs, and bamboos. In the study area, a diverse array of plant and grass species contribute to the ecological richness. Notable plant species include *Phyllanthus emblica*, *Azadirachta indica*, *Terminalia chebula*, *Terminalia arjuna*, *Mangifera indica*, *Terminalia bellirica*, *Aloe vera*, *Carissa carandas*, *Ficus benghalensis*, *Ficus religiosa*, *Lawsonia inermis*, *Butea monosperma*, and *Vachellia nilotica*. Grasses are represented by *Saccharum spontaneum*, *Heteropogon* sp., *Vetiveria zizanioides*, *Cynodon* sp., and *Bambusa-Broom grass*. Surveys were also conducted for ground-dwelling spiders and those inhabiting decaying tree bark, debris, and rock crevices.

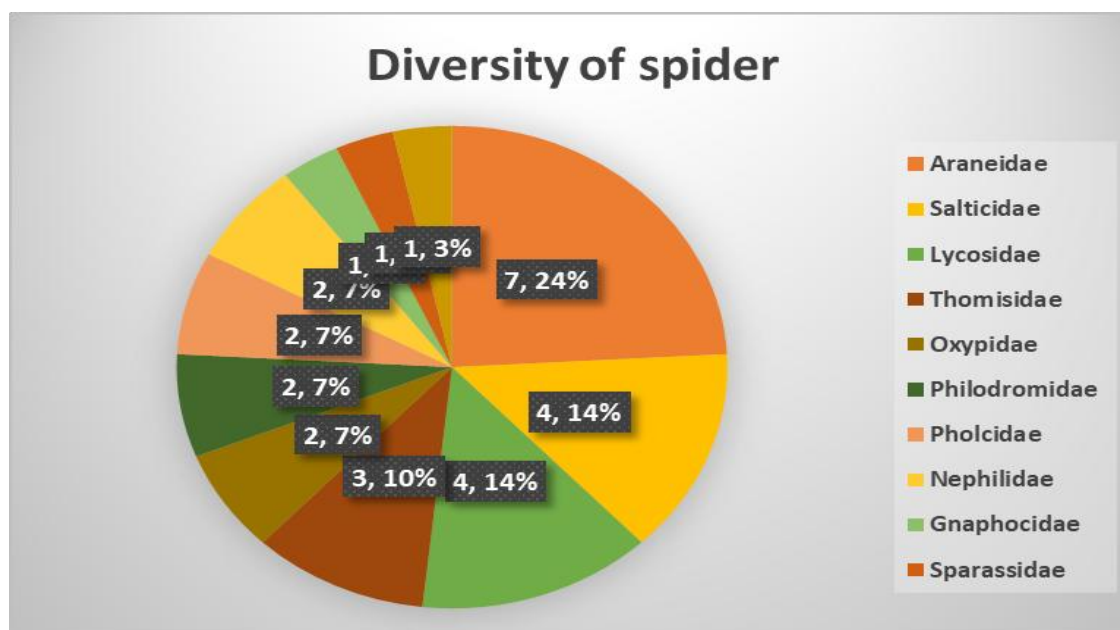
3.3. Sampling Method: -Established sampling protocols for spider collections were employed in selected sampling plots, including pitfall trapping, sweep netting, ground hand collection, aerial hand collection, vegetation beating, and litter sampling. Collections were conducted during early morning hours (08:00 to 11:00) and daytime (16:00 to 18:00)

3.4. Photograph and Identification- The sample was photographed across multiple dimensions using both a DSLR camera and a mobile phone during field observations. Spider guild structure designation was based on established ecological characteristics of the family (Young and Edwards, 1990; Uetz et al., 1999; Cardoso et al., 2011). Adult spiders were identified to the family level using available literature (Tikader, 1987; Sebastian and Peter, 2009). and nomenclature adhered to the World Spider Catalog as defined by Platnick (2014).

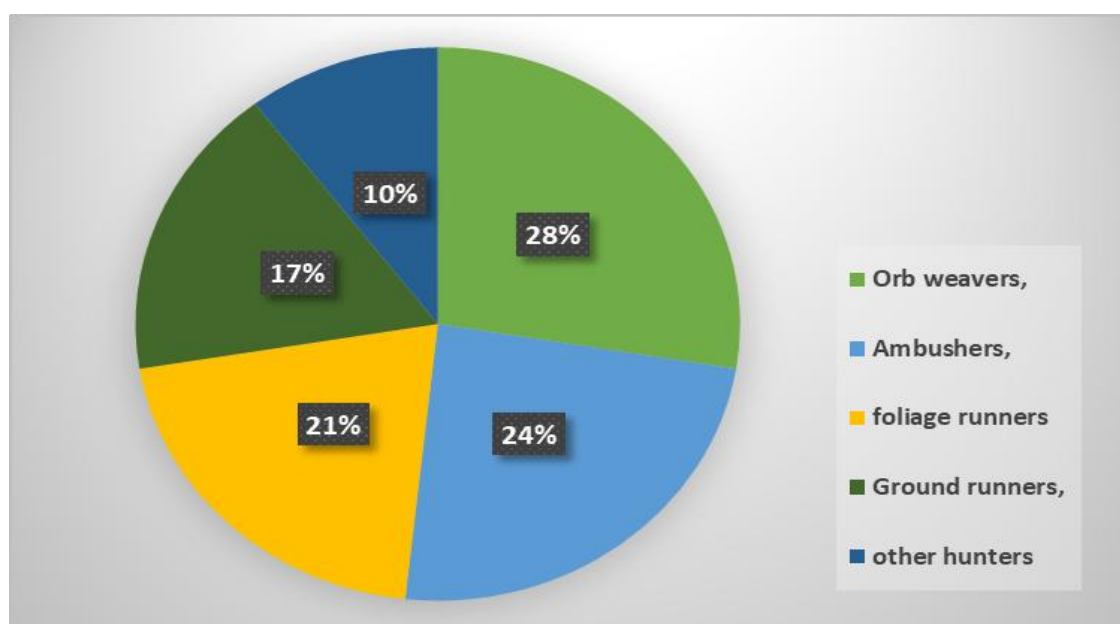
Table-1. Checklist of spider fauna recorded during the study period in Barmkela forest Sarangarh-Bilaigarh, District.

SL.NO.	Name of Species	Genus
I	FAMILY: ARANEIDAE SIMON,1895	
1.	<i>Argiope aemula</i> (Walckenaer, 1841)	1. <i>Argiope</i> Audouin, 1826
2..	<i>Argiope anasuja</i> (Thorell, 1887)	
3..	<i>Argiope catenulata</i> (Doleschall, 1859)	
4.	<i>Argiope pulchella</i> Thorell,1881	
5.	<i>Cyclosa bifida</i> (Doleschall, 1859)	2. <i>Cyclosa</i> Menge, 1866
6.	<i>Eriovixia laglaizei</i> (Simon, 1877)	3. <i>Eriovixia</i> Archer, 19516.
7	<i>Neoscona theisi</i> (Walckenaer, 1841)	4. <i>Neoscona</i> E. Simon, 1864
II	FAMILY: GNAPHOSIDAE POCKOCK, 1898	
8	<i>Drassodes sagarensis</i> (Tikader, 1982)	5. <i>Drassodes</i> Westring,
III	FAMILY: LYCOSIDAE SUNDEVALL, 1833	

9	<i>Hippasa holmerae</i> (Thorell, 1895)	6. <i>Hippasa</i> Simon, 1885.
10	<i>Pardosa laura</i> (Karsch, 1879)	7. <i>Pardosa</i> C. L. Koch, 1847
11	<i>Pardosa pseudoannulata</i> (Bösenberg & Strand, 1906)	
12	<i>Pardosa sumatrana</i> (Thorell, 1890)	
IV	FAMILY: NEPHILIDAE SIMON 1984	
13	<i>Nephila kuhlii</i> (Doleschall, 1859)	8. <i>Nephila</i> Leach, 1815[
14	<i>Nephila pilipes</i> (Fabricius, 1793	
V	FAMILY: OXYOPIDAE THORELL, 1870	
15	<i>Oxyopes javanus</i> (Thorell, 1887)	9. <i>Oxyopes</i> Latreille, 1804
16	<i>Peucetia viridana</i> (Stoliczka, 1869)	10. <i>Peucetia</i> Thorell,
VI	FAMILY: PHILODROMIDAE THORELL, 1870	
17.	<i>Thanatus vulgaris</i> Simon, 1870	11. <i>Thanatus</i> C. L. Koch, 1837
VII	FAMILY: PHOLCIDAE C. L. KOCH, 1850	
18.	<i>Artema atlanta</i> Walckenaer, 1837	12. <i>Artema</i> Walckenaer, 1837
19	<i>Micropholcus fauroti</i> (Simon, 1887)	13. <i>Micropholcus</i> Deeleman-Reinhold & Prinsen, 1987[
20	<i>Pholcus phalangioides</i> (Fuesslin, 1775)	14. <i>Pholcus</i> Walckenaer, 1805
VIII	FAMILY: SALTICIDAE BLACKWALL, 1841	
21.	<i>Menemerus bivittatus</i> (Dufour, 1831	15. <i>Menemerus</i> Simon, 1868[
22.	<i>Plexippus paykulli</i> (Audouin, 1825)	16. <i>Plexippus</i> C. L. Koch, 1846[
23	<i>Plexippus petersi</i> (Karsch, 1878)	
24	<i>Telamonia dimidiata</i> (Simon, 1899)	17. <i>Telamonia</i> Thorell, 1887[
XIV	SPARASSIDAE BERTKAU, 1872	
25.	<i>Heteropoda venatoria</i> (Linnaeus, 1767	18. <i>Heteropoda</i> Latreille, 1804
X	FAMILY: TETRAGNATHIDAE MENGE, 1866	
26	<i>Leucauge decorata</i> (Walckenaer, 1842)	19. <i>Leucauge</i> White, 1841
XI	FAMILY: THOMISIDAE SUNDEVALL, 1833	
27	<i>Diaea dorsata</i> (Fabricius, 1777)	20. <i>Diaea</i> Thorell, 1869
28	<i>Thomisus lobosus</i> (Tikader, 1965)	21. <i>Thomisus</i> Walckenaer, 1805
29	<i>Thomisus projectus</i> (Tikader 1960)	



Figur-2: Graphical representation of diversity of different species.



Figur-2: Graphical representation of ecological guild structure of different specie

4. RESULT AND DISCUSSION- A habitat characterization of Barmkela forest indicates that it is a tropical dry deciduous forest with grey-black soil, exhibiting humidity levels between 40% and 70%. The average temperature ranges from 24°C to 42°C. This diverse and healthy environment in Barmkela supports 13.06 % of the total spider families found in Chhattisgarh state, encompassing 29 species from 21 genera (Table 1, Figure 1), as well as numerous plant species, including grasses.

The study identified 11 spider families, with Araneidae being the most dominant, encompassing 4 genera. Salticidae and Lycosidae were each represented by 4 species, followed by Thomisidae with 3 species. Oxyopidae, Philodromidae, Pholcidae, and Nephilidae were each represented by 2 species, while Gnaphosidae and Sparassidae were each represented by a single species. The majority of families were represented by a single genus and species, (Table -1), whereas Das(2026)investigate Thirty-six spider species, belonging to 28 genera and 13 families, were identified across the selected habitats. The Araneidae family was the most abundant, represented by 11 species and 8 genera from Tripura, India

A checklist of plant species from the various study areas within the Barmkela forest was compiled, revealing a diverse array of grasses and other plant species. In natural systems, insect diversity and abundance often exhibit a positive correlation with plant diversity (Wenninger & Inouye, 2008). The prevalence of a high number of Araneids may be attributed to the mixed vegetation of the forest, which provides ample space for constructing webs of varying sizes and offers protection from predators, aligning with the findings of Bhatkar (2011). The abundance of Thomisidae and Araneids in this region is likely due to the availability of flowering plants and dense vegetation within the forest area. The dry deciduous forest, characterized by a rich shrub understory, supports a greater number of Salticids and Lycosidae's, which are stalker predators. A higher prevalence of foraging guild specialists, Araneidae, was observed across all localities, with a high number of Nephila species present.

Spiders identified in forest of Barmkela can be classified into 5 ecological guilds based on foraging strategy, including orb weavers, space-web builders, sheet-web builders, ambush predators, ground runners, and foliage runners. Of the total spider species recorded, approximately 28% were orb weavers, 24% ambushers, 21 % foliage runner, 17% ground runners, 10% other hunters (Table -2; figer-2) whereas Sawane (2022) reported the relative abundance of spider species, with approximately 43% identified as orb weavers, 17% as stalkers, 14% as ground runners, 13% as ambushers, 8% as foliage runners, 3% as space web builders, and 2% as sheet web builders. The high occurrence of Araneidae may be attributed to the forest's diverse vegetation, which offers ample space for web construction of varying sizes and provides protection from predators. Das (2026) a study was conducted in the fragmented forests and adjacent residential areas of the Unakoti hill range, Tripura, India, to investigate spider diversity and ecological guild structure. Five functional groups were observed: orb-web builders, stalkers, ambushers, space-web builders, and ground runners.

A higher prevalence of foraging guild specialists, Araneidae, was observed across all localities, with a high number of Nephila species present in study area. The abundance of web-building spiders (Araneidae, Oxyopidae) was positively correlated with vegetation exhibiting a heterogeneous composition of trees, shrubs, and climbers. These findings are consistent with research conducted by Bhatkar (2011) in Wan Sanctuary, Melghat Tiger Reserve, and Lia and Hindayana (2022) in Bogor, West Java, Indonesia. Krishnaveni & Kandeepan (2019) documented a comprehensive spider survey of Sirumalai hills, Tamil Nadu, identifying 112 species representing 78 genera across 35 families. The spider community was categorized into six feeding guilds: orb-web builders, foliage hunters, ground hunters, sheet web builders, scattered line weavers, and ambushers. The researchers further analyzed the complex interactions between spider populations and climatic factors, including high rainfall and humidity, in relation to topographical features.

In grassland ecosystems, Argiope sp. and Oxyopidae are the predominant spider species, a finding consistent with Gajbe's (2004) observations. Conversely, giant wood spiders (Nephila sp.) are more dominant in forested areas with three tiers of vegetation. This aligns with Tharaka et al.'s (2019) study in Sri Lanka, which noted a higher abundance and healthier populations of Nephila species in forested environments. Ground-dwelling spiders (Salticidae & Lycosidae) exhibit greater diversity in grassland, leaf litter, and leaf foliage habitats, a conclusion supported by Labanon et al. (2020).

5.CONCLUSION- The present study indicates that the study area harbors a significant number of spider species. Several factors, including vegetation, seasonal patterns, habitat complexity, and climatic conditions, are directly associated with the diversity patterns of species composition. The presence of significant populations of various spider families, specifically Araneidae, Nephilidae, and Thomisidae, within this particular region can be attributed to the abundant availability of dense vegetation. This deep, layered vegetation structure offers a complex habitat and various guild structures. Furthermore, the presence of numerous flowering plants distributed throughout the forest area plays a crucial role in supporting these spider populations. These flowering plants attract a diverse array of insects, which subsequently serve as a primary food source for many of the spider families mentioned, contributing to their proliferation and sustained presence in the ecosystem. The intricate relationship between the vegetation, flowering plants, and insect populations creates a favorable environment for Araneidae, Nephilidae, and Thomisidae spiders to thrive in this region. The findings of this study provide valuable insights into the spider species diversity of the Barmkela Forest and can serve as a foundation for future research on the spider

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**PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS) IN COSMETICS: OCCURRENCE,
EXPOSURE PATHWAYS, HEALTH CONCERNS AND EMERGING REGULATORY
RESPONSES**

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ABSTRACT

Per- and polyfluoroalkyl substances (PFAS) are a large class of synthetic fluorinated chemicals increasingly recognized as persistent environmental and human contaminants (EPA, 2023; Peaslee et al., 2021). PFAS are intentionally added to many cosmetic and personal care products to enhance spreadability, water resistance, film formation, and long-lasting performance, and may also enter formulations unintentionally as impurities or degradation products of precursor ingredients (FDA, 2025; ToxStrategies, 2025). Recent analytical surveys report that a substantial proportion of foundations, mascaras, lipsticks, and other colour cosmetics sold in North America and Europe contain high levels of fluorine, suggesting widespread PFAS use (Peaslee et al., 2021; University of Notre Dame, 2024). While cosmetics are not the dominant source of aggregate PFAS exposure, their direct, frequent application to skin, lips, and peri-ocular areas raises concern, particularly for long-lasting and waterproof products marketed for daily use (Exponent, 2026; Wigle et al., 2025). Multiple epidemiological and toxicological studies link certain well-studied PFAS (for example, PFOA and PFOS) to kidney and testicular cancers, immune suppression, endocrine disruption, dyslipidaemia, and developmental toxicity, although cosmetic-specific risk assessments remain limited and uncertain (WHO, 2022; ECHA, 2023). Regulatory agencies in the United States, Canada, and the European Union are now reassessing PFAS in cosmetics under broader “forever chemical” control strategies, but current measures vary in scope and stringency and safety determinations are incomplete (FDA, 2026; ECHA, 2023). This review summarizes current knowledge on PFAS types used in cosmetics, product categories affected, exposure and toxicological concerns, and evolving regulatory responses, and highlights key research gaps relevant for risk assessment and safer-by-design formulation.

Introduction

PFAS constitute a broad family of more than 4700 synthetic organic chemicals characterized by highly fluorinated carbon chains that impart exceptional stability, oil and water repellency, and surfactant properties (EPA, 2023; OECD, 2022). These properties underpin extensive use of PFAS in industrial applications and consumer products, including non-stick cookware, food contact materials, textiles, firefighting foams, and a wide range of cosmetic products (ECHA, 2023; SGS, 2025).

In cosmetics, PFAS function primarily as emulsifiers, film-formers, and surface-modifying agents that improve slip, spreadability, durability, water resistance, and a “smooth” or “airbrushed” appearance on skin and hair (FDA, 2025; ToxStrategies, 2025). Analytical studies and product ingredient reviews indicate that PFAS can be present in colour cosmetics (foundations, concealers, lipsticks, mascaras), skincare (moisturizers, sunscreens), hair conditioners, and certain hygiene products, either as intentionally added ingredients or as impurities and degradation products (Peaslee et al., 2021; University of Notre Dame, 2024; PubMed, 2024).

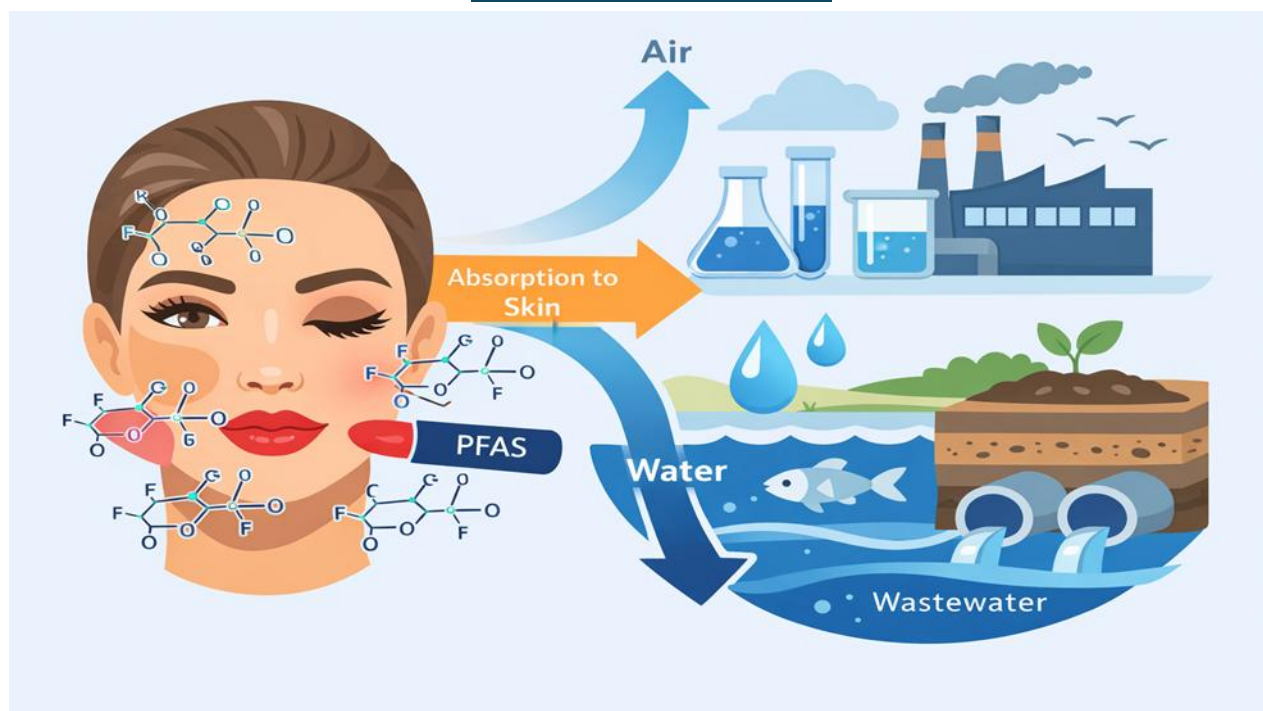


Figure 1: Occurrence of PFAS in Personal Care Products

PFAS in Cosmetics: Uses and Product Categories

Multiple lines of evidence show that PFAS use in cosmetics is both intentional (listed ingredients) and unintentional (residuals or breakdown products). The U.S. FDA notes that PFAS are added to condition and smooth skin and hair, enhance shine, and modify product consistency, while also acknowledging their presence as impurities or degradation products (FDA, 2025; FDA, 2026). A qualitative survey of cosmetic products in Europe identified 11 distinct PFAS as labeled ingredients, with polytetrafluoroethylene (PTFE) and perfluorodecalin being the most frequently reported (PubMed, 2024).

Screening studies using total fluorine as a marker for PFAS have demonstrated that a large share of tested commercial cosmetics have elevated fluorine levels, especially long-wear, water-resistant, or transfer-resistant formulations (Peaslee et al., 2021; University of Notre Dame, 2024). One North American survey of more than 200 products reported high fluorine in about 56% of foundations and eye products, 48% of lip products, and 47% of mascaras, indicating likely PFAS use (Peaslee et al., 2021). PFAS-containing categories often include liquid lipsticks, waterproof mascaras, and long-lasting foundations, aligning with their water and oil repellent functionality (Exponent, 2026; Wigle et al., 2025).

Table 1. Examples of PFAS Use and Concerns in Cosmetics

Aspect	Key information
Typical PFAS functions in cosmetics	Emulsifiers, film-formers, texture modifiers, water/oil repellents, shine and slip enhancers (FDA, 2025; SGS, 2025).
Common product types with PFAS	Foundations, concealers, eye shadows, eyeliners, mascaras, lipsticks, leave-on moisturizers, face powders, some hair conditioners and nail products (Peaslee et al., 2021; University of Notre Dame, 2024; PubMed, 2024).
Frequently reported PFAS ingredients	PTFE, perfluorodecalin and other perfluoroalkyl compounds; at least 35 PFAS types identified in cosmetic formulations (PubMed, 2024; FDA, 2026).
Detection via total fluorine screening	High fluorine in about half of tested foundations, eye products, and lip products, suggesting widespread PFAS use in North American cosmetics (Peaslee et al., 2021; University of Notre Dame, 2024).

Main exposure routes from cosmetics	Dermal absorption, inadvertent ingestion (lip products), peri-ocular exposure, and indirect environmental release via wastewater and air (FDA, 2026; ToxStrategies, 2025; Wigle et al., 2025).

Exposure Pathways and Human Health Concerns

Cosmetics can contribute to PFAS exposure through direct dermal contact, accidental ingestion from lip products, and potential absorption via the eye area (FDA, 2026; ToxStrategies, 2025). Frequent and prolonged use of long-lasting and waterproof formulations may increase cumulative exposure, particularly for consumers applying several PFAS-containing products daily (Peaslee et al., 2021; Wigle et al., 2025). Although some national risk assessments have concluded that PFAS levels in cosmetics are likely too low to pose acute risk, experts caution that these products add to already significant background exposure from drinking water, food, and other consumer goods (ToxStrategies, 2025; Wigle et al., 2025).

Associations between elevated body burdens of specific PFAS and adverse health outcomes are increasingly well documented in the broader literature. Reported effects include kidney and testicular cancers, liver damage, altered cholesterol levels, immune system effects, thyroid and reproductive hormone disruption, reduced fertility, low birth weight, and developmental toxicity (WHO, 2022; ECHA, 2023). Children, pregnant women, and individuals with pre-existing conditions may be especially vulnerable, and there is concern about exposure of fetuses and infants via maternal body burdens and breast milk (ECHA, 2023; WHO, 2022). Because PFAS are highly persistent and in some cases bioaccumulative, even low-level cosmetic exposures may be of concern when viewed within a lifetime cumulative risk framework (FDA, 2026; ECHA, 2023; SGS, 2025).

Recent Research and Key Findings

Growing regulatory and public attention has prompted new analytical, exposure, and risk-assessment studies focused specifically on PFAS in cosmetics (FDA, 2026; Exponent, 2026; ToxStrategies, 2025). A recent report prepared under the U.S. Modernization of Cosmetics Regulation Act (MoCRA) reviewed available data on PFAS use, exposure, and safety, concluding that there is insufficient evidence to determine the overall safety of PFAS in cosmetic products and highlighting major data gaps in ingredient identity, toxicity, and exposure (FDA, 2026; Exponent, 2026). The report identified eye shadows, face and neck products, eyeliners, face powders, and foundations as key categories containing PFAS, together representing a major share of PFAS-containing cosmetics in the evaluated data set (FDA, 2026).

A qualitative survey of PFAS as cosmetic ingredients confirmed their presence across hygiene, skincare, make-up, and perfumes, with PTFE and perfluorodecalin particularly prevalent (PubMed, 2024). Parallel screening studies in North America using total fluorine measurements demonstrated that PFAS-associated fluorine is especially common in products marketed as long-wear or water-resistant, supporting the functional role of PFAS in performance claims (Peaslee et al., 2021; University of Notre Dame, 2024). Emerging risk-assessment work has started to estimate potential dermal and oral doses from PFAS-containing facial cosmetics but uncertainties remain high due to variability in PFAS composition, absorption parameters, and user behaviour (ToxStrategies, 2025; FDA, 2026).

Environmental health perspectives emphasize that PFAS-containing cosmetics are yet another daily source of “forever chemical” emissions. Once these products enter wastewater, PFAS can persist and cycle through water, sediment, and biota, contributing to wider community exposure even when individual use is modest (ECHA, 2023; Wigle et al., 2025; SGS, 2025). Some commentators therefore advocate restricting PFAS in cosmetics to only truly essential uses, if any, and prioritizing non-fluorinated alternatives wherever feasible (ECHA, 2023; Wigle et al., 2025).

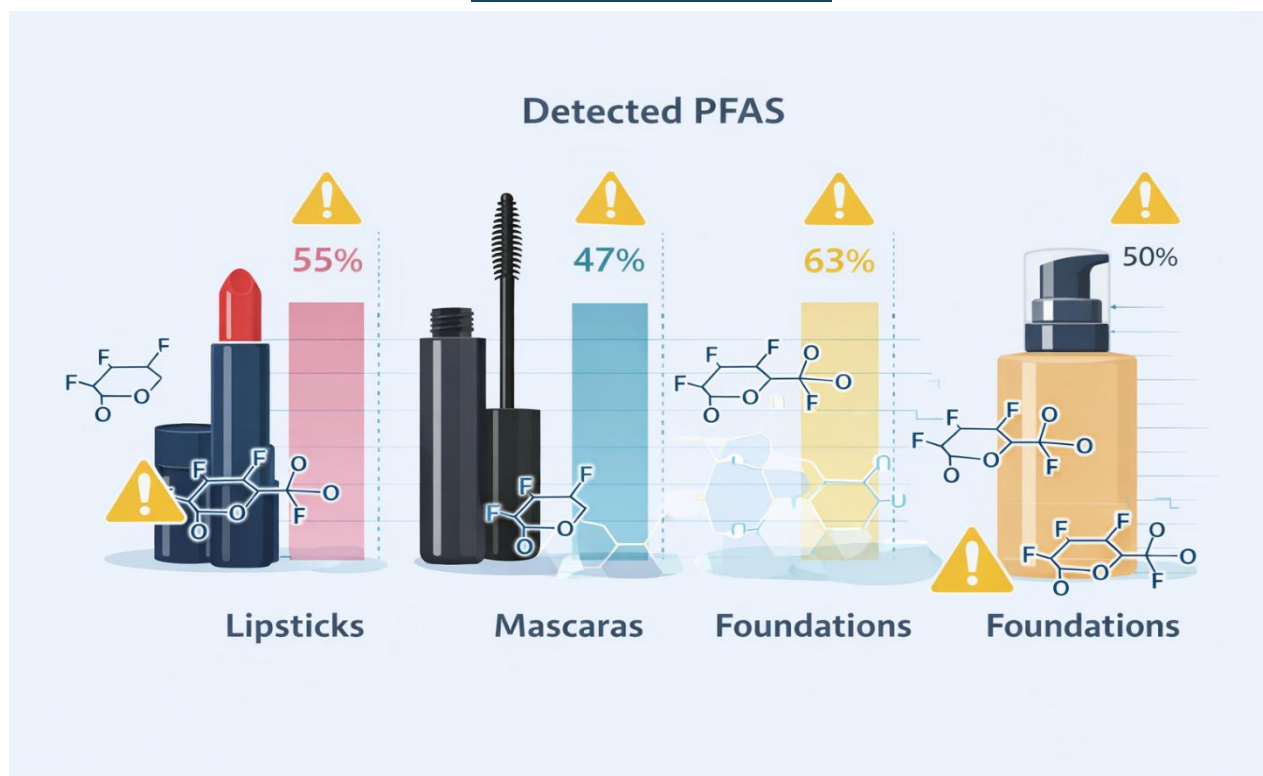


Figure 2: PFAS detected in cosmetics.

Regulatory Landscape and Industry Response

The regulatory approach to PFAS in cosmetics is evolving rapidly but remains heterogeneous across jurisdictions (FDA, 2026; ECHA, 2023; EcoMundo, 2024). In the United States, the Modernization of Cosmetics Regulation Act (MoCRA) framework has expanded federal oversight of cosmetic ingredients, including PFAS, and legislative proposals such as the ‘No PFAS in Cosmetics Act’ have sought to prohibit PFAS in make-up, moisturizers, and perfumes, although comprehensive bans are not yet in place (FDA, 2026; Cosmetics Business, 2025). The U.S. FDA currently lists around 35 PFAS used as ingredients in several hundred cosmetic formulations based on historical registration data, but acknowledges incomplete reporting and limited hazard data (FDA, 2026; FDA, 2025).

In Europe, PFAS in cosmetics fall under broader chemical management initiatives driven by concerns about persistence and long-range environmental transport (ECHA, 2023). The European Chemicals Agency (ECHA) is evaluating a far reaching proposal from Denmark, Germany, the Netherlands, Norway, and Sweden to restrict the manufacture and use of PFAS across most applications, including cosmetics, with implementation expected after 2026 (ECHA, 2023; EcoMundo, 2024). Several of the most hazardous PFAS have already been banned from cosmetic use in Europe and North America, and additional restrictions on groups of PFAS are being considered (ECHA, 2023; Cosmetics Business, 2025). At the same time, some national evaluations have suggested that PFAS levels in cosmetics might not pose immediate risk at current concentrations, highlighting ongoing scientific and regulatory debate (ToxStrategies, 2025; Wigle et al., 2025).

Industry responses include voluntary removal of intentionally added PFAS from product lines, reformulation toward non-fluorinated alternatives, increased reliance on “PFAS-free” or “clean beauty” marketing claims, and engagement with third-party certification schemes to demonstrate low PFAS contamination (SGS, 2025; Wigle et al., 2025). However, investigations of nominally PFAS-free products have sometimes detected residual fluorine, suggesting challenges related to supply-chain contamination, analytical limits, and complex PFAS chemistries (Peaslee et al., 2021; Wigle et al., 2025). Robust analytical methods, standardized reporting, and clearer regulatory criteria are therefore needed to support genuine PFAS phase-out in cosmetics (ECHA, 2023; FDA, 2026; SGS, 2025).

Conclusion

Evidence from ingredient surveys, fluorine screening, and regulatory reviews demonstrates that PFAS are widely used in cosmetic and personal care products, particularly in long-lasting and water-resistant make-up formulations (Peaslee et al., 2021; University of Notre Dame, 2024; PubMed, 2024). While cosmetics are one of many contributors to overall PFAS exposure, their direct and repeated application to skin and mucosal surfaces, coupled with the extreme environmental persistence of these chemicals, raises legitimate public health and environmental concerns (FDA, 2026; ECHA, 2023; Wigle et al., 2025).

Regulatory bodies in North America and Europe acknowledge significant data gaps regarding the identity, toxicity, and exposure profiles of PFAS used specifically in cosmetics and have begun to strengthen oversight, consider bans, and pursue group-based restrictions (FDA, 2026; ECHA, 2023). In parallel, industry is under increasing pressure to innovate safer, non-fluorinated alternatives and to verify “PFAS-free” claims through rigorous analytical control (SGS, 2025; Wigle et al., 2025). Priority research needs include comprehensive characterization of PFAS used in cosmetics; improved dermal and oral exposure modelling; systematic epidemiological studies addressing cosmetic use patterns; and life-cycle assessments capturing environmental releases from production to disposal (ToxStrategies, 2025; FDA, 2026). Addressing these gaps will be essential for science-based regulation and for ensuring that cosmetic benefits do not come at the expense of long-term human and ecosystem health (ECHA, 2023; WHO, 2022; SGS, 2025).

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EVALUATION OF WATER QUALITY ON LANA RIVER

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ABSTRACT

This study evaluates the water quality in the Lana River through the analysis of physicochemical parameters, nutrients, and major ions during three different sampling periods: October 2025, December 2025, and February 2026. This six-month period represents different seasonal conditions, allowing for a comparative assessment of environmental influences on river chemistry. Physical-chemical parameters, including temperature, pH, electrical conductivity, and dissolved oxygen, were measured alongside nutrient concentrations such as nitrates, nitrites, ammonium, and phosphates. In addition, the major ions (e.g., calcium, magnesium, sodium, potassium, chloride, and sulfate) were analysed to better understand the pollution level, water quality and potential sources of contamination. The results indicate noticeable seasonal fluctuations in water quality parameters. Lower temperatures and higher dissolved oxygen levels were observed during the winter months, while variations in nutrient concentrations suggest possible influences from urban runoff, wastewater discharge, and precipitation patterns. Elevated levels of certain nutrients, particularly nitrates and phosphates, may indicate anthropogenic inputs, raising concerns about eutrophication risks in specific periods. Similarly, changes in ionic composition reflect both natural geological contributions and human activities within the river basin. Overall, the findings highlight the dynamic nature of the Lana River system and emphasize the importance of continuous monitoring to detect pollution trends and assess ecological health. This study provides valuable baseline data for future environmental assessments and supports the development of effective water management strategies aimed at preserving the quality of this urban river ecosystem.

Keywords: Lana River, Nutrients, Physical-chemical parameters, Water analyse, UV-Vis analyzes

Introduction

Urban river systems represent some of the most heavily impacted aquatic environments worldwide due to the concentrated pressures from population density, industrial activity, and inadequate wastewater management. These pressures are particularly evident in rapidly growing cities, where the increase in impervious surfaces, expansion of sewage networks, and intensification of commercial and domestic activities lead to complex and often severe alterations in water quality. As urbanization accelerates, monitoring the ecological health of urban rivers has become a critical priority, not only for environmental protection but also for safeguarding public health and ensuring sustainable management of freshwater resources. In this context, physico-chemical assessments serve as foundational tools for understanding the dynamics of water quality and identifying the main anthropogenic stressors that influence aquatic ecosystems.

The Lana River, which pass throught the city of Tirana, Albania, is a prominent example of an urban watercourse experiencing intense anthropogenic pressures. Multiple studies have repeatedly identified Lana as one of the most polluted tributaries of the Ishmi basin, characterized by continuous inputs of untreated municipal wastewater, stormwater runoff, and solid waste discharges. Hoxha et al. (2018) describe the Lana River as having “very bad environmental quality” when compared to international standards, driven primarily

by uncontrolled urban wastewater releases along its midstream and downstream stretches. Similar findings have been reported by Kucaj et al. (2022), who used spatial-temporal GIS-based analysis to demonstrate that urban sections of the Lana consistently exhibit elevated concentrations of nutrients and suspended solids, marking the river as a critical hotspot for environmental degradation within the Tirana metropolitan area. Albania's rivers more broadly reflect comparable patterns of environmental stress. A multi-river assessment conducted by Lazo (2007) revealed that rivers in the Adriatic lowlands frequently exhibit high total suspended solids (TSS), excessive nutrient levels, and recurrent episodes of low dissolved oxygen (DO), with the Lana and Gjanica rivers identified as among the most polluted in the national network. According to this study, the deterioration of these rivers is closely linked to untreated sewage discharges, agricultural runoff, and erosion-driven sedimentation—factors that remain prevalent in the Lana River's catchment. More recent regional work by Jaku et al. (2025) further reinforces the idea that Albanian rivers, including Ishmi, Osumi, and Shkumbin, face substantial environmental pressures arising from urban runoff, industrial activity, and insufficient waste management infrastructure, all of which contribute to elevated contaminant loadings and disruptions in aquatic habitat quality 4.

Within this broader regional and national context, the Lana River represents a critical case for ongoing environmental monitoring. Its location at the core of Albania's largest and fastest-growing urban center makes it especially vulnerable to pollution but also highly significant for policy-making. The river's role in urban drainage, its proximity to densely populated neighborhoods, and its visibility as part of Tirana's public landscape underscore the importance of assessing and managing its water quality. Furthermore, ongoing infrastructural and urban development projects in the city may influence the river's hydrological regime and pollution load, making continuous monitoring indispensable for understanding the changing environmental conditions of the system.

Physico-chemical parameters—including temperature, pH, dissolved oxygen (DO), electrical conductivity, total dissolved solids (TDS), turbidity, total suspended solids (TSS), and nutrient concentrations—offer essential insights into the functioning and health of the river. Temperature plays a critical role in controlling metabolic and chemical processes in aquatic ecosystems, influencing dissolved oxygen solubility and rates of biological activity. pH fluctuations can indicate shifts in chemical equilibria, wastewater inputs, or biological processes such as respiration and photosynthesis. Dissolved oxygen levels are universally recognized as indicators of ecological health and are strongly influenced by organic load, temperature, and flow conditions. Elevated TDS and conductivity often signal increased pollution from urban runoff, wastewater inputs, and geological contributions, while turbidity and TSS provide evidence of erosion, stormwater discharge, and particulate pollution. Nutrients such as nitrates, nitrites, ammonium, and phosphates are key drivers of eutrophication, and their elevated concentrations in urban rivers are strongly associated with untreated sewage, fertilizer runoff, and decaying organic matter.

Seasonal assessments of water quality are equally important, as they help differentiate between changes driven by natural hydrological cycles and those arising from human activities. Seasonal patterns in Albanian rivers often include higher dissolved oxygen concentrations in winter due to lower temperatures, increased dilution from rainfall, and reduced microbial respiration, while summer months typically show higher nutrient concentrations, reduced flow, and elevated organic pollution. Lazo's (2007) multi-season river survey, for example, documented the tendency of Albanian rivers to exhibit severe oxygen depletion near urban centers during warmer months, a finding that aligns with observations in the Lana River during earlier monitoring campaigns. Likewise, the use of spatial-temporal interpolation methods by Kucaj et al. (2022) confirmed that seasonal dynamics play a significant role in shaping nutrient and ion concentrations in Tirana's river network.

The present study builds upon this foundational body of research by providing a detailed assessment of the physico-chemical characteristics of the Lana River across three critical periods: October 2025, December 2025, and February 2026. These periods represent distinct seasonal conditions that offer valuable insights into both immediate pollution patterns and broader hydrological dynamics. October reflects late-summer/early-autumn conditions when temperatures remain relatively high and dilution capacity is reduced. December coincides with increased rainfall, lower temperatures, and a transitional hydrological regime, while February represents mid-winter conditions characterized by cooler waters, higher oxygen solubility, and increased surface runoff.

Across eight monitoring stations—Ura News24, Materniteti Ri, Piramida, Vasil Shanto, Pallati me Shigjeta, Astir, Casa Italia, and Yrshek—this study examines the spatial variability within the river system. These stations encompass upstream segments with relatively lower human impact, midstream stretches adjacent to high-density urban development, and downstream sections exposed to cumulative pollutant loads. By

analysing spatial patterns, this study provides insights into the longitudinal effects of urbanization, wastewater release, and hydrological conditions as the river flows through the city.

Overall, the monitoring effort aims to (1) characterize the physico-chemical status of the Lana River across three seasons, (2) compare spatial differences across eight urban monitoring stations, and (3) contextualize the results within the broader scientific literature on Albanian and Balkan rivers. By integrating quantitative measurements, graphical interpretation, and comparisons with regional studies, this introduction establishes the foundation for understanding the complex environmental dynamics governing the Lana River and underscores the necessity of ongoing, comprehensive water quality monitoring programs.

Materiaile and Methods

2.1. Sampling of water samples in Lana River

Eight monitoring stations were sampled along the Lana River: Ura News24, Materniteti Ri, Piramida, Vasil Shanto, Pallati me Shigjeta, Astir, Casa Italia, and Yrshek. 1.5 L of water were taken from each station. The water samples were taken according to the ISO 5667-14:2016 method. At each of the stations where the water samples were taken, field measurements were made with the HANNA 9529 model apparatus for determining temperature, PH, DO, conductivity, turbidity and TDS. Water samples were transported and stored at +4°C prior to their analysis in the laboratory.

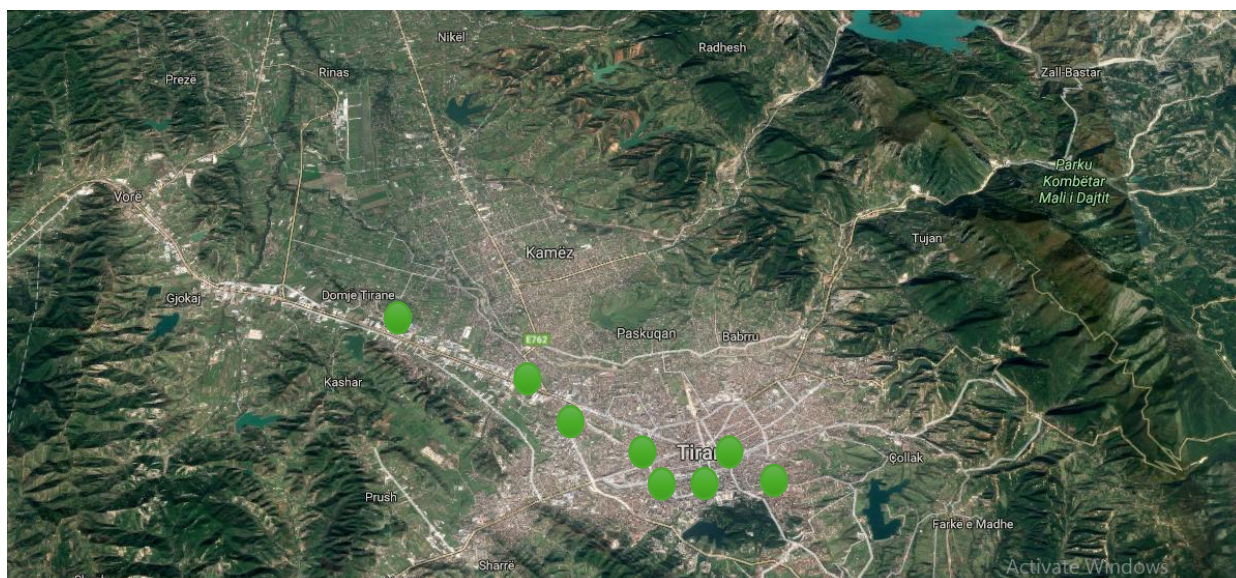


Figure 1. The map of sampling of water samples in Lana River

2.2. On-field measurements by using multimeric apparatus

Temperature, PH, DO, conductivity, turbidity and TDS were determined directly in the Lana River water for each station using a portable HANNA 9259 model device, while other parameters were determined in the laboratory.

2.3. Semi-automated methods for BOD and COD determination

To assess the biological oxygen demand of microorganisms in the Lana River water, automatic sensors model Oxytop were used. Respirometric method was used for BOD (5 day) determination. To determine the chemical oxygen demand, standard tubes pre-prepared with mercury sulfate and a PF-3 spectrophotometer with a wavelength suitable for COD analysis were used.

2.4. Determiantion of nutrients and sulfates by using UV-VIS technique

The UV 31 SCAN ONDA apparatus was used to measure the concentrations of nutrients and sulfates. The analysis of NO₃ in water is based on the ISO 7890-3: 1988 method for their determination with the spectrophotometric technique at the wavelength of 420 nm. The analysis of NO₂⁻ in water is based on the ISO 6777: 1984 method for their determination with the colorimetric method at 543 nm. The analysis of NH₄⁺ in

water is based on the ISO 7150/1: 1984 method for their determination with the spectrophotometric technique at 655 nm. N-total was determined using complete disintegration of the sample with K₂S₂O₈ and determination of nitrogen in both wave lengths 220 nm and 275 nm. All forms of N are oxidized to NO₃. P-total was determined using the disaggregation method which aims to oxidize all forms of phosphorus to PO₄ ions and further determine them using the spectrophotometer method at 880 nm. The analysis of sulfates in water is based on method 9038 for the determination of sulfates by the turbidimetric method at a wavelength of 420 nm.

2.5. Determination of main ions by titration method

The Cl⁻, Ca²⁺ and Mg²⁺ ions were determined by the titration method. The chloride ions were determined by the argentometric method (4500-Cl⁻ B, Argentometric Method also known as the Mohr method. The data obtained for chloride ions in seawater were used to calculate salinity. The concentration of calcium ions in seawater was determined using the EDTA titration method in the presence of the indicator Erichrom black T (3500-Ca B). Magnesium ions were determined in seawater using the MgCl₂ titration of the complex that Mg²⁺ forms with EDTA (3500-Mg B, C).

2.6. Gravimetric method for TSS determination

The analysis of suspended solids (TSS) was based on their determination by the gravimetric method using glass filters with a diameter of 32 mm and a pore size of 0.45 µm in a vacuum filtration system. Their weights were made before and after filtration. The particles were dried at 105°C for 4 hours.

Results and Discussions

1. Overview of Physico-Chemical Variability

Water quality parameters measured along the Lana River during October 2025, December 2025, and February 2026 show marked spatial and seasonal variation, reflecting the combined influence of hydrological conditions, urban discharges, and catchment characteristics. Seasonal differences were particularly visible in temperature, dissolved oxygen (DO), and nutrient concentrations, while spatial differences were most pronounced at high-impact urban stations such as Pallati me Shigjeta, Astir, Casa Italia, and Yrshek. These results are consistent with earlier studies showing the Lana River to be one of the most polluted watercourses in the Tirana region due to untreated municipal effluents. The plotted data support these general patterns, showing expected seasonal reductions in temperature from October to February and concomitant rises in DO at several stations, as well as spatial clustering of elevated TDS in downstream/urbanized sites.

ARTIFICIAL INTELLIGENCE POWERED CLIMATE CHANGE MODELLING

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ABSTRACT

Artificial Intelligence revolutionises climate change modeling by using models which will also be able to rapidly increase simulation speeds, improve accuracy, and perform extensive processing with big data to enable faster, more cost-effective, and actionable climate projections. Machine learning enhances short-term weather predictions, refines long-term temperature predictions, predicts extreme events (e.g., floods, heatwaves) and tracks land-use changes such as deforestation. AI does not displace physics; instead, it enhances insight, making it much easier to pick up small signals cascading through complex, nonlinear systems. These advancements have profound real-world implications, such as insurance pricing, agricultural policies, energy demand predictions, infrastructure resilience to disaster preparedness during shifting rainfalls, unexpected powerful storms and rising heat extremes.

AI can accurately downscale coarse global outputs to show localised effects like sea-level rise. Convolutional neural networks make it possible to analyse satellite data in real time to see things like deforestation, land degradation, and changes in the environment. AI also fixes biases and parameterises unresolved small-scale physics. These abilities also help make renewable energy grids work better, find weak spots in infrastructure, and help create policies for adaptation and mitigation that are based on facts. Recent operational advancements—like ECMWF's AIFS, NOAA's AI-driven global models, NVIDIA's Earth-2 platform, and long-term simulations that can run 1,000 years of climate in hours—show how AI is moving from research to real-world forecasting, allowing for more thorough scenario testing and better decision-making. Even though explainable, AI needs to build trust and transparency and high-quality data. In addition to that, it is hard to apply AI to new climates that have never happened before.

Keywords: Artificial Intelligence, climate change modeling, Machine learning, disaster preparedness

INTRODUCTION

Climate change is one of the greatest challenges of 21st-century humanity, necessitating accurate, timely and scalable modeling tools that can help shape policy, adaptation and mitigation. This review explores crucial tools needed to drive action and evaluate the literature and models.

Conventional physics-based models, such as General Circulation Models (GCMs) and Earth System Models (ESMs) were useful in laying significant groundwork but have strong computational costs and uncertainties in parameterizing small-scale parameters like clouds, aerosols and convection (Randall et al., 2018; Schneider et al., 2017).

Artificial Intelligence (AI), particularly machine learning (ML) and deep learning, takes this category to the next level using enormous satellite datasets, reanalysis products such as ERA5, and observations (Hersbach et al., 2020). AI provides faster data processing, improved effective resolution and better predictions (Reichstein et al., 2019). The AI does not replace physics; it complements it by mimicking unresolved processes, bias-correcting outputs, and uncovering hidden patterns in nonlinear dynamics (Gentine et al., 2021).

In this article, we review some key techniques, applications of AI, examples that incorporate hybrid approaches, their impact on society as whole, along with challenges and prospects for the future of AI development for climate modeling by early 2026 (Eyring et al., 2024). Dimensional analysis in the classical climate model and climate modelling limitations.

LIMITATIONS OF TRADITIONAL CLIMATE MODELING

Dimensional analysis in the classical climate model has limitations. Classic numerical weather prediction (NWP) and climate model computations model systems which solve systems of partial differential equations governing fluid dynamics, thermodynamics, and radiation, etc. They provide a means to deal with systems of partial differential equations that govern fluid dynamics, thermodynamics and radiation (Bauer et al., 2015). Though they can be interpreted, they are also subject to certain limitations (Palmer, 2019):

- Computational cost: High resolution, global runs require weeks or months on a supercomputer (Schneider et al., 2017; Neumann et al., 2019).
- Parameterization issues: Sub-grid phenomena will require an approximation for the models that introduce systematic errors in modelling and this is often a challenge since some of them are large with time scales (Randall et al., 2018; Gentile et al., 2021).
- Problems in data integration: Comprehensively combining diverse observations at scale is slow and resource consuming (Reichstein et al., 2019; Bauer et al., 2021).
- Ensemble constraints: Predictive forecasting of extreme events requires many simulations and they are more expensive due to large numbers of simulations required by the probability of being able to estimate the maximum value of extreme phenomena (Palmer, 2019; Sippel et al., 2020).

Those limitations diminish the timely and meaningful information that is shared by decision-makers facing rapid weather acceleration and land use shifts (Eyring et al., 2024).

AI TECHNIQUES REVOLUTIONIZING CLIMATE MODELING

AI can detect complex patterns within high dimensional data (Reichstein et al., 2019). Prominent methods include:

- Graph Neural Networks (GNNs): Utilized in visualizations of atmospheric states on multi-scale meshes for medium-range forecasting as in Google DeepMind's GraphCast (Lam et al., 2023).
- Fourier Neural Operators (FNOs) and associated architectures: The FNOs in models like FourCastNet efficiently predict the future (Pathak et al., 2022).
- Transformers and hybrid architectures: Applied in systems like Pangu-Weather for processing multimodal data and capturing long-range dependencies (Bi et al., 2023).
- Hybrid physics-ML frameworks: NeuralGCM integrates a differentiable dynamical core with machine-learned parameterizations for unresolved physics, achieving strong performance across weather and climate timescales (Kochkov et al., 2024).

Recent hybrids, like the University of Washington's Deep Learning Earth System Model (DL ESyM), simulated current climate variability for up to 1,000 years in approximately 12 hours (Watt-Meyer et al., 2023) on a single processor (compared to approximately 90 days on a supercomputer).

DISCUSSION

Short-Term Weather Predictions: AI models, like GraphCast, that outperform traditional systems like ECMWF's HRES can do 10-day forecasts for the majority of variables, but also get results in seconds to minutes as opposed to hours (Lam et al., 2023; ECMWF, 2022). Hybrids enhance prediction of extreme precipitation (Ravuri et al., 2021).

Long-Term Temperature and Climate Projections: AI emulators speed ensemble generation and allow for regional downscaling of global projections (Watson-Parris et al., 2022). They mitigate biases in extremes of precipitation and provide good coverage of interannual variability (Dagon et al., 2023). For example, CondensNet helps to maintain long-term hybrid simulation stability by using adaptive physical constraints (Mooers et al., 2024).

Extreme Event Prediction: Deep learning techniques are great for detecting, segmenting, and forecasting floods, droughts, heatwaves, wildfires, and cyclones using anomaly detection and multimodal integration

(Prabhat et al., 2021; Logar et al., 2021). Transformer-based methodologies are able to integrate satellite and climate data for effective impact assessment (Veillette et al., 2020).

Land-Use Change Tracking: Computer vision and transfer learning can be used in satellite data to monitor deforestation, urbanization, and ecosystem change in near-real-time and can serve as key inputs for coupled climate-land simulations (Parente et al., 2021; Gomez et al., 2016).

Hybrid Physics-AI Models: They offer the best of both techniques. Pure data-driven models pose a risk of drift off the physical plane over long horizons, where purely physics-based models run at a very high computational cost (Kochkov et al., 2024). Hybrid strategies, either incorporated (ML as integrated within physics) or composite, have better chances (Reichstein et al., 2019). NeuralGCM and physics-limited networks, such as PCNN-GCM (including CondensNet), provide decade-scale stability with physics invariability (Kochkov et al., 2024; Wang et al., 2026). Explainable AI methods improve not only interpretability but also scientific trust (Mamalakis et al., 2025; O'Loughlin et al., 2025).

Real-World Implications: AI-powered modelling provides impactful benefits across industries.

- Insurance and risk pricing- Enhanced probabilistic estimates of extremes increase accuracy and precision.
- Agricultural policies- The early detection of drought or changes in rainfall will help to develop drought resilient cropping and irrigation systems.
- Energy systems- Improved forecasting on renewable variability and demand helps grid performance and reduce waste.
- Infrastructure and disaster preparedness- Downscaled projections guide planning for sea-level rise, heat extremes and changing precipitation.
- Policy support- AI underpins user-friendly interfaces for complex model outputs.

The global AI-based climate computing market was valued at around USD 266 million in 2024 and is expected to grow at a CAGR greater than 23% through 2034, demonstrating great momentum.

CONCLUSION

AI-powered climate change modeling represents a fundamental shift toward faster, more accurate, and actionable projections. By intelligently augmenting physics with data-driven insights, these approaches better equip society to address a warming world. The AI and climate research community plays a pivotal role in realizing this potential for a more resilient future. Looking ahead, foundation models, multi-modal digital twins, and seamless integration into assessment processes promise kilometer-scale, near-real-time global simulations by the early 2030s.

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TOKYO SUMMIT-XI

TOKYO 11TH INTERNATIONAL INNOVATIVE STUDIES & CONTEMPORARY SCIENTIFIC RESEARCH CONGRESS

İlgili makama;

Tokyo 11. Uluslararası Yenilikçi Çalışmalar ve Modern Bilimsel Araştırmalar Kongresi 6-7 Nisan 2026 tarihleri arasında Tokyo'da, 13 farklı ülkenin akademisyen/araştırmacılarının katılımıyla gerçekleşmiştir. Kongre kapsamında sunumu yapılan 120 bildirinin 52 adeti Türkiye'den katılımcılar tarafından; 68 bildiri ise 12 ülkeden katılımcılar tarafından sunulmuştur. Kongre 16 Ocak 2020 Akademik Teşvik Ödeneği Yönetmeliğine getirilen *"Tebliğlerin sunulduğu yurt içinde veya yurt dışındaki etkinliğin uluslararası olarak nitelendirilebilmesi için Türkiye dışında en az beş farklı ülkeden sözlü tebliğ sunan konuşmacının katılım sağlaması ve tebliğlerin yarısından fazlasının Türkiye dışından katılımcılar tarafından sunulması esastır."* değişikliğine uygun düzenlenmiştir.

Bilgilerinize arz edilir,
Saygılarımla,

DR. FROILAN D. MOBO

On behalf of the Organizing Committee

Please, visit the conference web address to find more information about the event: www.tokyosummit.org

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February 13, 2026

This Official Protocol Declaration is hereby issued by London Sovereign School (hereinafter referred to as "the Institution"), a duly constituted academic and research entity operating within the United Kingdom and possessing full legal personality under applicable UK law.

Pursuant to the Institutional Charter, Academic Regulations, and Internal Statutes, the Senate of the Institution, at its duly convened session held on **14 January 2026**, did hereby adopt and enact Resolution No. **2026/7**, whereby it is formally decreed that the scientific event specified hereunder shall be organized under the official auspices and academic supervision of the Institution. The said event shall be deemed an official academic undertaking of London Sovereign School and shall be conducted in strict conformity with principles of academic integrity and all applicable legal and regulatory provisions in force.

By virtue of the aforesaid Resolution, the academicians and designated officials serving within the Organizing Committee, Scientific Committee, Advisory Board, and related academic bodies have been duly nominated and ratified by the Senate. The list of appointed members constitutes an integral and legally operative part of this Declaration.

This Declaration shall enter into force upon issuance and remain in full force and effect unless otherwise amended by Senate resolution.



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Title and Venue of the Scientific Event: Tokyo Summit – XI International Congress on Innovative Studies and Modern Scientific Research

Official Date(s) of the Event: April 6-7 2026 / Tokyo - Japan

Official Web Address: <https://www.tokyosummit.org/>