

E-SOUVENIR CUM ABSTRACT BOOK

INTERNATIONAL CONFERENCE
ON
SUSTAINABLE DEVELOPMENT
AND
INTELLIGENT INNOVATION

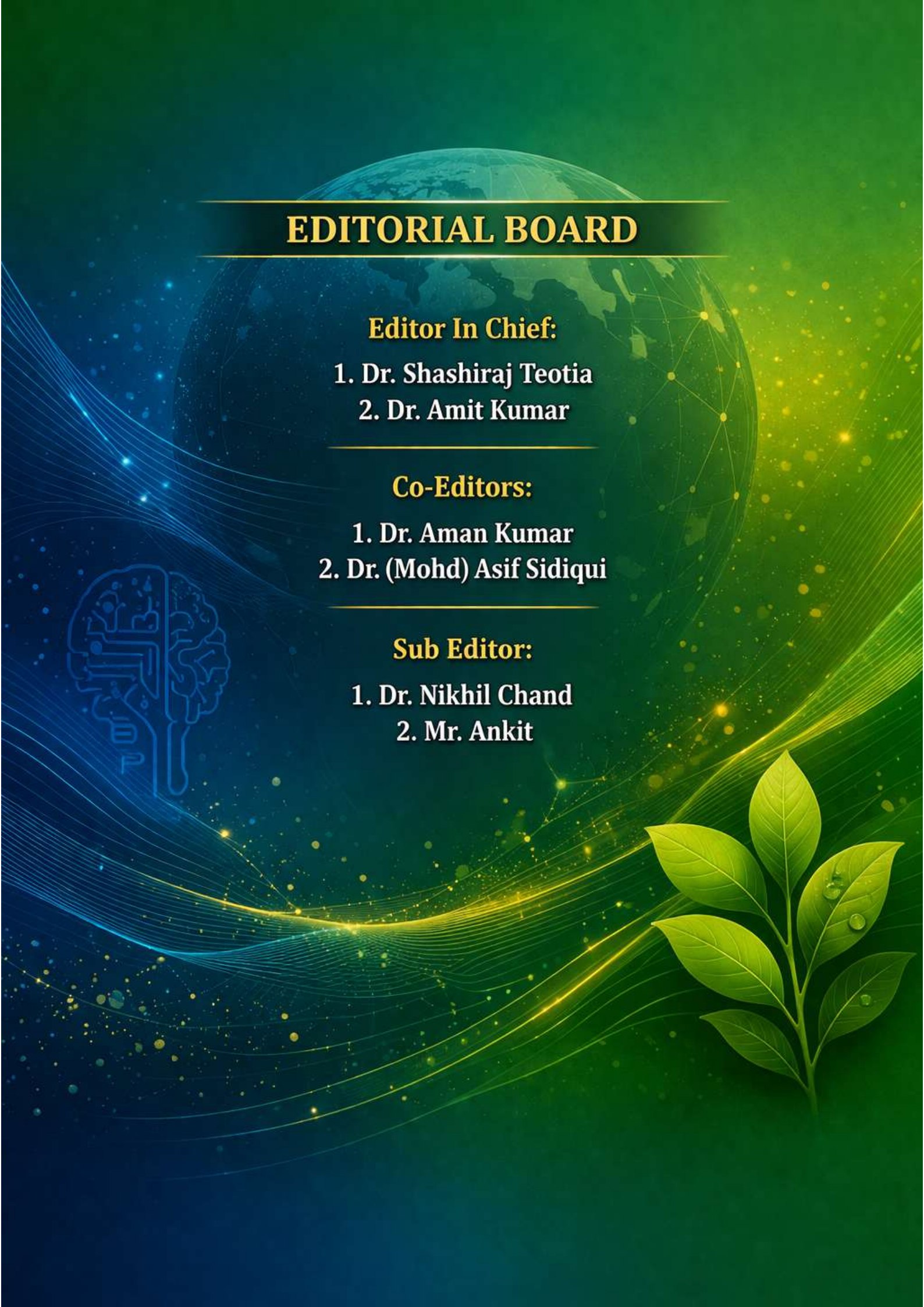
 **26 – 28 March 2026**

Organized by
Keral Verma Subharti College of Science
In Association With
UBA, IIT Roorkee and Unnat Bharat
Cell – SVSU



Swami Vivekanand Subharti University
Meerut, Uttar Pradesh, India

ISBN 978-93-49911-38-3



EDITORIAL BOARD

Editor In Chief:

1. Dr. Shashiraj Teotia
2. Dr. Amit Kumar

Co-Editors:

1. Dr. Aman Kumar
2. Dr. (Mohd) Asif Siddiqui

Sub Editor:

1. Dr. Nikhil Chand
2. Mr. Ankit

The Three-Day International Conference on Sustainable Development & Intelligent Innovation (ICSДИ-2026) aims to bring together academicians, researchers, industry experts, and students on a common platform to deliberate on recent advancements, emerging challenges, and future directions in the fields of science, technology, and innovation. The conference seeks to foster interdisciplinary collaboration and knowledge exchange, addressing critical global issues through sustainable and intelligent solutions. It will serve as a forum for sharing cutting-edge research, promoting innovation, and encouraging meaningful discussions that contribute to scientific progress and societal development. We invite experts to share the issues and benefits with all conference participants under the following themes:

1. Advances in Information Technology for Sustainability
 - Artificial Intelligence for Sustainable Development
 - Machine Learning and Data Analytics for Environmental Protection
 - Internet of Things (IoT) and Smart Cities
 - Big Data for Climate Change Analysis
 - Cloud Computing for Green IT
2. Smart and Sustainable Technologies
 - Smart Agriculture and Precision Farming
 - Smart Energy Systems and Smart Grids
 - Renewable Energy Technologies
 - Smart Transportation Systems
 - Intelligent Water Management Systems
3. Environmental Science and Climate Change
 - Climate Change Mitigation and Adaptation
 - Environmental Monitoring using IT and Remote Sensing
 - Disaster Management and Early Warning Systems
 - Biodiversity Conservation and Technological Interventions
 - Waste Management Technologies
 - Air and Water Quality Monitoring Systems
4. Sustainable Engineering and Innovation
 - Sustainable Manufacturing Technologies
 - Eco-friendly Materials and Processes
 - Digital Transformation for Rural Development
 - Technology for Healthcare and Public Welfare
 - AI-driven Cybercrimes and Their Impact
 - AI-enabled Cyber Threats and Social Security
 - Artificial Intelligence and the Changing Nature of Crime
5. Advances in Biological Sciences
 - Personalized Medicine and Precision Oncology
 - Drug Discovery, Delivery, and Development
 - Microbiome and Human Health
 - Stem Cell Biology and Regeneration
 - Nano-biotechnology in Human Welfare
 - Genomics, Proteomics, and Transcriptomics

ABOUT THE UNIVERSITY

Swami Vivekanand Subharti University (SVSU), Meerut, is a recognized university under Section 2(f) of the University Grants Commission (UGC) Act, 1956. It was established under the Swami Vivekanand Subharti Vishwavidyalaya, Uttar Pradesh Adhiniyam, 2008 (UP Act No. 29 of 2008), as enacted by the Uttar Pradesh Legislature and approved by the Hon'ble Governor of Uttar Pradesh in September 2008.

The University has been accredited with a prestigious '*Grade A*' by the National Assessment and Accreditation Council (NAAC). With 18 constituent colleges offering more than 220 professional and academic programs, SVSU has emerged as one of the leading universities in the country. It is widely recognized for its high academic standards, diverse range of courses, distinguished faculty, vibrant co-curricular environment, and state-of-the-art infrastructure. The University continues to strive for excellence in education, research, and innovation with growing national and international recognition.

ABOUT THE COLLEGE

Keral Verma Subharti College of Science, established in 2013 (formerly known as the Faculty of Science), is committed to delivering quality education across various disciplines of science. The college currently comprises five well-established and fully equipped departments, supported by a team of highly qualified and experienced faculty members dedicated to academic excellence and research.

Under expert guidance, students are encouraged not only to excel academically but also to actively participate in seminars, conferences, workshops, and educational as well as industrial visits. Regular co-curricular and extracurricular activities are organized to ensure the holistic development of students, enhancing both their academic competence and personal growth.

In addition to undergraduate and postgraduate programs, the college offers Ph.D. programs in multiple disciplines. In alignment with the National Education Policy (NEP), the college has introduced several new and interdisciplinary courses since 2022 in collaboration with various departments, thereby fostering innovation, flexibility, and skill-based learning.

ORGANIZING COMMITTEE

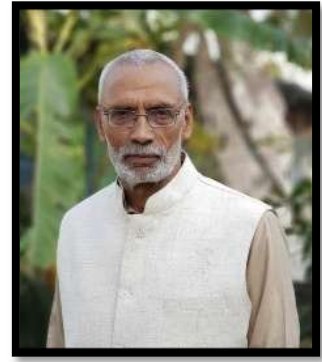
Dr. Manoj Kumar-Associate Professor-KVSCOS	Co-Convener
Dr. Amit Kumar- Associate Professor-KVSCOS	Organizing Secretary
Dr. Dheerpal Singh- Associate Professor-KVSCOS	Joint Organizing Secretary
Dr. (Mohd) Asif Siddiqui - Assistant Professor-KVSCOS	Co-Organizing Secretary
Mr. Ankit Kumar- Assistant Professor-KVSCOS	Co-Organizing Secretary

ADVISORY COMMITTEE

Prof. (Dr) Beer Pal Singh Director (R&D) Chaudhary Charan Singh University, Meerut	Prof. (Dr.) Nand Kumar Singh, Department of Biotechnology MNNIT, Prayagraj, UP India
Dr. R.S.Sengar, Professor, Department of Biotechnology, SVPUA&T Meerut.	Prof. (Dr.) Kedar Singh, Department of Physics, JNU, New Delhi
Prof. (Dr.) Yang-Wei Lin, Department of Chemistry, National Changhua University of Education, 1 Jin-De Road, Changhua City, 50007, Taiwan	Dr. Hanane ETABTI, LIMAS, Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fez 30000, Morocco.
Prof. (Dr.) Ajeet Jain, Department of Finance , Central Connecticut State University, New Britain CT	Dr. Mamta Rani, Professor, Department of CS, Central University of Rajasthan, India

CO-ORGANIZING COMMITTEE MEMBERS

Dr. Naveen Chandra-Associate Professor	Dr. Preeti- Assistant Professor
Dr. Aman- Assistant Professor	Dr. Sarita- Assistant Professor
Dr. Amit Kumar- Assistant Professor	Dr. Anu Chauhan- Assistant Professor
Dr. Nikhil Chand- Assistant Professor	Mr. Lalit- Assistant Professor
Dr. Anuj Yadav- Assistant Professor	Ms. Pragati Jain- Assistant Professor
Mr. Krishanpal Singh- Assistant Professor	Ms. Almash Saifi-Lecturer
Mr. Mukul Sharma- Lecturer	Mr. Mragesh Pratap Singh Lecturer



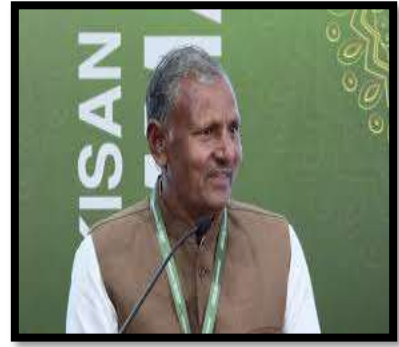
MESSAGE

It gives me immense pleasure to learn that Swami Vivekanand Subharti University, Meerut is organizing a Three Days International Conference on “Sustainable Development & Intelligent Innovation (ICSDII-2026)” from 26th to 28th March 2026. This initiative reflects a commendable effort towards addressing contemporary global challenges through knowledge sharing and innovation. In the present era, where sustainable development has become a global priority, the role of intelligent technologies and innovative thinking is crucial in shaping a better future. Such international platforms provide an excellent opportunity for academicians, researchers, industry experts, and students to exchange ideas, collaborate, and work towards meaningful solutions.

I sincerely appreciate the efforts of the organizers, especially Keral Verma Subharti College of Science, for creating a platform that promotes interdisciplinary research and global cooperation. I am confident that this conference will serve as a catalyst for new ideas and progressive developments in science, technology, and sustainability.

I extend my best wishes to all participants and hope that the conference achieves grand success.

Best Regards,
Padm Shri Bharat Bhushan Tyagi



MESSAGE

It gives me immense pleasure to learn that Swami Vivekanand Subharti University, Meerut is organizing a Three Days International Conference on “Sustainable Development & Intelligent Innovation (ICSDII-2026)” from 26th to 28th March 2026. This initiative reflects a commendable effort towards addressing some of the most pressing global challenges through knowledge sharing and innovation.

In today’s rapidly transforming world, the integration of sustainable development with intelligent technological advancements is essential for ensuring a balanced and progressive future. Platforms like this international conference bring together academicians, researchers, industry experts, and students from across the globe, fostering collaboration and the exchange of ideas that can lead to impactful solutions.

I appreciate the efforts of the organizers, especially Keral Verma Subharti College of Science, for providing such a valuable forum that promotes interdisciplinary research and global partnerships. I am confident that this conference will significantly contribute to advancing scientific knowledge and inspiring innovative approaches for sustainable growth.

I extend my best wishes to all participants and hope that the conference achieves great success in fulfilling its objectives.

Best Regards,
Padm Shri Sethpal Singh



MESSAGE

It gives me immense pleasure to know that Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut is organizing a Three-Days International Conference on **“Sustainable Development & Intelligent Innovation (ICSДИ-2026)”** from **26th to 28th March 2026**. This conference provides an excellent platform for academicians, researchers, industry experts, and students to exchange ideas and deliberate upon emerging challenges and innovations in the fields of science, technology, and sustainable development.

In the present era, sustainable development has become a global priority. The integration of intelligent technologies, scientific research, and innovative approaches plays a vital role in addressing environmental challenges, promoting smart solutions, and ensuring a better future for society. Conferences like ICSДИ-2026 help in strengthening interdisciplinary collaboration and encourage the sharing of knowledge that contributes to the achievement of Sustainable Development Goals (SDGs).

I appreciate the efforts of the organizing committee for taking this initiative to bring together distinguished scholars and experts from India and abroad. Such academic gatherings promote research culture, innovation, and meaningful dialogue among participants.

I extend my best wishes for the grand success of the conference and hope that the deliberations and outcomes of this event will significantly contribute to scientific advancement and sustainable development.

Prof. (Dr.) Pramod Kumar Sharma
Vice Chancellor



Dr. Shalya Raj,

M.D.S



**SWAMI VIVEKANAND
SUBHARTI
UNIVERSITY**
Meerut



UGC Approved GRADE 'A' ACCREDITED BY NAAC

Chief Executive Officer,
Swami Vivekanand Subharti University, Meerut

Professor,
Dept. of Conservative Dentistry & Endodontics
Subharti Dental College, Meerut

Subhartipuram, NH-58, Delhi-Haridwar Meerut Bypass Road, Meerut-250005
Website: www.subharti.org, Email: ceo@subharti.org, Ph: 0121-2439043, 2439052, Fax: 0121-2439067

Dated: 12.03.2026

Message

It gives me great pleasure to learn that Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut is organizing a Three-Days International Conference on “Sustainable Development & Intelligent Innovation (ICSII-2026)” from 26th to 28th March 2026.

In today's rapidly evolving world, the integration of scientific research, technology, and intelligent innovation is essential for achieving sustainable development and addressing global challenges. Conferences like ICSII-2026 provide a valuable platform for academicians, researchers, industry experts, and students to exchange ideas, share research findings, and explore collaborative opportunities for the advancement of science and society.

Such initiatives not only strengthen academic and industry partnerships but also encourage young researchers to think innovatively and contribute toward building a sustainable and technologically empowered future.

I congratulate the organizing committee for their dedicated efforts in hosting this important international conference and bringing together experts from diverse fields. I extend my best wishes for the grand success of the conference and hope that the deliberations will lead to meaningful outcomes and new avenues of research and innovation.

Jai Hind.

Prof. (Dr.) Shalya Raj
Chief Executive Officer
Swami Vivekanand Subharti University
Meerut

Swami Vivekanand Subharti University, Meerut Where Education is a Passion NAAC "A" Accredited

Constituent Colleges / Faculties of the University

| Subharti Dental College | Jyotirao Phule Subharti College of Physiotherapy | Subharti Medical College | Panna Dhai Maa Subharti Nursing College | Sardar Patel Subharti Institute of Law | Chhatrapati Shahuji Subharti Institute of Tech & Engg. | Acharya Vishnu Gupta Subharti Institute of Management & Commerce | Utkalmani Gopabandhudas Faculty of Education | Ganesh Shankar Vidyarthi Subharti Institute of Journalism & Mass Communication | Department of Physical Education | Department of Library & Information Science | Kharvel Subharti College of Pharmacy | Nandlal Bose Subharti Institute of Fine Arts & Fashion Design | Bhikaji Cama Subharti Institute of Hotel Management | Faculty of Arts & Social Science | Department of Para Medical Science | Maharishi Aurobindo Subharti College & Hospital of Naturopathy & Yogic Sciences | Keral Verma Faculty of Science | School of Buddhist Studies



MESSAGE

It is a matter of great pride and satisfaction that Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut is organizing a Three-Days International Conference on “*Sustainable Development & Intelligent Innovation (ICSДИ-2026)*” from 26th to 28th March 2026.

This conference serves as a significant academic platform that brings together researchers, academicians, scientists, and industry professionals to discuss innovative ideas and emerging trends in science and technology. The theme of the conference is highly relevant in today’s context, where sustainable development and intelligent innovations are essential for addressing global challenges and ensuring environmental balance.

The Faculty of Science has always been committed to promoting quality research, interdisciplinary learning, and scientific temperament among students and scholars. This conference reflects our continuous efforts to encourage intellectual exchange, collaborative research, and practical solutions for real-world problems.

I am confident that ICSДИ-2026 will foster meaningful discussions, inspire young researchers, and contribute towards the development of innovative and sustainable strategies for the future. Such initiatives not only enhance academic excellence but also strengthen the research ecosystem of the institution. I extend my heartfelt congratulations to the organizing committee for their dedicated efforts and wish the conference a great success.

Prof. (Dr.) Ravindra Kumar Jain

Dean, Faculty of Science

Swami Vivekanand Subharti University, Meerut



MESSAGE

It gives me immense pleasure to welcome all the distinguished academicians, researchers, industry experts, and students to the **Three-Days International Conference on “Sustainable Development & Intelligent Innovation (ICSDII-2026)”**, being organized by Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut from **26th to 28th March 2026**. The objective of this conference is to provide a dynamic platform for researchers and professionals from across the world to share their knowledge, research findings, and innovative ideas related to sustainable development, emerging technologies, and intelligent innovations. In the present era, the integration of science, technology, and sustainability is crucial to address global challenges and ensure balanced development for future generations.

ICSDII-2026 aims to encourage interdisciplinary discussions on topics such as artificial intelligence, environmental sustainability, smart technologies, renewable energy, biotechnology, and innovative engineering solutions. Through keynote lectures, research paper presentations, and academic interactions, the conference will foster collaboration and inspire new research directions. I sincerely thank our Hon’ble dignitaries, keynote speakers, advisory members, organizing committee, and all participants for their valuable support and contribution. Their enthusiasm and dedication are instrumental in making this conference a meaningful academic gathering.

I hope that the deliberations during this conference will generate insightful discussions and fruitful outcomes that contribute significantly to scientific advancement and sustainable development. I extend my warm welcome to all participants and wish the conference great success.

Dr. Shashiraj Teotia

Convener – ICSDII-2026

HoD, Department of Computer Applications

Keral Verma Subharti College of Science

Swami Vivekanand Subharti University, Meerut



MESSAGE

It is my great pleasure to warmly welcome all distinguished academicians, researchers, industry experts, and students to the Three-Day International Conference on “*Sustainable Development & Intelligent Innovation (ICSДИ-2026)*”, organized by Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, from 26th to 28th March 2026. The primary objective of this conference is to provide a vibrant and interactive platform for scholars and professionals from around the globe to exchange knowledge, present research findings, and share innovative ideas in the fields of sustainable development and emerging technologies. In today’s rapidly evolving world, the integration of science, technology, and sustainability has become essential to address global challenges and ensure inclusive and balanced development for future generations.

ICSДИ-2026 aims to promote interdisciplinary dialogue on diverse themes, including artificial intelligence, environmental sustainability, smart technologies, renewable energy, biotechnology, and innovative engineering solutions. The conference, through keynote lectures, technical sessions, and scholarly interactions, seeks to foster collaboration, stimulate intellectual exchange, and inspire new avenues of research. I extend my sincere gratitude to our Hon’ble dignitaries, keynote speakers, advisory board members, organizing committee, and all participants for their invaluable support and contributions. Their commitment and enthusiasm play a vital role in making this academic event both meaningful and impactful.

I am confident that the deliberations and discussions during this conference will lead to insightful outcomes and significantly contribute to scientific progress and sustainable development. I once again extend a warm welcome to all participants and wish the conference every success.

Dr. Amit Kumar
Organizing Secretary
ICSДИ-2026,
Associate Professor,
Keral Verma Subharti College of Science
Swami Vivekanand Subharti University, Meerut

Preface

It gives me great pleasure to present the proceedings of the Three-Day International Conference on Sustainable Development & Intelligent Innovation (ICSDDI-2026) on 26th to 28th March 2026, organized by Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut. The conference provides an interdisciplinary platform for academicians, researchers, industry experts, and students to share knowledge, discuss emerging trends, and explore innovative solutions for sustainable development.

ICSDDI-2026 focuses on key areas including advances in information technology for sustainability, smart and sustainable technologies, environmental science and climate change, sustainable engineering, and innovations in biological sciences. The conference highlights the role of artificial intelligence, renewable energy, smart systems, environmental monitoring, and modern biotechnological approaches in addressing global challenges.

The objective of this conference is to promote research collaborations, encourage knowledge exchange, and inspire innovative thinking aligned with sustainable and technological advancement. It also aims to bridge the gap between academia and industry while fostering young researchers.

We express our sincere gratitude to all contributors, speakers, reviewers, and the organizing committee members for their valuable efforts. We also acknowledge the support of Swami Vivekanand Subharti University, Meerut for making this event successful.

We hope that this volume of proceedings (ISBN) will serve as a valuable resource for researchers and inspire further advancements in the field of sustainable development and intelligent innovation.

INDEX

S.No.	Title of Abstracts and Author Name	Page No.
1.	The importance of National Gas Sensor Testing and Certification Facility and metal oxide based high performance gas sensors Preetam Singh* <i>CSIR-National Physical Laboratory, Dr. K.S. Krishnan Marg, New Delhi, 110012, India</i> *Email: singhp.nplindia@csir.res.in	1
2.	Green Nanomaterial Platforms: Sustainable Environmental Monitoring and Active Pollution Remediation Yang-Wei Lin* <i>Department of Chemistry, National Changhua University of Education, Taiwan</i> *Email: linywjerry@cc.ncue.edu.tw	2
3.	Structural Insights into a Thermostable Hydrolase for Phthalate Detoxification and PET Plastic Biodegradation Pravindra Kumar Department of Biosciences and Bioengineering, Indian Institute of Technology Roorkee Roorkee-247667, Uttarakhand, India Email: pravindra.kumar@bt.iitr.ac.in	3
4.	Inorganic Surfaces as Catalytic Platforms <u>Manjinder Kour</u> ^{*a} , Sapna Jadoun ^b ^a Montana State University, Bozeman, Montana, 59717 United States of America. ^b Universidad de Tarapacá: Arica, Parinacota, Chile. *Corresponding author: <u>^a manjinderkour1992@gmail.com</u>	4
Theme 1-Advances in Information Technology for Sustainability		
1.	AI-Driven Digital Forensics: Enhancing Evidence Identification Using Machine Learning Shashiraj Teotia Department of Computer Application, Swami Vivekanand Subharti University Meerut, 250001	6
2.	Exploring AI with Sustainability in Precision Agriculture Sandeep Computer Application, SVSU Meerut	7
3.	Quantum Machine Learning Models Deployed over Fog Computing Infrastructure for IoT Applications Shashi Department of computer application, CCS University Meerut, UP.	8
4.	AI-Driven Personalized Learning and Its Impact on Sustainable Education in Business Schools Archana Singh ¹ , and Neha Saini ² Research Scholar, Suresh Gyan Vihar University, Jaipur Assistant Professor Suresh Gyan Vihar University, Jaipur	9
5.	A Comparative Analysis of Software Testing Models and Standards for Selecting the Best Testing Techniques in the Software Development Life	10

	Cycle Almash Saifi PhD Scholar, Computer Applications, Swami Vivekanand Subharti University, Meerut	
6.	Technology-Driven Waste Management Systems in Haryana, India: Supporting Sustainable Cities and Responsible Consumption (SDG-11 and SDG-12) Satya Pratap Singh¹, and Tanu Gaur² ¹<i>Research Scholar, Subharti University, Meerut</i> ²<i>Assistant Professor, Vinayak Vidyapeeth, Meerut & Research Scholar, subharti University, Meerut</i>	11
7.	Smart and Digital Technologies for Biodiversity Conservation in Haryana, India: Pathways to Achieve SDG-13 and SDG-15 Tanu Gaur Research Scholar, Subharti University, Meerut, India	12
8.	Exploring Text Classification Methods for Efficient Information Extraction from Research Articles Himanshu, Prem Kishor Gautam, and Srishti Agarwal Meerut Institute of Technology, Meerut, Uttar Pradesh, India	13
9.	Digital Entrepreneurship and Sustainable Development: Leveraging Intelligent Innovation for Inclusive Growth ¹Lekhika Prakash, ²Himanshu, and ²Ritika Garg ¹Department of Applied Science & Management, Meerut Institute of Technology ²Department of Computer Science & Engineering, Meerut Institute of Technology	14
10.	Online Movie Booking System Manshi Department of Computer Application, Swami Vivekanand Subharti University, Meerut	15
11.	Student Dropout Prediction System Nitish Rana Department of Computer Application, Swami Vivekanand Subharti University, Meerut.	16
12.	Energy-Efficient Consensus: A Comparative Analysis of Sharding and Proof-of-Stake in Sustainable Blockchain Architectures Krishanpal Singh Department of Computer Application, Swami Vivekanand Subharti University Meerut,250001	17
13.	Beyond Irreversibility: Inverse Physical Scene Reconstruction from Degraded Observations via Hybrid Transformer–Mamba Modelling Daksh Bhardwaj Department of Computer Science, KVSCOS, Swami Vivekanand Subharti University, Meerut, India	18
14.	IoT and Smart cities Kanak Sharma	19

	B.Sc. Forensic Science, KVSCOS, Swami Vivekanand Subharti University, Meerut	
15.	The Role of Artificial Intelligence in Modern Criminal Activities and Social Security: Forensic Insights into AI Misuse in Cybercrime Anuradha M.Sc. Forensic Science, Department of Forensic Science, Chaudhary Charan Singh University, Meerut	20
16.	A Deep Learning Framework for Long-Horizon Traffic Congestion and Travel Time Prediction Sanjeev Panwar ¹ , Paramjeet Rawat ² Department of Computer Application, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India	21
17.	Proposed CNN–NLP Framework for Behavioral and Semantic Threat Detection Mragesh Pratap Singh Research Scholar, PhD, Department of Computer Application, KVSCOS, Swami Vivekanand Subharti University, Meerut, India.	22
18.	Seminar Hall Booking for College Rohan Rudhiyal (PG Scholar) Department of Computer Application, Swami Vivekanand Subharti University, Meerut	23
19.	Vehicle Theft Online Complaint System Aman Silot (PG Scholar) Department of Computer Application, Swami Vivekanand Subharti University, Meerut.	24
20.	Breast Cancer Disease Prediction Using Machine Learning Mitali Saini Department of Computer Application, Swami Vivekanand Subharti University, Meerut, India	25
21.	The Smart Energy Monitoring System Garvit Chaudhary (PG Scholar) Department of Computer Application, Swami Vivekanand Subharti University, Meerut	26
22.	Design and Optimization of Energy-Aware Green IoT Systems for Smart Cities Ankit Kumar Department of Computer Application, Faculty of Science, SVSU, Meerut	27
23.	College Voting System for Leader Election Anushikha Tomar (PG Scholar) Master of Computer Application (MCA), Department of Computer Application, Swami Vivekanand Subharti University, Meerut.	28
24.	Crime Data Analysis System Chitransh Tyagi Department of Computer Application, Swami Vivekanand Subharti University, Meerut.	29
25.	AI-Driven Automated Software Bug Detection and Repair	30

	Manoj Kumar Associate Professor, Department of computer application Swami Vivekanand Subharti University, Meerut.	
26.	Carbon-Differential Workload Migration in Distributed Cloud Data Centers: A Deterministic Energy-Proportional Scheduling Framework Naveen Chandra Department of Computer Applications, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India	31
Theme 2-Smart and Sustainable Technologies		
1.	Length-Weight Relationship and Growth Pattern Analysis of Channa punctatus from the Ganga River, Bijnor and Cirrhinus mrigala from Ram Taal Lake, Meerut: A Comparative Study of Allometric Growth and Environmental Influence Shagun Rathi, Neeru Singh*, Mohd. Faisal Siddiqui, Dheer Pal Singh, Aanchal Sharma Department of Life Science, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut	33
2.	Green Chemistry Approaches for Sustainable Development: Strategies for a Cleaner and Greener Future ^a Namra Babar*, ^a Nisha ^a Department of Chemistry, Faculty of Science, Swami Vivekanand Subharti University, Meerut	34
3.	Biochemical conversion of agri-food waste into high value biopolymers: A sustainable biorefinery approach towards circular bioeconomy. Purvi kalkhande Department of life science (biochemistry), Kerala Verma Subharti College of Science, Swami Vivekananda Subharti University, Meerut, UP, India	35
4.	Effect of Integrated Nutrient Management in Bread Wheat (Triticum Aestivum L.) Aarushi Vats ¹ , and Saurabh Tyagi ² ¹ Researcher (PG), Department of Agriculture (KVSCOS), Swami Vivekanand Subharti University, Meerut, (UP) India ² Department of Agriculture (KVSCOS), Swami Vivekanand Subharti University, Meerut, (UP) India Email Id-aarushivats51@gmail.com	36
5.	Climate Smart Nutrients and Water Management Strategies for Sustainable Rice Production Kanika ^{1*} , and Saurabh Tyagi ² ¹ Researcher (PG), Department of Agriculture (KVSCOS), Swami Vivekanand Subharti University, Meerut, UP, India ² Department of Agriculture (KVSCOS), Swami Vivekanand Subharti University, Meerut, UP, India	37
6.	Artificial Intelligence in Drug Discovery: Computational Methods, Tools, and Emerging Applications Mohd Asif Siddiqui ¹ , and Indu ²	38

	¹ Department of Life Science, Swami Vivekanand Subharti University, Subhartipuram, NH-58, Delhi-Haridwar Bypass Road, Meerut-250005. ² Assistant Professor, School of Arts and Humanities, IIMT University, Meerut	
7.	An inclusive Review on Fermented Chilli Extract in Sustainable Agriculture: Biopesticidal Mechanisms, Applications and Future Opportunities Priyanshu Rana, Ashwani Kumar*, Aysha Pundir, Shagun Tomar, Kanupriya Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India	39
8.	The Efficacy and Potential of Fermented Ginger (<i>Zingiber officinale</i>) as a Sustainable Biopesticide: A Comprehensive Review Shagun Tomar, Ashwani Kumar*, Aysha Pundir, Priyanshu Rana, Kanupriya Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India	40
9.	Novel Approaches in Drug Discovery: Integrating Natural Bioactives, Nanotechnology, and Computational Methods Bhupesh Singh*, Dhanendra Kumar Rai Department of Life Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India, 250005	41
10.	A single vendor and multiple buyers integrated inventory policy in demand declining market Ankit Kumar Goyal Department of Basic Science, Keral Verma Subharti College of Science, SVSU, Meerut	42
11.	Nanostructured Metal Oxides as Foliar Modulators of Growth, Photosynthesis, and Seed-Oil Bioactivity in Moringa (<i>Moringa oleifera</i> L.) Anupriya Rana ¹ , Ashwani Kumar ¹ , Sarita Rana ¹ , Ritika Yadav ¹ , Shachi Tiwari ¹ ¹ Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh.	43
12.	Application of Spices as Bio preservative in Indian Food Mehrukh Iffat Ph.D. Scholar, Biotechnology, KVSCOS, SVSU, Meerut	44
13.	Hospital Management System Ritik Singh (PG Scholar) Department of Computer Application, Swami Vivekanand Subharti University, Meerut	45
14.	Tracing Lineage and Relations: Ethical AI-Driven Sustainable Forensic Anthropology Lalit Panwar Department of Forensic Science, Faculty of Science, Swami Vivekanand Subharti University, Meerut 250005, U.P., India	46
15.	AI-Driven Strategies for Combating New-Age Cybercrime: Towards Sustainable Digital Security Pragati Jain Department of Forensic Science, Faculty of Science, Swami Vivekanand Subharti University, Meerut 250005, U.P., India	47

16.	Hi-Tech Polyhouse – A True Value of Protected Cultivation Mahima Sharma and Saurabh Tyagi Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University Meerut; (UP) India	48
17.	IoT-Based Agriculture: The Future of Indian Farming Saurabh Tyagi and Sunil Kumar Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University Meerut; (UP) India	49
18.	Climate Smart Agriculture for a Sustainable World Saurabh Tyagi and Apurv Kaintura Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University Meerut; (UP) India	50
19.	Smart Agro-forestry Management for One Health Saurabh Tyagi and Neha Pant Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University, Meerut; (UP) India	51
20.	Intelligence-Based Plant Breeding for Improved Food Quality Pulkit Sharma and Mahima Sharma Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University Meerut; (UP) India	52
21.	Role and Importance of Smart Botanical Gardens in India Satvaan Kumar Singh and Mohd. Rizwan Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University, Meerut; (UP) India	53
22.	Sensor-Based Water Management in Rice–Wheat Cropping System Apurv Kaintura and Saurabh Tyagi Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University Meerut; (UP) India	54
Theme 3-Environmental Science and Climate Change		
1.	A Review of The Toxic Effect of Fungicides on Various Physiological Aspects of Fish Tanya ^{1*} , and Neeru Singh ^{2*} ¹ Ph.D. Scholar, Assistant Professor, Department of Zoology, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut- 250005, U.P. ² Department of Zoology, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut- 250005, U.P.	56
2.	To test the efficacy of some fungal isolates for biodegradation of plastic polymer Shagun ¹ , Abhishek Thakur ¹ and Shipra Chaudhary ¹ ¹ Meerut Institute of Engineering and Technology, Meerut	57
3.	Qualitative Screening of Microbial Strains Isolated from Different Sources for Pectin-Degrading Capability Misbah Fatima*, Almas Nauseen, Ananya Chaudhary and Dr. Ashima Kathuria Department of Biotechnology, Meerut Institute of Engineering & Technology, Meerut	58
4.	Microbial Consortia for Rice Stubble Decomposition: Mechanisms, Efficiency, and Environmental Impacts – A Systematic Review	59

	Ritik Joshi¹, Adesh Kumar^{2*} Ashwani Kumar² and Ravinder Kumar Jain² ¹Ph.D. Scholar Microbiology, Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut Uttar Pradesh, India, 250005 ^{2*}Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut Uttar Pradesh, India, 250005	
5.	Phytochemical Screening and Comparative Study of Antioxidant Potential in Different Commercial Brands of Herbal Tea Masala Nikhil Kumar and Adesh Kumar Department of Life Science, Keral Verma Subharti College of Science, Subharti University, Meerut, Uttar Pradesh	60
6.	Industrial Enzymes: Empowering Bioeconomy and Environment Sustainability Ashima Kathuria and Khushboo Gupta* Department of Biotechnology, Meerut Institute of Engineering & Technology, Meerut, U.P.	61
7.	Nano-fertilizer-Mediated Nutrient Delivery for Improved Productivity and Sustainable Cultivation of Soybean and Groundnut Palak Sharma, Anupriya Rana^{1*}, Ashwani Kumar¹, Sarita Rana¹, Ritika Yadav¹ ¹ Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh.	62
8.	Biodiversity Loss in the Anthropocene: Challenges and Sustainable Solutions Asad Chauhan¹, Farhan Khan², Amit Adhikari³ Department of Life Science, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India	63
Theme 4- Sustainable Engineering and Innovation		
1.	An ab initio Study of Double Perovskite Cs₂NaTiBr₆ for Solar Cell Application Aadi Verma^{1*}, Anshika Sharma¹, Nikki Sharma¹, Sana¹, Aman Kumar², Vivek Kumar Nautiyal¹ ¹Department of Physics, Chaudhary Charan Singh University Campus, Meerut- 250004, INDIA ²Department of Physics, KVSCOS, Swami Vivekanand Subharti University, Meerut 250005, India	65
2.	Continuous Fixed-Bed Column Studies on Cadmium Removal Using Sodium Carbonate–Modified Tea Factory Waste Samarpita Gupta¹, and Subhrajyoti Deb² ¹M.Tech Scholar, Water Resources Engineering, Department of Civil Engineering, The ICFAI University Tripura, India ²Assistant Professor, Department of Civil Engineering, The ICFAI University Tripura, India	66
3.	Eco-Friendly Electricity Generator from Busy Road Kaushal Pratap Singh¹, and Nitin Verma² ¹BN College of Engineering & Technology, Lucknow, U.P. ²RV. Institute of Technology, Bijnor, U.P	67

4.	Comparative Analysis of Phthalocyanine-Based Charge Transport Layers in Lead-Free Perovskite Solar Cells Kanishka Choudhary Research Scholar, Physics Department, SRM Institute of Science and Technology NCR Campus, Modinagar, Ghaziabad U.P.	68
5.	First-Principle Study of Double Perovskite $\text{Rb}_2\text{NaTiBr}_6$ for Optoelectronics Properties Anshika Sharma ^{1*} , Aadi Verma ¹ , Nikki Sharma ¹ , Sana ¹ , Aman Kumar ² , Vivek Kumar Nautiyal ¹ ¹ Department of Physics, Chaudhary Charan Singh University, Meerut-250004, India ² Department of Physics, KVSCOS, Swami Vivekanand Subharti University, Meerut 250005, India	69
6.	A DFT study of double perovskite $\text{Cs}_2\text{NaTiCl}_6$ for photovoltaic application Nikki Sharma ^{1*} , Aadi Verma ¹ , Anshika Sharma ¹ , Sana ¹ , Aman Kumar ² , Vivek Kumar Nautiyal ¹ ¹ Department of Physics, Chaudhary Charan Singh University Campus, Meerut- 250004, INDIA ² Department of Physics, KVSCOS, Swami Vivekanand Subharti University, Meerut 250005, India	70
7.	Recent progresses in design, fabrication and applications of iron-based nanoparticles Geetanjali Singh, and Preeti Singh* Department of Basic Science, Faculty of Science, Swami Vivekanand Subharti University, Meerut 250005, U.P. India.	71
8.	Chemical Assessment of Major Essential Elements (Na, Mg, K, and Ca) in Groundwater Shakebul Hasan ^{1*} , Venus Dillu ² ^{1,2} Department of Applied Physics, Gautam Buddha University, Gautam Budh Nagar, Uttar Pradesh, India - 201312	72
9.	Artificial Intelligence in Ethical and Black Hat Hacking: A Forensic Perspective for Sustainable Digital Development Vanshika Department of Forensic Science, Keral Verma Subharti College of Science	73
10.	Fixed Point Approximation Using Refined Iterative Method for Enriched Suzuki Mappings in Banach Space Sumbul Kaneez ¹ , Faeem Ali ² , and Aftab Alam ³ ^{1,3} Department of Mathematics, Swami Vivekanand Subharti University, Meerut-250005, India ² Department of Applied Mathematics, Aligarh Muslim University, Aligarh-202002, India	74
11.	Structural and Optical Response of Ceria to Gamma Irradiation Charul Uniyal ¹ , Akanksha Malik ² , Anshu Singh ^{3*} , Ankur Kumar ^{4*} , Manoj Yadav ^{1*} ¹ Department of Physics, Sri Dev Suman Uttarakhand University Campus	75

	Rishikesh, Uttarakhand- 249201, India ²Department of Physics, Kanya Gurukul Campus, Gurukul Kangri Deemed to be University, Haridwar, Uttarakhand-249404, India ³Department of Basic Science, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India ⁴Department of Physics, Sri Dev Suman Uttarakhand University Campus Gopeshwar, Uttarakhand-246401, India	
12.	Impact of Fe Concentration on the Properties of Fe and W co-doped V₂O₅ Akanksha Malik¹, Anshu Singh^{2*}, and Richa Saini^{1*} ¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India ⁶Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India	76
13.	The Effect of La doping on Cerium Oxide for the Enhanced Dielectric Performance Ritul^{1*}, Akanksha Malik¹, Richa Saini^{1*}, Anshu Singh^{2*} ¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India ²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India	77
14.	Structural & Optical Properties of Gamma Irradiated CeO₂ Thin Films Anshu Singh^{1*}, Akanksha Malik², Richa Saini² ¹Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India ²Department of Physics, Kanya Gurukul Campus, Gurukul Kangri Vishwavidyalaya, Haridwar, Uttarakhand-249404, India	78
15.	Structural, and Magnetic Properties of Cerium Oxide Nanoparticles Synthesized by Sol-gel Method Aditi Chauhan^{1*}, Akanksha Malik¹, Richa Saini^{1*}, Anshu Singh^{2*} ¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India ²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India	79
16.	Structural and Phase Analysis of V₂O₅ via X-ray Diffraction & Rietveld Refinement Saloni Chauhan^{1*}, Akanksha Malik¹, Richa Saini^{1*}, Anshu Singh^{2*} ¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India ²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India	80
17.	In Vitro Assessment of Sodium Chloride-Induced Salinity Stress on Germination and Seedling Development in Dalbergia sissoo Roxb. Nikhil Chand¹, Ritika Yadav¹, Dhanendra Kumar Rai¹, Sarita Rana¹ ^{1,2,3,4}Department of Biotechnology, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut-250005 (INDIA).	81
18.	A Comprehensive Theoretical Analysis of Cs₂KGaX₆ (X = Cl, Br, I): for Green Energy Solutions	82

	Aman Kumar Department of Physics, K.V. Subharti College of Science, Swami Vivekanand Subharti University, Meerut, 250005, India	
19.	Optimization of Fe Doping in V ₂ O ₅ Nanoparticles for Improved Structural and Optical Properties Divyanshi Giri ¹ , Akanksha Malik ¹ , Richa Saini ^{1*} , Anshu Singh ^{2*} ¹ Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India ² Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India	83
20.	Review on Biochemical Characterization of Enzymes in Biofuel-Producing Cyanobacteria: Mechanisms, Applications and Future Perspectives ¹ Jigyasa Yadav, ^{2*} Ashwani Kumar, ³ Punjab Singh Malik, and ² Sarita Rana ¹ Ph.D Scholar Biochemistry, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India ^{2*} Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India ³ Department of Botany, Meerut College Meerut, Uttar Pradesh, India	84
21.	Stability Analysis of Thermal Convection in a Rivlin –Ericksen Nanofluid Induced by Thermophoresis with Nanoparticle Transport Between Parallel Plates Aftab Alam Department of Basic Science, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut	85
22.	Modification of the Structural and Luminescence Properties of Ni doped V ₂ O ₅ Nanoparticles Harshita Verma ¹ , Akanksha Malik ¹ , Richa Saini ^{1*} , and Anshu Singh ^{2*} ¹ Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India ² Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India	86
23.	Fe dopant Tuned the Properties of Vanadium Pentoxide Nanoparticles Jahanvi Kukreti ¹ , Akanksha Malik ¹ , Richa Saini ^{1*} , and Anshu Singh ^{2*} ¹ Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India ² Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India	87
24.	Applications of Smart Technologies in Healthcare: The Role of Ai and Machine Learning Deepshikha Hudda ^{*1} and Aftab Alam ¹ ¹ Department of Basic Science, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut	88

25.	Effect of W Doping on the Structural and Optical Properties of V ₂ O ₅ Nanoparticles for Thermoelectric Applications Nikita Pundir ¹ , Akanksha Malik ¹ , Richa Saini ^{1*} , Anshu Singh ^{2*} ¹ Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India ² Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India	89
26.	Review on Role of Nutrition in Preventing Lifestyle Diseases Ashwani Kumar*, Shagun Sharma, Anupriya Rana, Adesh Kumar Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India	90
27.	Correlation of Structural and Morphological Properties in W-Doped V ₂ O ₅ for Thermoelectric Applications Bhawana Joshi ¹ , Akanksha Malik ¹ , Richa Saini ^{1*} , Anshu Singh ^{2*} ¹ Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India ² Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India	91
28.	Investigating Noise-Resilient Circuit Topologies for Variational Quantum Eigen solvers Amit Kumar Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India	92
29.	Use of Bioinformatics Tools for Early Detection and Prediction of Genetic Diseases Surya Saini ¹ , Manshi ² , Nikhil Chand ³ , Dhanendra Kumar Rai ⁴ ^{1,2} Department of Life Science, Keral Verma Subharti College of Science, Swami Vivekananda Subharti University, Meerut. ^{3,4} Assistant Professor, Department of Life Science, Keral Verma Subharti College of Science, Swami Vivekananda Subharti University, Meerut.	93
30.	MnO ₂ /MWCNT Nanocomposites as High-Performance Supercapacitor Electrodes Riya Gaur ^{1*} , Sonia Zeba Hashmi ¹ , Department of Chemistry, Banasthali Vidyapith, Rajasthan, 304022, India	94
31.	Highly Sensitive Hydrogen Gas Detection using Magnetron Sputtered Pt-Decorated 2D MoSe ₂ Nanostructured Thin Film Sensor Pawan kumar ¹ , and Anuj Kumar ^{1,*} ¹ Molecular Simulation and Energy Storage Laboratory, Department of Physics, Chaudhary Charan Singh University, Meerut,250001, Uttar Pradesh, India.	95
32.	Mathematical Modeling on Hedge Fund Investment Strategies in Emerging Markets under Geopolitical and ESG-Related Crises Vikas Kumar ¹ and Amita ² ¹ Department of Basic Sciences, Keral Verma Subharti College of Science Swami Vivekanand Subharti University, Meerut	96

	² Research Scholar, Department of Basic Sciences, Keral Verma Subharti College of Science Swami Vivekanand Subharti University	
33.	A Review of Graphs Associated with Finite Groups Vikas Kumar ¹ and Sonia ² ¹ Department of Basic Sciences Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut ² Research Scholar, Department of Basic Sciences, Keral Verma Subharti College of Science Swami Vivekanand Subharti University, Meerut	97
34.	Forecasting of Hedge Fund Strategies by Mathematical Models in Capital Markets Vikas Kumar Department of Basic Sciences, SVSU	98
Theme 5- Advances in Biological Sciences		
1.	The Separated Self: Human-Nature Disconnection as the Unaddressed Root Driver of Anthropocene Destabilization Amit Adhikari Department of Life Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India	100
2.	Multi-Omics Integration Reveals Microbial Consortia-Driven Sugarcane Trash Decomposition for Sustainable Agriculture: A Review ¹ Anuradha Sinha, ² Adesh Kumar ² Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India, 250005	101
3.	Toxicity and Recovery Response of Malathion on Biochemical, Physiological, and Genotoxic Parameters in Channa punctatus from the Meerut Region Gauri Sharma ¹ and Dr. Dheer Pal Singh ² ^{1,2} Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut	102
4.	Green Synthesis and Characterization of Bioplastics for A Sustainable Environment Harshita Nagar ¹ , and Sangeeta Dayal ² ¹ Research scholar, Department of Life Science, Swami Vivekanand Subharti University, Meerut ² Department of Life Science, Swami Vivekanand Subarctic University, Meerut	103
5.	Sustainable Plant-Based Innovation in Cancer Therapeutics: Proposed In-Vitro Evaluation of Ocimum sanctum Leaf Extract Shweta Chaudhary ^{1*} , and Mohd Asif Siddiqui ² ¹ Ph.D. Research Scholar, Department of Biotechnology, Keral Verma Faculty of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India ² Department of Biotechnology, Keral Verma Faculty of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India	104
6.	Quality Assessment of Raw Milk and Dairy Products through Biochemical and Microbiological Analysis	105

	Abhishek kumar ^{1*} , Rekha Yadav ¹ ¹ Department of Biotechnology and microbiology, Meerut Institute of Engineering and Technology, Meerut.	
7.	Biodegradation of Low-Density Polyethylene by Indigenously Isolated Microbial Consortia Megha Verma, Mohd Asif Siddiqui Department of Life Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India	106
8.	In Silico Approaches for the Identification of Anticancer Bioactive Compounds from Medicinal Mushrooms Anjali Verma ¹ , Krishna Sundari Sattiraju* Department of Biotechnology, Jaypee Institute of Information Technology, A-10, Sector-62, 201309, Noida, Uttar Pradesh	107
9.	Antimicrobial Activity of Turmeric against Biofilm Forming Staphylococcus Aureus Isolate from Cow Milk Shudanshu Sharma ¹ , Ravindra Kumar Jain ^{1*} ¹ Department of Biotechnology, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, U.P. India – 250005	108
10.	A Comparative Analysis of Antimicrobial Resistance Patterns among Escherichia coli, Pseudomonas aeruginosa and Staphylococcus aureus Sushil Giri ^{1,2} , Umesh ² and Adesh Kumar ¹ ¹ Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut Uttar Pradesh, India, 250005 ² Department of Microbiology, Govt. Medical College Haldwani, Nainital, Uttarakhand-263139	109
11.	TLC based Comparative Analysis of Qualitative Phytochemical Characteristics of Eclipta alba and Eclipta prostate Anuj ¹ , Ashwani Kumar* ² , Ravindra Kumar Jain ² , and Nikhil Chand ² ¹ Research Scholar, Biotechnology, Swami Vivekanand Subharti University, Meerut, India ² Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India	110
12.	Therapeutic Potential of Naringin in the Prevention of Age-Related Disorders-A Systematic Review ¹ Shrashti Teja, ^{2*} Ashwani Kumar, ² Ravindra Kumar Jain, ² Adesh Kumar ¹ Ph.D Scholar Biotechnology, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India ² Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India	111
13.	Plant-Derived Bioenzymes: Efficacy, Extraction Strategies, and Versatile Applications – A Comprehensive Review ¹ Unaiza Hashmi, ^{2*} Ashwani Kumar, ² Ravindra Kumar Jain, ² Dheer Pal Singh, ² Neeru Singh, ² Anchal Sharma	112

	¹ Ph.D Scholar Biotechnology, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India ² Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India	
14.	Waste to Wealth: Converting Plant Residues into Sustainable Bioplastic for a Plastic-Free Future Harshita Nagar ¹ , and Sangeeta Dayal ² ¹ Research scholar, Department of Life Science, Swami Vivekanand Subharti University, Meerut ² Department of Life Science, Swami Vivekanand Subarctic University, Meerut, UP, India	113
15.	Resveratrol as a Promising Antitumor Phytochemical: Mechanisms, Therapeutic Potential, and Future Perspectives ¹ Damini Rajora, ^{2*} Ashwani Kumar, ² Ravi Kumar, ³ Shlok Jindal ¹ Ph.D Scholar Biotechnology, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India ^{2*} Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India ³ CRS Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India	114
16.	Phytochemical Analysis and Potential Bioactive Properties of Turmeric Leaves Bioenzyme Aysha Pundir, Ashwani Kumar*, Shagun Tomar, Priyanshu Rana, Kanupriya Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India	115
17.	Phytochemical Analysis and Potential Bioactive Properties of Garlic (Allium sativum) Bioenzyme Kanupriya, Ashwani Kumar*, Shagun Tomar, Priyanshu Rana, Aysha Pundir Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India	116
18.	Isolation of Antibiotic-Resistant Bacteria from Municipal Sewage Water Ashwani Kumar*, Shubham Raj, Anupriya Rana, Ritika Yadav Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India	117
19.	Novel Approaches in Drug Discovery and Development: A Multidisciplinary Perspective Tosha, Sarita Rana, Dhanendra Kumar Rai Department of Life Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India	118
20.	Antibacterial and Phytochemical Exploration of Moringa Leaves: Sweta Kumari ,Sanjana Kumari , Dhanendra Kumar Rai Department of Life Science, Swami Vivekanand Subharti University, Meerut,	119

	India	
21.	Isolation and characterization of Cellulose producing microorganisms from soil sample Mariva Shehzad ¹ , Anuradha Sinha ¹ , Adesh Kumar ¹ , Ravinder Kumar Jain ¹ ¹ Department of Life Sciences, Swami Vivekanand Subharti, University, Meerut, India	120
22.	Discovery of Bioactive Phytochemicals with Antibacterial Activity from <i>Azadirachta indica</i> Leaves Sanjana Kumari, Sweta Kumari, Dhanendra Kumar Rai Department of Life Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India	121
23.	Microbiome–Immunity Axis: Emerging Insights into the Role of the Human Microbiome in Human Health and Disease Anupriya Kumari*, Dhanendra Kumar Rai, Nikhil Chand Department of Life Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India	122
24.	Using AI and Bioinformatics to Track Antimicrobial Resistance (AMR) and discover new drugs target ¹ Kirti, and ² Nikhil Chand ¹ Research scholar, Department of life science, Swami Vivekanand Subharti University, Meerut ² Department of Life Science, Swami Vivekanand Subharti University, Meerut	123
25.	Optimization of Biofilm-Forming Microbial Consortia for Textile Effluent Treatment Komal Sharma, and Ravindra Kumar Jain* Department of Biotechnology, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, U.P. India – 250005	124
26.	Comparative Stress Responses of Salt-Sensitive and Salt-Tolerant Wheat under NaCl and PEG-Induced Osmotic Stress Amit Kumar Faculty of Science, Swami Vivekanand Subharti University Meerut-250005	125
27.	Recent Developments in Microbial Enzymes for Industrial and Biotechnological Applications Sarita Rana, Anu Chauhan, Ritika Yadav, Dhanendra Kumar Rai, Ashwini kumar Department of Life Sciences, Swami Vivekanand Subharti University, Meerut	126
28.	Drug Discovery, Delivery, and Development: Modern Approaches in Pharmaceutical and Biotechnology Research Varnika Ahalawat and Nikhil Chand Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India	127
29.	EV Recharge: Finding the Nearest Electric Vehicle Charging Station Manish Dayal Nishad Department of Computer Application, Swami Vivekanand Subharti	128

	University, Meerut	
30.	Online Complaint Registration and Management System Mohd Shahvej Department of Computer Application, Swami Vivekanand Subharti University, Meerut, India	129
31.	Proposed Energy-Efficient Renewable Energy Framework for Sustainable Development Mukul Sharma Department of Computer application, KVSCOS, Swami Vivekanand Subharti University, Meerut	130
32.	AI-Based Early Flood Prediction System Using Edge Computing Ritika goel MCA, Department of Computer Applications, KVSCOS, Swami Vivekanand Subharti University, Meerut, India	131
33.	Environmental pollution: its effects on life and its remedies Ruqayya Saleem & Dr. Dheer Pal Singh Department of Life science K.V Subharti college of science, Swami Vivekanand Subharti university, Meerut U.P (INDIA)	132
34.	First-Principles Insights into Structural, Optical, and Thermoelectric Characteristics of BaTiO ₃ for Multifunctional Applications Aarzoo Chaudhary, and Aman Kumar Department of Basic Sciences, (Physics), KVSCOS, Swami Vivekanand Subharti University, Meerut-250005, India.	133
35.	Autonomous Symbiotic Resource Network (ASRN), An AI-Driven Closed-Loop Framework for Sustainable and Resilient Urban Infrastructure Sharad Yadav Swami Vivekanand Subharti University, Meerut, India	134
36.	Eco-Friendly Materials and Sustainable Processes for Environmental Protection Sonia Choudhary* and Dheer Pal Singh Department of Life Science, K. V. Subharti College of Science, Swami Vivekanand Subharti University, Meerut (U.P.), India	135
37.	Data Visualization Dashboard for University Vikas Dhaka Department of Computer Application, Swami Vivekanand Subharti University, Meerut	136
38.	Exploring The Role of Human Micro Biome and Plant Based Antimicrobials for Improving Human Health Vanshika Tyagi, Sangeeta Dayal Department of life science, swami Vivekanand Subharti University, Meerut, UP, India	137
39.	Role of Beneficial Microorganisms in Accelerated Composting and Plant Disease Control Vishwajit Kumar and Amit Kumar Department of Agriculture, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, UP, India	138

40.	Feed Hope- A Web-Based Platform for Sustainable Food and Resource Distribution Yash Kaushik Swami Vivekanand Subharti University, Meerut	139
41.	Experimental Analysis of Bamboo Fibre Reinforced Concrete Daud Chauhan Ph.D. Scholar, Civil Engineering Department Glocal School of Science and Technology, The Glocal University	140
42.	Synergistic Antibacterial Activity of Selected Herbal Plant Extracts combined with Antibiotics Against Carbapenem-Resistant Escherichia coli Sandhya, Amit Kumar Department of Microbiology, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, NH 58, Subhartipuram, Meerut-250005, U.P. (INDIA)	141
43.	An Integrative Review on the Role of Forests in Combating Climate Change and for Sustainable Development. Amardeep Kumar, Anuj Yadav Department of agriculture, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, NH 58, Subhartipuram, Meerut-250005, U.P. (INDIA)	142
44.	Comparative FPGA Implementation of FIR Filters Using Vedic and Conventional Techniques Padum Kant Mishra ¹ , Aman Kumar ¹ and Ekta Gupta ² ¹ Department of Physics. KVSCOS, Swami Vivekanand Subharti University, Meerut, U.P, India, ² Meerut Institute of Engineering & Technology, Meerut, U.P, India,	143
45.	Identifying Key Factors Influencing the Adoption of Generative Ai Among Teachers of Private Higher Education Institutions. Sonal Ahlawat ¹ , and Anshu Choudhary ² Research Scholar, NICE School of Business Studies, Shobhit Deemed University, Meerut, (U.P.) Associate Professor, NICE School of Business Studies, Shobhit Deemed University, Meerut, (U.P.)	144
46.	Isolation and characterization of Cellulase producing microorganisms from soil sample Mariva Shehzad ¹ , Anuradha Sinha ² Adesh Kumar Ravinder Kumar Jain' Department of Life Sciences, Swami Vivekanand Subharti, University, Meerut, India *Corresponding author. Email: adesh.du@gmail.com	145
47.	Screening and Characterization of Thermostable Xylanase-Producing Microbial Isolates from Soil Khizra Siddiqui ¹ , Anuradha Sinha ² Adesh Kumar ^{3*} Ashwani Kumar ⁴ Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India *Corresponding author. Email: adesh.du@gmail.com	146

S.No.	Title of Chapters and Author Name	Page No.
1.	Transformative Impacts of Artificial Intelligence in Sports: Perspectives on Performance, Engagement, Safety, and Management Dr. Shashiraj Teotia, Head of Department, Department of Computer Application, KVS College of Science, Subharti University Amit Kumar, Research Scholar, Department of Computer Application, KVS College of Science, Subharti University	148-162
2.	Multi-Omics Integration Reveals Microbial Consortia-Driven Sugarcane Trash Decomposition for Sustainable Agriculture: A Review Anuradha Sinha and Adesh Kumar, Swami Vivekanand Subharti University, Meerut, UP, India	163-170
3.	Continuous Column Studies on Cadmium Removal Using Modified Tea Factory Waste Samarpita Gupta and Subhrajyoti Deb, Department of Civil Engineering, ICFAI University, Agartala, Tripura, India	171-184
4.	Climate Change Effects on Morpho-physiological, Biochemical, and Molecular Traits of Wheat (<i>Triticum aestivum</i> L.): A Comprehensive Analysis Amit Kumar and Shivani, Department of Biotechnology, Keral Verma Subharti College of Science, SVSU, Meerut	185-199
5.	Enhancing Data Security in Cloud Computing Using Encryption Techniques Srishti Agarwal, Prem Kishor Gautam and Himanshu, Meerut Institute of Technology, Meerut, UP	200-209
6.	Rasa, Aesthetics, and Healing: Psychological Dimensions of Indian Painting and Art-Based Wellbeing Mohd Asif Siddiqui, Department of Life Science, Swami Vivekanand Subharti University, Meerut Indu, Assistant Professor, School of Arts and Humanities, IIMT University, Meerut	210-226
7.	Therapeutic Potential of Naringin in the Prevention of Age-Related Disorders-A Systematic Review Shrashti Teja, Ashwani Kumar, Ravindra Kumar Jain, Adesh Kumar and Ritika Yadav Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India	227-238
8.	Resveratrol as a Promising Antitumor Phytochemical: Mechanisms, Therapeutic Potential, and Future Perspectives Damini Rajora, Ashwani Kumar, Dheer Pal Singh, Anupriya Rana, Nikhil Chand, Sarita Rana, Dhanendra Kumar Rai Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India	239-249
9.	TLC based Comparative Analysis of Qualitative Phytochemical Characteristics of <i>Eclipta alba</i> and <i>Eclipta prostrata</i> Anuj, Ashwani Kumar, Adesh Kumar, Dhanendra Kumar Rai, Nikhil Chand, Sarita Rana, Anupriya Rana	250-267

	Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India	
10.	Isolation of Antibiotic-Resistant Bacteria from Municipal Sewage Water Ashwani Kumar, Shubham Raj, Anupriya Rana, Ritika Yadav, Ravi Kumar Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India	268-282
11.	Plant-Derived Bioenzymes: Efficacy, Extraction Strategies, and Versatile Applications – A Comprehensive Review Unaiza Hashmi, Ashwani Kumar, Ravindra Kumar Jain, Dheer Pal Singh, Neeru Singh, Anchal Sharma Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India	283-302
12	AI-Driven Personalized Learning and Its Impact on Sustainable Education in Business Schools. Archana Singh (Research Scholar), Neha Saini Suresh Gyan Vihar University, Jaipur, RJ, India	303-314
13	Industrial Applications of Microbes in Bioremediation of Polluted Environments Preeti Yadav and Ravindra Kumar Jain Department of Life Sciences, Keral Verma Subharti College of Science Swami Vivekanand Subharti University Meerut. Uttar Pradesh. India	315-327
14	Biofilm-Based Fermentation in Dairy Products: Opportunities and Safety Challenges Imroz khan, and Ravindra Kumar Jain Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh India - 250005	328-355

Abstracts

The importance of National Gas Sensor Testing and Certification Facility and metal oxide based high performance gas sensors

Preetam Singh*

CSIR-National Physical Laboratory, Dr. K.S. Krishnan Marg, New Delhi, 110012, India

*Email: singhp.nplindia@csir.res.in

Air pollution is one of the most challenging problems worldwide due to various toxic/hazardous gases bio/chemical waste materials, which are generated from different sources like industries, vehicles, smoke, pesticides/insecticides used in the agriculture, etc. Considering this severe air pollution in India too, a large number of solid-state gas sensors are being installed at various locations across the country to measure the air pollution due to toxic gases and pollutants. Depending on the sensing materials and environmental conditions, these gas sensors are prone to degradation. As a result, the performance parameters of sensors, such as sensitivity, selectivity, stability, and response/recovery time, may not be reliable over a period of time. Validation and periodic testing of such commercial gas sensors are essential to ensure precise measurement for obtaining reliable data. A clean environment demands accurate measurements of toxic gases and pollutants, and as of now, the country does not have any “Apex calibration capability” for these sensors, which is crucial and a ‘need of the hour’ requirement. CSIR-NPL (NMI), is establishing the National Gas Sensor Testing and Certification Facility to support the industry, MSME, and startups. It will be a unique platform to provide services to commercial sensor manufacturers and sensor developers at academic and research institutes. Provide a platform in India that will cater to sensor manufacturers' requirements for quality assurance of their products in the global market and to develop globally competitive and reliable technologies for gas sensor manufacturing. Further, we have developed high performance CO, NO_x, H₂S, etc gas sensors based on metal oxide thin films such as SnO₂, ZnO, WO₃, NiO by magnetron sputtering technique.

Green Nanomaterial Platforms: Sustainable Environmental Monitoring and Active Pollution Remediation

Yang-Wei Lin*

Department of Chemistry, National Changhua University of Education, Taiwan

*Email: linywjerry@cc.ncue.edu.tw

Heavy metal pollution, especially from mercury (Hg^{2+}) and iron (Fe^{2+}) ions, poses a serious threat to global water systems and local ecosystems. Tackling this issue is essential for achieving Sustainable Development Goals (SDGs 6, 11, and 15) and demands low-cost, portable, and on-site detection methods. In this work, a fully integrated and eco-friendly green chemistry strategy is presented, combining nanotechnology with sustainable environmental engineering. A multifunctional nanomaterial platform is developed using natural biomolecules and raw biomass, completely avoiding toxic reagents. The study is organised into three interconnected phases. First, in direct passive sensing, tannic acid (TA), a natural plant-derived polyphenol, is employed as a molecular recognition unit. Its multiple hydroxyl groups enable strong binding with metal ions, allowing rapid, instrument-free colourimetric detection of Fe^{2+} (red) and Au^{3+} (purple), with detection limits of $0.08\ \mu\text{M}$ and $0.5\ \mu\text{M}$, respectively. In the second phase, catalytic amplification and sensing, TA serves as both a reducing and stabilising agent to synthesise highly stable gold nanoparticles (TA-AuNPs). This transition from passive detection to active catalytic sensing, involving mechanisms such as Au–Hg amalgamation and Fenton reactions, enables ultra-sensitive and selective detection of Hg^{2+} (LOD: $18\ \text{nM}$) and Fe^{2+} (LOD: $96\ \text{nM}$) in real water samples. Finally, in the active remediation phase, carbon quantum dots (CQDs) are synthesised entirely from raw biomass (gardenia seeds and genipin) via mild pyrolysis. These CQDs act as both reducing agents and stabilisers to form CQDs–AuNP hybrids, which exhibit excellent catalytic performance in degrading toxic pollutants. The system achieves up to 99.7% degradation of aromatic nitro compounds (such as 4-nitrophenol) within 10 minutes and maintains strong stability for up to 60 days. By integrating direct sensing, catalytic amplification, and active remediation into a single platform, this work offers a scalable, cost-effective, and environmentally friendly solution. It represents a shift from conventional toxic and expensive approaches to sustainable, nature-inspired technologies, supporting the broader vision of environmental sustainability.

Structural Insights into a Thermostable Hydrolase for Phthalate Detoxification and PET Plastic Biodegradation

Pravindra Kumar

Department of Biosciences and Bioengineering, Indian Institute of Technology Roorkee

Roorkee-247667, Uttarakhand, India

Email: pravindra.kumar@bt.iitr.ac.in

Abstract

Phthalate diesters are pervasive environmental contaminants with well-documented endocrine-disrupting effects, posing significant risks to both ecological systems and human health. Despite the identification of microbial esterases capable of transforming phthalates, detailed structural and mechanistic understanding of these enzymes remains limited.

In this study, we report the comprehensive biophysical and structural characterization of EstS1, a thermostable and pH-tolerant esterase derived from *Sulfobacillus acidophilus* DSM10332. The enzyme demonstrates efficient catalytic activity toward the high-molecular-weight plasticizer bis(2-ethylhexyl) phthalate (DEHP), along with measurable activity against polyethylene terephthalate (PET), highlighting its potential for applications in plastic waste bioremediation. An integrative methodological framework combining enzyme kinetics, biophysical analyses, and high-resolution X-ray crystallography of the apo enzyme and its ligand-bound complexes was employed to elucidate its catalytic mechanism. Structural investigations reveal the presence of a well-defined catalytic tunnel that facilitates substrate access and product release. The catalytic process is mediated by a conserved Ser–His–Asp triad operating via a bi–bi ping-pong mechanism involving a tetrahedral intermediate. Site-directed mutagenesis further identifies Met207 as a critical determinant of substrate binding and catalytic efficiency. Collectively, these findings advance our understanding of esterase function at the molecular level and establish EstS1 as a promising candidate for the development of sustainable enzymatic strategies for phthalate detoxification and PET plastic degradation.

Keywords: Phthalate diesters, Endocrine disruptors, Esterase; EstS1, *Sulfobacillus acidophilus*, Bis(2-ethylhexyl) phthalate (DEHP), Polyethylene terephthalate (PET), Bioremediation.

Inorganic Surfaces as Catalytic Platforms

Manjinder Kour ^{*a}, Sapna Jadoun ^b

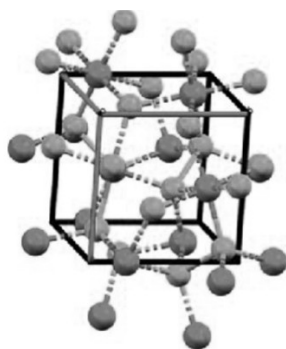
^a Montana State University, Bozeman, Montana, 59717 United States of America.

^b Universidad de Tarapacá: Arica, Parinacota, Chile.

*Corresponding author: ^a manjinderkour1992@gmail.com

Abstract

Mineral surfaces have long been proposed as potential drivers of redox chemistry prior to the emergence of enzymatic catalysis (Lubitz et al., 2014). Among naturally occurring materials, iron sulfides are of particular interest because their metal–sulfur coordination environments resemble structural motifs found in modern hydrogenase enzymes, which catalyse hydrogen activation in biological systems. These similarities have motivated the idea that certain inorganic surfaces may have been capable of supporting simple hydrogen-related transformations before the evolution of complex biological catalysts. In natural anoxic environments where hydrogen and metal sulfide minerals coexist, such surfaces could have provided chemically active interfaces capable of mediating electron transfer reactions. Understanding how these mineral surfaces interact with hydrogen and how their reactivity responds to subtle changes in surface composition remains an important step toward evaluating the catalytic potential of inorganic systems in geochemical settings.



These observations highlight the sensitivity of iron sulfide surfaces to their local metal environment and suggest that mineral surfaces may possess intrinsic capabilities for hydrogen-related redox chemistry. While the results do not imply direct equivalence with biological catalysts, they demonstrate that simple inorganic surfaces can support measurable redox activity that is responsive to metal composition. Such behavior provides a useful framework for examining how mineral surface chemistry may have interacted with hydrogen in early geochemical environments and may offer insights into possible chemical pathways preceding biological catalysis.

Keywords: Iron-sulfides; Hydrogen Oxidation; Early life; Redox chemistry; Catalysis

References:

Lubitz, W.; Ogata, H.; Rüdiger, O.; Reijerse, E. Hydrogenases. *Chem. Rev.* **2014**, *114* (8),

4081–4148.

THEME 1:

**Advances in Information Technology
for Sustainability**

Abstract 1**AI-Driven Digital Forensics: Enhancing Evidence Identification Using Machine Learning**

Shashiraj Teotia

Department of Computer Application, Swami Vivekanand Subharti University
Meerut, 250001

Email Id- hod.ca@subharti.org

Abstract

The rapid growth of digital technologies and internet usage has significantly increased the volume and complexity of cybercrimes. Traditional digital forensic techniques often struggle to process large-scale digital evidence efficiently, resulting in delays in cybercrime investigations. Artificial Intelligence (AI) and Machine Learning (ML) have emerged as powerful tools to enhance the efficiency and accuracy of digital forensic investigations. This paper explores the role of AI-driven techniques in improving evidence identification and analysis in digital forensics. The proposed study focuses on the application of machine learning algorithms for automated evidence detection, classification, and prioritization from large digital datasets. Techniques such as supervised learning, deep learning, and pattern recognition can assist investigators in identifying suspicious files, abnormal user behaviour, and hidden digital artefacts more efficiently than traditional manual methods. The research also examines the integration of AI-based forensic tools with existing forensic frameworks to support faster and more reliable investigations. Furthermore, this paper highlights the benefits of AI-driven digital forensics, including reduced investigation time, improved accuracy in evidence identification, and enhanced capability to handle large volumes of heterogeneous data. Challenges such as data privacy concerns, algorithm transparency, and legal admissibility of AI-generated evidence are also discussed. The study concludes that the integration of machine learning into digital forensic processes can significantly enhance the effectiveness of cybercrime investigations and support law enforcement agencies in addressing emerging cyber threats in the digital era.

Keywords: Digital Forensics, Artificial Intelligence (AI), Machine Learning, Cybercrime Investigation

Abstract 2**Exploring AI with Sustainability in Precision Agriculture**

Sandeep

Computer Application, SVSU Meerut

Email Id- sanghanghas1991@gmail.com

Abstract

Precision agriculture can achieve SDG 2 (Zero Hunger) through autonomous reasoning and multi-step execution thanks to the quick integration of Agentic AI (AAI). However, the substantial energy requirements of large-scale autonomous models frequently outweigh the environmental advantages of higher yields. The S-Agentic Framework (S-AF), a unique assessment model intended to strike a compromise between agricultural precision and computational sustainability, is proposed in this research. The approach assesses whether the carbon footprint of AI inference is justified by the physical resources saved by adding the Sustainability-to-Yield (S2Y) metric and a Net-Green Benefit (Gnet) computation. Eco-Sensor, Carbon-Aware Controller, and Execution Agents are among the multi-agent hierarchy that the design uses to optimize resource application and schedule complex calculations during periods of high renewable energy. Comparing the S-AF model to normal AAI systems, simulations show a 15% reduction in nitrogen runoff and a 60% reduction in computation power, with very little loss in water efficiency. In order to ensure that the digital footprint of contemporary farming is as efficient as its physical output, this research offers a standardized framework for assessing the environmental ROI of autonomous agents.

Keyword: Agriculture, Agentic, footprint, energy.

Abstract 3**Quantum Machine Learning Models Deployed over Fog Computing Infrastructure for IoT Applications**

Shashi

Department of computer application, ccs university Meerut, UP.

Email Id-teotia.shashi@gmail.com

Abstract

The rapid proliferation of Internet of Things (IoT) devices has led to a massive increase in distributed data streams that require low-latency, intelligent processing close to the network edge. Conventional cloud-centric architectures often fail to meet stringent delay, bandwidth, and scalability requirements of real-time applications such as autonomous systems, industrial automation, and smart cities. Fog computing addresses these limitations by extending computation, storage, and networking capabilities from centralized clouds to intermediate fog nodes located near data sources. In parallel, quantum machine learning (QML) has emerged as a promising paradigm that exploits quantum parallelism and entanglement to accelerate model training and inference, offering potential advantages in pattern recognition, optimization, and anomaly detection over classical machine learning. This paper conceptually investigates the deployment of QML models over fog computing infrastructure, defining a multilayer architecture in which selected fog nodes are augmented with access to quantum resources and quantum-inspired optimization algorithms for real-time IoT analytics. The proposed framework discusses task partitioning between edge, fog, and cloud; quantum-enhanced scheduling and resource allocation; and application scenarios in industrial IoT and 6G-enabled networks. Potential benefits include reduced inference latency, improved energy efficiency, and enhanced predictive performance, while challenges arise in terms of quantum hardware integration at the edge, error resilience, orchestration complexity, and security. The paper concludes by outlining open research directions related to hybrid classical–quantum model design, quantum-aware fog orchestrators, and post-quantum security mechanisms for QML-enabled fog environments.

Keywords: Quantum machine learning; Fog computing; Edge intelligence; Internet of Things (IoT); Quantum-edge cloud; 6G networks; Quantum-inspired optimization; Low-latency analytics; Industrial IoT; Post-quantum security.

Abstract 4**AI-Driven Personalized Learning and Its Impact on Sustainable Education in Business Schools****Archana Singh¹, and Neha Saini²**

Research Scholar, Suresh Gyan Vihar University, Jaipur

Assistant Professor Suresh Gyan Vihar University, Jaipur

Email: Neha.saini@mygyanvihar.com, arch.udaipur@gmail.com

Abstract

The rapid advancement of Artificial Intelligence (AI) is transforming the environment of higher education, particularly in professional programs such as PGDM/MBA where skill development is central to employability. Business Schools are increasingly exploring AI-driven learning tools to create personalized, adaptive, and student-centric learning environments. Such approaches align strongly with the broader goal of sustainable education, which emphasizes inclusive, continuous, and skills-oriented learning systems that prepare students for evolving workplace requirements. This paper examines the role of AI-driven personalized learning in enhancing sustainable education within business schools, with a particular focus on the development of communication and interview skills among management students. The study is contextualized through integration of AI-enabled learning tools implemented at a business school in Ahmedabad, India, where AI tools incorporated into PGDM/MBA training modules to support students in improving their business communication, presentation abilities, and interview preparedness. These tools provide individualized feedback, simulate real-time interview scenarios, and enable students to practice and refine their professional communication skills at their own pace. The research explores how AI-supported personalized learning contributes to improved student engagement, self-directed learning, and continuous skill enhancement, which are critical pillars of sustainable education. It also examines the perceived effectiveness of AI tools in helping students overcome communication barriers, build confidence, and prepare for competitive corporate recruitment processes.

Keywords: Artificial Intelligence, Personalized Learning, Sustainable Education, Management Education, Communication Skills Development.

Abstract 5**A Comparative Analysis of Software Testing Models and Standards for Selecting the Best Testing Techniques in the Software Development Life Cycle**

Almash Saifi

PhD Scholar, Computer Applications, Swami Vivekanand Subharti University, Meerut

Email: shanusaiifi7300@gmail.com

Abstract

Software testing is essential to guaranteeing the security, dependability, and performance of current software systems. Organisations must increasingly implement suitable testing procedures that complement their development methodologies and project requirements due to the quick development of sophisticated software applications. Selecting the most effective software testing model remains challenging because of the wide array of tests and methodologies used throughout the Software Development Life Cycle (SDLC). Studying and classifying different software testing methods utilised in modern the field of software engineering processes is the main goal of this work. The study looks at popular testing paradigms like DevOps-based ongoing evaluation, Agile testing, Waterfall testing, V-Model, and Spiral testing. The structure, workflow, benefits, drawbacks, and applicability of each model for various project situations are all examined. Additionally, this study suggests a set of selection criteria that might help team leaders, software developers, and testing select the best testing approach for particular job scenarios. Project size, development approach, risk level, financial limitations, testing automation capacity, and time needs are some of the suggested criteria. Organisations can adopt testing strategies that improve software quality and lower project risks by analysing these factors. The results of the research provide a methodical classification of software testing models together with practical suggestions for model selection. The research enhances the field of software engineering by presenting an objective framework for selecting software testing methodologies. The end result is using the appropriate testing methodology can significantly improve software reliability, lower errors, and maximise development productivity.

Keyword: SDLC, software, V-Model, DevOps-based.

Abstract 6**Technology-Driven Waste Management Systems in Haryana, India: Supporting Sustainable Cities and Responsible Consumption (SDG-11 and SDG-12)****Satya Pratap Singh¹, and Tanu Gaur²**¹Research Scholar, Subharti University, Meerut²Assistant Professor, Vinayak Vidyapeeth, Meerut & Research Scholar, subharti University, Meerut

Email Id-singh.satya222@gmail.com

Abstract

In many growing areas, like Haryana, India, the production of municipal solid trash has dramatically increased due to rapid urbanization, population growth, and shifting consumer habits. There are still significant environmental and public health issues due to ineffective garbage collection, poor segregation procedures, and a lack of infrastructure for recycling. In this regard, using technology-driven waste management systems has become a crucial tactic to enhance urban trash management's sustainability, efficiency, and openness. This study investigates how contemporary technologies, including data-driven waste tracking platforms, Internet of Things (IoT)-based monitoring systems, smart trash cans, and geographic information systems (GIS), might improve waste management procedures in Haryana. The study emphasises how smart and digital technology can facilitate improved resource recovery and recycling procedures, source segregation, and garbage collection planning. Additionally, the study looks at how technology-enabled waste management systems might support responsible consumer habits and sustainable urban growth. The study highlights how technological interventions can help achieve Sustainable Development Goals 11 (Sustainable Cities and Communities) and 12 (Responsible Consumption and Production) by coordinating waste management strategies with global sustainability frameworks. According to the results, the region's sustainable waste management systems may be greatly strengthened by combining cutting-edge technologies with efficient governance, public involvement, and policy support.

Keywords: Waste Management Technologies; Smart Waste Systems; Sustainable Cities; Responsible Consumption; Municipal Solid Waste; Haryana.

Abstract 7**Smart and Digital Technologies for Biodiversity Conservation in Haryana, India:
Pathways to Achieve SDG-13 and SDG-15**

Tanu Gaur

Research Scholar, Subharti University, Meerut, India

E mail: tanugaurs91@gmail.com

Abstract

Ecosystem stability and sustainable development are at risk due to two key environmental challenges: biodiversity loss and climate change. Due to rising urbanisation, land-use change, and intense farming methods, Haryana, an agriculturally intensive state in India, is facing mounting strain on its natural ecosystems. In this regard, the combination of digital and smart technology has tremendous prospects for efficient environmental management and biodiversity conservation. The potential importance of technologies like artificial intelligence, remote sensing, geographic information systems (GIS), drones, and the Internet of Things (IoT) in monitoring, safeguarding, and managing biodiversity in Haryana is examined in this paper.

The study looks at how technology-driven methods can improve habitat mapping, species monitoring, early environmental change detection, and data-driven conservation planning decision-making. The report also emphasises how the use of digital tools may help sustainable ecosystem management and climate adaptation techniques. The report highlights how technology innovation can help achieve Sustainable Development Goals 13 (Climate Action) and 15 (Life on Land) by connecting it to global sustainability goals. The results indicate that the region's efforts to conserve biodiversity can be greatly strengthened by combining smart technology with community involvement, policy backing, and scientific study. Policymakers, environmental managers, and researchers can use the study's conclusions to create technologically enabled conservation strategies that promote long-term ecological sustainability.

Keywords: Biodiversity Conservation; Digital Technologies; Climate Action; Sustainable Development Goals; Environmental Monitoring; Haryana.

Abstract 8**Exploring Text Classification Methods for Efficient Information Extraction from Research Articles**

Himanshu, Prem Kishor Gautam, and Srishti Agarwal

Meerut Institute of Technology, Meerut, Uttar Pradesh, India

E-mail: Himanshu.sirohi@mitmeerut.ac.in, premkishor.gautam@mitmeerut.ac.in,
Srishti.Agarwal@mitmeerut.ac.in

Abstract:

Analysing large amounts of unstructured text data in order to extract insightful information is known as text mining, or text data mining. Businesses manage large volumes of text data from many sources, such as call transcripts, social media, applications, websites, and consumer evaluations. The text-mining process may be made much more efficient by using tools and approaches that are specific to the area. The study's findings are presented in a thorough review of text mining and the status of the field. These days, text mining research is one of the most popular areas for studying texts written in natural language. The current paper provides a thorough review of text mining and the state of research in this area. The literature indicates that using data mining methods to address information extraction from research publications has limitations. Finding pertinent patterns and trends in a large number of text documents is still a difficult problem to solve. There are several techniques and resources available for text analysis that help find important information for further investigation and decision-making. Sophisticated text mining methods reduce the amount of time and effort needed to extract important insights quickly. This paper offers insights into text mining techniques and applications in a variety of fields. It also draws attention to problems in text mining that affect the precision and applicability of the findings.

Keywords: Text Mining, Information Extraction Information Retrieval

Abstract 9**Digital Entrepreneurship and Sustainable Development: Leveraging Intelligent Innovation for Inclusive Growth**

¹Lekhika Prakash, ²Himanshu, and ²Ritika Garg

¹Department of Applied Science & Management, Meerut Institute of Technology

²Department of Computer Science & Engineering, Meerut Institute of Technology

Email Id: Lekhika.prakash@mitmeerut.ac.in, Himanshu.sirohi@mitmeerut.ac.in,
ritika.garg@mitmeerut.ac.in

Abstract:

The rapid growth of digital technologies has transformed the entrepreneurial landscape, creating new opportunities for innovation, economic development, and social inclusion. Digital entrepreneurship has emerged as a key driver of sustainable development by enabling entrepreneurs to use intelligent technologies such as artificial intelligence, big data analytics, cloud computing, and digital platforms to develop innovative and scalable solutions. Digital platforms have reduced traditional barriers to entrepreneurship, allowing individuals and small businesses to access wider markets and participate more actively in the digital economy. Through efficient resource utilization and data-driven strategies, digital ventures can create employment opportunities, strengthen economic resilience, and encourage responsible business practices. This paper reviews existing literature and trends in digital entrepreneurship, intelligent innovation, and sustainable development. It concludes that supportive policies, strong digital infrastructure, and entrepreneurial skill development are essential for promoting inclusive and sustainable economic growth.

Keyword: Digital technologies, data-driven, artificial intelligence.

Abstract 10**ONLINE MOVIE BOOKING SYSTEM**

Manshi

Department of Computer Application, Swami Vivekanand Subharti University, Meerut

Email: manshikataria9@gmail.com

Abstract

The Online Movie Booking System is a web-based application designed to simplify the process of reserving movie tickets through an online platform. In the traditional ticket booking system, customers often face long queues at cinema halls and may not always get their preferred seats or show timings. The proposed system aims to overcome these limitations by providing an efficient and user-friendly digital platform where users can easily browse movies, check show timings, select seats, and book tickets from anywhere using the internet. The system allows users to view the list of currently available movies along with detailed information such as movie descriptions, show schedules, available theaters, and seat availability. Through a secure login interface, users can create accounts, manage their bookings, and receive confirmation for their selected movie tickets. The system also provides an organized database structure that stores customer information, movie details, and booking records to ensure accurate and reliable data management. From the administrative perspective, the system includes a management module that allows administrators to update movie listings, manage show timings, monitor seat availability, and handle booking records efficiently. This helps cinema management maintain accurate scheduling and improve operational efficiency. The application focuses on improving the overall customer experience by reducing manual effort, saving time, and providing a convenient ticket booking solution. The Online Movie Booking System is developed using standard web technologies and database management concepts commonly studied in the MCA curriculum. The implementation of this system demonstrates how information technology can be applied to automate real-world processes and enhance service accessibility. The project highlights the practical use of software development principles to create a reliable and scalable solution for modern digital entertainment services.

Keywords: Online Movie Booking System, Web-Based Application, Ticket Reservation, Database Management, User Authentication, Seat Selection

Abstract 11**Student Dropout Prediction System**

Nitish Rana

Department of Computer Application, Swami Vivekanand Subharti University, Meerut.

Email: Nitishranajaat@gmail.com

Student dropout is one of the major challenges faced by educational institutions around the world. Many students leave their studies before completing their academic programs due to various academic, personal, and social factors. This not only affects the student's future but also impacts the performance and reputation of educational institutions. Therefore, it is important to identify students who are at risk of dropping out at an early stage so that appropriate support and intervention can be provided. The Student Dropout Prediction System is a web-based application designed to analyze student academic data and predict the probability of a student dropping out from an institution. The system collects and processes various parameters such as attendance records, internal marks, assignment submission status, academic performance, and student engagement. By analyzing these factors, the system can detect patterns that indicate whether a student is likely to continue their studies or is at risk of leaving the program. The proposed system uses data analysis and machine learning techniques to classify students into different risk categories such as low risk, medium risk, and high risk of dropout. The prediction results help teachers and administrators identify students who require additional attention and support. Once high-risk students are identified, educators can take preventive measures such as counseling, mentoring, academic assistance, and regular monitoring to improve student performance and reduce dropout rates. The system provides different modules such as an Admin Panel, Teacher Dashboard, and Student Module. The admin can manage student records and view overall reports, teachers can monitor student performance and predictions, and students can view their academic progress. The system also generates analytical reports and visualizations that help institutions make better data-driven decisions. The main objective of this project is to improve student retention and academic success by providing early prediction and timely intervention. By implementing this system, educational institutions can better understand student behavior and take proactive steps to support students who are at risk of dropping out.

Keyword: academic data, Admin Panel, Teacher Dashboard

Abstract 12**Energy-Efficient Consensus: A Comparative Analysis of Sharding and Proof-of-Stake in Sustainable Blockchain Architectures**

Krishanpal Singh

Department of Computer Application, Swami Vivekanand Subharti University
Meerut,250001

Email Id- krishanpal.su202400402@subharti.co

Abstract

The environmental impact of Proof-of-Work (PoW) mechanisms remains a significant barrier to the mainstream adoption of blockchain technology in Computer Science and Engineering. This research investigates the trade-offs between energy consumption, throughput, and security in emerging green consensus protocols. We present a simulation-based study comparing Ethereum's Proof-of-Stake (PoS) architecture against a proposed modular sharding protocol designed for IoT-intensive environments. Our findings indicate that the proposed sharding mechanism reduces per-transact energy overhead by 30% while maintaining a sub-10 second finality. Furthermore, we address the "scalability trilemma" by analyzing how data availability sampling (DAS) can maintain network decentralization without increasing the carbon footprint of individual validator nodes. This paper contributes to the development of sustainable digital infrastructures, aligning blockchain evolution with global carbon neutrality goals.

Keywords: Include 5–6 relevant terms (e.g., Smart Contracts, Consensus Algorithms, Proof-of-Stake (PoS), sharding protocol, data availability sampling (DAS)).

Abstract 13**Beyond Irreversibility: Inverse Physical Scene Reconstruction from Degraded Observations via Hybrid Transformer–Mamba Modelling**

Daksh Bhardwaj

Department of Computer Science, KVSCOS, Swami Vivekanand Subharti University,
Meerut, India

Email Id- daksh.su202600085@subharti.co

Abstract

Reconstructing past environmental scenes from degraded physical observations is a challenging inverse problem at the intersection of artificial intelligence, computational physics, digital heritage modeling, and physics-informed machine learning. Physical signals such as reflected light, geological measurements, and astronomical observations undergo complex transformations including scattering, absorption, and diffusion governed by classical wave equations, radiative transfer theory, and thermodynamic irreversibility. Although macroscopic physical processes are formally irreversible, the structured nature of physical propagation operators — characterized by finite condition numbers, sparse spectral support, and known symmetry groups — implies that traces of past environmental states may remain recoverable from degraded measurements under appropriate regularization. Let x_t denote the latent environmental scene at time t and y the observed degraded signals. The observation process is modeled as $y = F(x_t) + \varepsilon$ where F represents the physical propagation and scattering operator and ε denotes measurement noise. The objective is to estimate x_t from corrupted observations y using physically consistent priors. We represent physical measurements as ultra-long sequences $y = (y_1, y_2, \dots, y_T)$ containing distributed traces of environmental structure across space and time. To process these signals efficiently, we propose a hybrid neural architecture interleaving Transformer layers with Mamba-2 state-space blocks. Transformer layers capture long-range spatial dependencies and physical constraints, while Mamba-2 enables scalable modeling of long sequences with linear computational complexity. Adaptive layer normalization (AdaLN) conditions the network on physical variables including noise level, propagation time, and operator conditioning. A diffusion-based denoising stage further refines latent scene estimates through score-based updates conditioned on observed signals.

Keyword: Physically consistent, noise level.

Abstract 14**IoT and Smart cities**

Kanak Sharma

B.Sc. Forensic Science, KVSCOS, Swami Vivekanand Subharti University, Meerut

Email Id- kanaksharma.maanu@gmail.com

Abstract

Rapid urbanization has placed immense pressure on cities to manage resources efficiently while ensuring environmental sustainability and improved quality of life. Advances in Information Technology, particularly the Internet of Things (IoT), have emerged as a transformative solution for developing sustainable smart cities. IoT refers to a network of interconnected devices equipped with sensors, software, and communication capabilities that collect and exchange real-time data over the internet. By integrating these technologies into urban infrastructure, cities can monitor, analyze, and optimize essential services more effectively. This paper explores the role of IoT in enabling sustainable urban development through smart city initiatives. IoT applications such as intelligent traffic management systems, smart energy grids, waste management solutions, water distribution monitoring, and environmental sensing contribute significantly to reducing resource consumption, minimizing pollution, and improving operational efficiency. For example, smart traffic systems reduce congestion and fuel consumption, while smart energy meters promote efficient electricity usage. Similarly, sensor-based waste management and leak detection systems help conserve natural resources and reduce environmental impact. Despite its numerous benefits, the implementation of IoT in smart cities also faces challenges, including high infrastructure costs, cybersecurity risks, data privacy concerns, and the need for reliable connectivity and skilled workforce. Addressing these issues is essential for the successful deployment of IoT-based urban systems. In conclusion, IoT-driven smart city technologies offer a promising pathway toward sustainable urban living by enhancing efficiency, reducing environmental footprint, and improving the overall quality of life for citizens. As cities continue to grow, the integration of advanced digital technologies will be crucial in building resilient, inclusive, and environmentally responsible urban environments for the future.

Keyword: IoT, sensor-based waste, environmentally.

Abstract 15**The Role of Artificial Intelligence in Modern Criminal Activities and Social Security:
Forensic Insights into AI Misuse in Cybercrime**

Anuradha

M.Sc. Forensic Science, Department of Forensic Science, Chaudhary Charan Singh
University

Email Id- www.anurajput269@gmail.com

Abstract

Artificial Intelligence (AI) has emerged as a transformative technology that significantly influences modern society by enhancing automation, efficiency, and decision-making processes. However, alongside its beneficial applications, AI has also created new opportunities for criminal misuse. This study explores the growing role of artificial intelligence in modern criminal activities and examines its implications for social security from a forensic perspective. AI functions as a dual-use technology that can be utilized for both beneficial and malicious purposes. Cybercriminals increasingly exploit AI to automate large-scale criminal operations, mimic human behaviour and voices, analyse large datasets to identify potential victims, and conduct sophisticated cyberattacks that are difficult to detect. The use of AI has expanded the scope of crimes such as cyber fraud, identity theft, deepfake manipulation, automated hacking, financial fraud, online harassment, and misinformation campaigns. These AI-enabled crimes pose serious threats to privacy, financial security, and public trust in digital communication systems. The rapid advancement of AI-driven criminal techniques has also created significant challenges for law enforcement agencies and cybersecurity professionals. As criminals adopt advanced technologies, the complexity of crime detection and investigation increases. Digital forensics therefore plays a crucial role in identifying, preserving, and analysing digital evidence related to AI-enabled crimes. Various forensic tools such as EnCase, FTK, Cellebrite, Autopsy, Magnet AXIOM, and network analysis tools are essential for tracing digital activities and verifying manipulated media content. To mitigate the risks associated with AI misuse, several preventive strategies are necessary.

Keywords: Artificial Intelligence, Cybercrime, AI-Enabled Crime, Digital Forensics, Deepfake Technology, Cybersecurity, Identity Theft, Online Fraud, Social Security

Abstract 16**A Deep Learning Framework for Long-Horizon Traffic Congestion and Travel Time Prediction**Sanjeev Panwar¹, Paramjeet Rawat²

Department of Computer Application, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India

Email Id- sanjeev.su201000105@subharti.co

Abstract

For intelligent transportation systems (ITS) to control traffic, optimize routes, and increase travel reliability, accurate long-horizon traffic congestion and trip time prediction is essential. Due to nonlinear traffic dynamics, temporal dependencies, and varying traffic patterns, forecasting traffic congestion levels and travel times over long periods of time is difficult. In order to extract long-term temporal dependencies from past traffic data, this study suggests a deep learning architecture. To improve model learning, the system uses temporal feature extraction, sliding window sequence generation, and data normalization. BiLSTM-based systems produce accurate long-horizon forecasts of congestion and trip time by modelling traffic dynamics. The system outperforms traditional models with RMSE = 7.84, MAE = 5.21, and MAPE = 8.63% when tested on a real-world traffic dataset from California. The outcomes show how successful the framework is and lay the groundwork for further LSTM and Transformer-based research on long-horizon traffic prediction.

Keywords: Deep Learning, BiLSTM, Time Series Forecasting, Spatiotemporal Traffic Data, Intelligent Transportation Systems, Long-Horizon Traffic Congestion Prediction, RMSE, MAE, and MAPE.

Abstract 17**Proposed CNN–NLP Framework for Behavioral and Semantic Threat Detection**

Mragesh Pratap Singh

Research Scholar, PhD, Department of Computer Application, KVSCOS, Swami Vivekanand
Subharti University, Meerut, India.

Email Id- mragesh.su202400796@subharti.co

Abstract

The rapid growth of digital communication platforms and online social networks has increased the risk of security threats, including cybercrime, misinformation, and harmful online behavior. Traditional threat detection systems often rely on rule-based approaches and manual monitoring, which are limited in their ability to detect complex behavioural patterns and hidden semantic meanings within large volumes of data. To address these challenges, this research proposes a CNN–NLP framework for behavioural and semantic threat detection aimed at improving the efficiency and accuracy of intelligent security systems. The proposed framework integrates Convolutional Neural Networks (CNN) and Natural Language Processing (NLP) techniques to analyze both behavioural patterns and textual information. CNN is employed to automatically extract deep features from data and identify behavioural patterns associated with suspicious activities. At the same time, NLP techniques are used to analyze textual content to understand contextual meaning, sentiment, and potential malicious intent present in online communications such as messages, posts, and comments. The combination of behavioural analysis and semantic interpretation enables the system to detect threats more effectively compared to traditional single-method approaches. The research methodology involves data collection from relevant online datasets, followed by preprocessing, feature extraction, model training, and evaluation. Performance of the proposed framework is measured using standard evaluation metrics such as accuracy, precision, recall, and F1-score. The expected outcome of this study is the development of a reliable and scalable threat detection framework capable of identifying suspicious activities at an early stage. The proposed approach can contribute significantly to enhancing cybersecurity, intelligent surveillance, and social media monitoring systems by enabling proactive and efficient detection of potential threats in digital environments.

Keyword: NLP techniques, CNN, digital communication.

Abstract 18**Seminar Hall Booking for College**

Rohan Rudhiyal (PG Scholar)

Department of Computer Application, Swami Vivekanand Subharti University, Meerut

Email: rohanrudhiyal@gmail.com

Abstract

The Seminar Hall Booking for College is a web-based application designed to simplify and automate the process of reserving seminar halls in educational institutions. In many colleges, seminar hall bookings are handled manually through registers or verbal communication, which can lead to scheduling conflicts, delays, and inefficient management of resources. The proposed system provides an online platform where authorized users such as faculty members and administrative staff can easily check hall availability and submit booking requests for academic events, seminars, workshops, and meetings. The system provides a user-friendly interface that allows users to view available time slots, select suitable dates, and confirm reservations. A centralized database maintains records of seminar halls, booking schedules, and user information to ensure accurate and organized data management. An administrative module allows administrators to approve or reject requests, update schedules, and monitor overall hall usage. This helps prevent double bookings and improves transparency in the reservation process. By digitizing the seminar hall booking procedure, the system reduces paperwork, saves time, and improves coordination between users and administration. The project demonstrates how a web-based management system can enhance operational efficiency in educational institutions and provide a reliable solution for managing seminar hall resources effectively.

Keywords: Seminar Hall Booking, Web-Based Application, College Event Management, Reservation System, User Authentication, Scheduling System

Abstract 19**Vehicle Theft Online Complaint System**

Aman Silot (PG Scholar)

Department of Computer Application, Swami Vivekanand Subharti University, Meerut.

Email: akkijaat22@gmail.com

Abstract:

The Vehicle Theft Online Complaint System is a web-based application developed to make the process of reporting stolen vehicles easier, faster, and more efficient. In many cases, victims of vehicle theft have to visit police stations and complete lengthy paperwork to register a complaint. This traditional process can be time-consuming and inconvenient. The proposed system aims to digitize this process by allowing users to submit vehicle theft complaints through an online platform. In this system, users can create an account and log in to register a complaint by providing essential details such as vehicle registration number, vehicle type, model, color, location of theft, and date and time of the incident. Users can also upload supporting documents or identification details if required. Once the complaint is submitted, the information is stored in a centralized database, which can be accessed by authorized police authorities for verification and further investigation. The system also provides an administrative interface for police officials to view, manage, and update the status of complaints. This helps authorities track stolen vehicles more efficiently and maintain proper digital records. Users can check the status of their complaint online, which increases transparency and improves communication between citizens and law enforcement agencies. The main objective of this project is to reduce paperwork, save time, and provide a convenient method for reporting vehicle theft. By using web technologies and database management systems, the Vehicle Theft Online Complaint System enhances efficiency, improves record management and supports the digitalization of public services.

Keyword: Theft, Vehicle, color.

Abstract 20**Breast Cancer Disease Prediction Using Machine Learning**

Mitali Saini

Department of Computer Application, Swami Vivekanand Subharti University, Meerut, India

Email: mitalisaini17112003@gmail.com

Abstract

Breast cancer is one of the most common and life-threatening diseases affecting women worldwide. Early detection and accurate diagnosis play a crucial role in improving survival rates and reducing mortality. Traditional diagnostic methods can sometimes be time-consuming and dependent on manual interpretation, which may lead to delays in treatment. Therefore, the application of machine learning techniques in medical diagnosis has become an important research area. The aim of this project is to develop a Breast Cancer Disease Prediction System using machine learning algorithms that can assist in the early detection of breast cancer. The system analyzes medical data such as tumor characteristics and other diagnostic features to classify tumors as benign (non-cancerous) or malignant (cancerous). Machine learning models are trained using a dataset containing various clinical parameters related to breast cancer.

Different machine learning algorithms such as Random Forest and deployed using Streamlit and Streamlit Cloud to analyze and predict the disease with high accuracy. The dataset is preprocessed and divided into training and testing sets to evaluate the performance of each algorithm. Performance metrics such as accuracy, precision, recall, and F1-score are used to measure the effectiveness of the models. The system is implemented using modern data analysis and machine learning tools, which help in processing large datasets and generating accurate predictions. The developed model can support healthcare professionals by providing a fast and reliable prediction system that aids in early diagnosis and decision-making. Overall, the Breast Cancer Disease Prediction System demonstrates how machine learning can contribute to the healthcare sector by improving diagnostic accuracy, reducing human error, and enabling early detection of serious diseases such as breast cancer.

Keyword: Cancer, machine learning, diagnosis.

Abstract 21

The Smart Energy Monitoring System

Garvit Chaudhary (PG Scholar)

Department of Computer Application, Swami Vivekanand Subharti University, Meerut

Email: garvitc484@gmail.com

Abstract

The Smart Energy Monitoring System is developed to monitor and manage electricity consumption efficiently using modern IoT and software technologies. The system collects real-time energy usage data through smart sensors and stores it in a centralized database for analysis and visualization. Users can track power consumption, receive alerts for abnormal usage, and make informed decisions to reduce energy wastage. The system also provides historical reports and graphical insights through a web or mobile interface. This project promotes energy efficiency, cost savings, and sustainable energy management practices, making it suitable for smart homes, industries, and institutional environments.

Keyword: Smart Energy, real-time.

Abstract 22**Design and Optimization of Energy-Aware Green IoT Systems for Smart Cities****Ankit Kumar**

Department of Computer Application, Faculty of Science, SVSU, Meerut

Email Id-ankit.su202200919@subharti.co

Abstract

Rapid development of smart city infrastructures has brought about an enormous deployment of Internet of Things (IoT) devices which, on the one hand, lead to drastically increased energy use and, on the other hand, cause considerable environmental footprint. In this context, Green IoT, i. e. Information and Communication Technologies for green and sustainable development, has been introduced as a new and very promising way of dealing with these problems through emphasis on energy efficiency, sustainability, and the reduction of carbon emissions. This research paper aims at designing and optimizing the energy-aware Green IoT system that will serve as the backbone of smart city applications. The paper presents an intelligent system which, by combining energy-efficient communication protocols, the dynamic allocation of resources, and the use of low-power sensing, sets out to reduce the energy consumption of all devices in the IoT network. To make the system more efficient and to give longer life to devices, various state-of-the-art optimization methods including machine-learning-based forecasting models are employed. The design that is proposed and to a great extent realized in software can also resort to the use of edge and fog computing to speed up response time and cut down the amount of energy going into communication with the cloud. Performance evaluation of the system is carried out using the most relevant KPIs of energy efficiency, network lifetime, scalability, and carbon footprint reduction. Experimental data indicate that the strategy put forth here yields great improvement in energy usage while at the same time ensuring excellent quality of service. This study lays foundation for further research insight into the creation of the next generation of smart cities characterized by going green through minimizing energy consumption by providing an IoT platform that is efficient and environmentally friendly.

Keywords: Green IoT, Smart Cities, IoT Optimization, Machine Learning, Carbon Footprint Reduction

Abstract 23**College Voting System for Leader Election**

Anushikha Tomar (PG Scholar)

Master of Computer Application (MCA), Department of Computer Application, Swami

Vivekanand Subharti University, Meerut.

Email: tomaranushikha29@gmail.com

Abstract:

The *College Voting System for Leader Election* is a digital solution designed to modernize and streamline the traditional student election process. In many educational institutions, elections are still conducted using paper ballots and manual vote counting, which require considerable time, resources, and administrative effort. These conventional approaches may also lead to counting errors, delays in result declaration, and limited transparency in the electoral process. To address these challenges, this study proposes an online voting system that enhances the efficiency, transparency, and reliability of student elections through the application of modern information technology. The proposed system enables eligible students to participate in the electoral process through a secure authentication mechanism using unique login credentials. After successfully logging into the system, voters can access detailed information about the candidates contesting for various leadership positions and cast their votes electronically through a simple and user-friendly interface. The system incorporates strict validation controls to ensure that each student is allowed to vote only once, thereby maintaining fairness and preventing duplication or manipulation of votes. All submitted votes are securely stored in a centralized database, where the system automatically processes and generates election results with high accuracy and minimal delay. This automated approach significantly reduces the likelihood of human error and enables faster result processing compared to traditional manual methods. In addition, the system preserves voter anonymity, ensuring that individual voting preferences remain confidential and that the election process remains unbiased and trustworthy. By integrating digital technology into the electoral framework, the College Voting System enhances transparency, accountability, and operational efficiency in student governance. The proposed model offers a practical and scalable approach for conducting elections in educational institutions while encouraging greater student participation in democratic decision-making processes.

Keyword: System, digital technology.

Abstract 24**Crime Data Analysis System**

Chitransh Tyagi

Department of Computer Application, Swami Vivekanand Subharti University, Meerut

Email: chitranshtyagi007@gmail.com

Abstract

Crime is one of the major issues affecting the safety and development of society. With the rapid growth of population and urbanization, the amount of crime data is increasing day by day. Traditional methods of analyzing crime data are time-consuming and inefficient. Therefore, there is a need for a smart system that can analyze crime data effectively and help authorities make better decisions. The Crime Data Analysis System is designed to analyze crime data using modern technologies such as Python, MySQL, and Power BI. In this system, crime data is stored in a MySQL database, which helps in managing and organizing large amounts of information efficiently. Python is used for data processing, data cleaning, and analysis with the help of libraries such as Pandas, NumPy, and Matplotlib. These tools help to extract meaningful insights from the data. After processing the data in Python, the results are visualized using Power BI dashboards. Power BI provides interactive charts, graphs, and reports that help users understand crime patterns easily. With the help of this system, users can analyze crime trends based on location, type of crime, time, and other factors. The main objective of this project is to help law enforcement agencies and researchers understand crime patterns and identify high-risk areas. By analyzing crime data visually, authorities can take preventive actions and improve public safety. This system also demonstrates how modern data analytics tools can be used to solve real-world problems. In conclusion, the Crime Data Analysis System provides an efficient and user-friendly way to analyze and visualize crime data. It helps in better decision-making and supports crime prevention strategies through data-driven insights.

Keyword: Crime Data, visualize.

Abstract 25

AI-Driven Automated Software Bug Detection and Repair

Dr. Manoj Kumar

Associate Professor, Department of computer application

Swami vivekanand subharti university, Meerut.

Email Id-manoj2002199@gmail.com

Abstract:

Software bugs remain a significant challenge in large-scale software development. Recent advances in artificial intelligence and program analysis have enabled automated approaches for detecting and repairing code defects. This research investigates AI-driven tools that use deep learning and natural language processing techniques to analyse source code and automatically suggest bug fixes. By training models on large code repositories, the proposed system aims to reduce debugging time and improve software reliability. The research also explores the integration of automated bug repair tools into modern DevOps pipelines.

Keyword: Software, AI-driven, DevOps pipelines.

Abstract 26**Carbon-Differential Workload Migration in Distributed Cloud Data Centers: A Deterministic Energy-Proportional Scheduling Framework**

Naveen Chandra

Department of Computer Applications, Keral Verma Subharti College of Science, Swami

Vivekanand Subharti University, Meerut, Uttar Pradesh, India

Email Id-naveen.svsu@gmail.com

Abstract

Conventional cloud orchestration frameworks schedule workloads based on CPU utilization and service-level parameters without accounting for the carbon intensity of the underlying energy supply, resulting in non-proportional energy consumption and avoidable carbon emissions. This paper presents a hierarchical, deterministic, carbon-differential scheduling framework for distributed cloud data centers that operates without reliance on artificial intelligence or machine learning models. A Carbon-Weighted Multi-Dimensional Resource Index (CMRI) is computed in real time for each server by integrating normalized operational metrics, real-time grid carbon intensity values, server-specific Energy Elasticity Coefficients (EEC), and thermal inefficiency factors. A deterministic multi-layer rule engine performs workload migration decisions across node, cluster, and data-center levels using precompiled finite-state decision structures incorporating carbon differential migration thresholds (ΔC_{min}), hysteresis controls, and carbon budget envelope constraints. Based on rule outcomes, workloads are migrated onto energy-proportional nodes, non-critical tasks are deferred during high-carbon periods, and servers undergo staged firmware-level power-state transitions — including voltage scaling, core parking, memory throttling, and controlled deep power-off — executed via ACPI, IPMI, or baseboard management controllers (BMC). The proposed framework achieves measurable physical energy reduction, prevents oscillatory workload migration behavior, and supports compliance with green IT mandates across public, private, hybrid, and federated cloud environments.

Keywords — carbon-differential scheduling, workload migration, CMRI, energy elasticity, deterministic rule engine, distributed cloud, green IT, energy-proportional computing

THEME 2:

Smart and Sustainable Technologies

Abstract 1**Length-Weight Relationship and Growth Pattern Analysis of *Channa punctatus* from the Ganga River, Bijnor and *Cirrhinus mrigala* from Ram Taal Lake, Meerut: A Comparative Study of Allometric Growth and Environmental Influence**

Shagun Rathi, Neeru Singh*, Mohd. Faisal Siddiqui, Dheer Pal Singh, Aanchal Sharma

Department of Life Science, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut

*Corresponding author: thatsneerus@gmail.com

Abstract

The length–weight relationship (LWR) and condition factor (K) of *Channa punctatus* and *Cirrhinus mrigala* collected from two ecologically distinct freshwater systems—the lentic Ram Taal Lake in Uttar Pradesh, India, and the lotic Ganga River—are examined in this study. Log-transformed linear regression was used to determine important growth parameters using biometric data from 20 specimens (10 per species). The findings indicated that *Channa punctatus* had negative allometric growth ($b = 2.468$, $R^2 = 0.995$) and *Cirrhinus mrigala* had positive allometric growth ($b = 3.342$, $R^2 = 0.7301$). Compared to *Cirrhinus mrigala* ($K = 14.96$), *Channa punctatus* ($K = 71.18$) had a significantly higher average condition factor (K), indicating superior physiological condition in riverine species. These results highlight how environmental factors affect fish health and growth, offering useful information for fishery management and conservation.

Keywords: Length–Weight Relationship (LWR), Condition Factor (K), Allometric Growth, *Channa punctatus*, *Cirrhinus mrigala*, Freshwater Fish, Riverine vs. Lentic Habitat.

Abstract 2**Green Chemistry Approaches for Sustainable Development: Strategies for a Cleaner and Greener Future**^aNamra Babar*, ^aNisha^aDepartment of Chemistry, Faculty of Science, Swami Vivekanand Subharti University,
Meerut

*Email Id- namrababar9897@gmail.com

Abstract:

Green chemistry has emerged as an essential scientific approach for promoting sustainable development by minimizing environmental pollution and improving the efficiency of chemical processes. It focuses on designing products and processes that reduce or eliminate the use and generation of hazardous substances. In the real world, industries, agriculture, pharmaceuticals, and environmental management sectors are increasingly adopting green chemistry strategies to address global challenges such as pollution, resource depletion, and climate change. One of the key principles of green chemistry is the use of renewable resources and eco-friendly materials in chemical production. For example, plant extracts, agricultural wastes, and biological systems are now widely used for the green synthesis of nanoparticles, biodegradable polymers, and environmentally safe chemicals. These alternatives reduce the dependence on toxic solvents and harmful reagents traditionally used in industrial processes. Green chemistry also emphasizes energy-efficient processes and the reduction of waste generation. Techniques such as catalytic reactions, solvent-free synthesis, and the use of biodegradable materials have significantly improved sustainability in chemical manufacturing. In wastewater treatment and environmental remediation, green chemical technologies help remove toxic dyes, heavy metals, and other contaminants from water and soil with minimal ecological impact. In agriculture, green chemistry contributes to the development of bio-based pesticides, nano-formulations, and eco-friendly fertilizers, which enhance crop productivity while reducing environmental damage. Similarly, in pharmaceuticals and materials science, green approaches are being used to develop safer drugs and sustainable materials. Overall, green chemistry provides practical strategies for balancing economic development with environmental protection.

Keywords: Green chemistry; Sustainable development; Environmental protection; Renewable resources; Eco-friendly technologies.

Abstract 3**Biochemical conversion of agri-food waste into high value biopolymers: A sustainable biorefinery approach towards circular bioeconomy**

Purvi kalkhande

Department of life science (biochemistry), Kerala verma subharti college of science,

Swami Vivekananda Subharti University, Meerut, UP, India

Email: purvi.kalkhanday26@gmail.com

Abstract

Agri-food waste reduction has become a major priority for many nations, including India, in order to develop a resilient and sustainable food ecosystem. The rapid increase in agri-food waste has created significant environmental and economic challenges worldwide. Biochemical conversion offers a sustainable and efficient approach for transforming agri-food waste into valuable biopolymers. This study investigates the biochemical conversion of diverse agri-food wastes, including fruit and vegetable residues, dairy by-products, and starchy effluents, into high-value biopolymers such as polyhydroxyalkanoates (PHAs), bacterial cellulose, xanthan gum, and hyaluronic acid. In the biochemical conversion pathway, complex organic materials are first hydrolyzed into simple sugars and nutrients, which are subsequently metabolized by selected microorganisms to synthesize biopolymers. These biopolymers exhibit desirable characteristics such as biodegradability, biocompatibility, and versatile applicability in packaging materials, biomedical products, and sustainable plastics. A multistage biorefinery framework was employed, integrating physicochemical pretreatment, enzymatic saccharification, and microbial fermentation using *Cupriavidus necator* and *Bacillus* species under controlled bioreactor conditions. The results demonstrate that substrate-specific fermentation strategies significantly enhance biopolymer productivity. Structural and physicochemical characterization using NMR, GPC, and SEM confirmed that the recovered biopolymers possess desirable material properties suitable for industrial applications. The proposed process not only reduces environmental pollution associated with food waste disposal but also contributes to the development of a circular bioeconomy by converting low-value waste into high-value bioproducts.

Keywords: Agri-food waste valorization; Biopolymers; Polyhydroxyalkanoates; Biorefinery; Microbial fermentation.

Abstract 4**Effect of Integrated Nutrient Management in Bread Wheat (*Triticum Aestivum* L.)**Aarushi Vats ¹, and Saurabh Tyagi ²¹ Researcher (PG), Department of Agriculture (KVSCOS), Swami Vivekanand Subharti University, Meerut, (UP) India² Department of Agriculture (KVSCOS), Swami Vivekanand Subharti University, Meerut, (UP) India

Email Id-aarushivats51@gmail.com

Abstract

Wheat (*Triticum aestivum* L.) is one of the most important staple food crops in India and many other countries, providing a major source of carbohydrates, proteins, vitamins, and minerals for human nutrition. In India, wheat is cultivated over a large area and plays a vital role in ensuring food security, with Uttar Pradesh being one of the leading wheat-producing states. However, the excessive and imbalanced use of synthetic fertilizers and chemicals to increase crop productivity has led to several environmental and soil health problems. Integrated Nutrient Management (INM) has emerged as a sustainable approach to maintain soil fertility, improve crop productivity, and reduce the negative impact of chemical fertilizers on the environment. INM involves the combined use of organic manures, chemical fertilizers, and biofertilizers to supply essential nutrients in a balanced manner. Several studies have reported that the adoption of INM practices in wheat cultivation improves plant growth, grain yield, nutrient uptake, and soil health while minimizing environmental hazards. This review paper highlights the role and benefits of integrated nutrient management in wheat production, focusing on its effects on crop growth, yield, nutrient uptake, and the efficient use of different nutrient sources applied individually or in combination for sustainable wheat cultivation.

Keywords: Integrated Nutrient Management (INM), Wheat (*Triticum aestivum* L.), Soil Health, Nutrient Uptake, Grain Yield, Sustainable Agriculture

Abstract 5**Climate Smart Nutrients and Water Management Strategies For Sustainable Rice Production**Kanika^{1*}, and Saurabh Tyagi²¹ Researcher (PG), Department of Agriculture (KVSCOS), Swami Vivekanand Subharti University, Meerut, UP, India² Department of Agriculture (KVSCOS), Swami Vivekanand Subharti University, Meerut, UP, India

Email Id-akinaksharma9045@gmail.com

Abstract

Climate Smart Nutrient and Water Management strategies are necessary to achieve sustainability and to improve productivity, resource use efficiency of Rice production despite irregular climatic conditions. Traditional method of cultivating Rice involves exploitation of resources which led to many problems such as leaching, volatilization, run off, water logging, emission of greenhouse gases. These strategies not only overcome these problems but also improve productivity. Climate-smart Nutrient management aims to increase nutrient use efficiency by focusing on optimizing the timing, placement of nutrients through various practices such as site-specific nutrient management, use of slow-release fertilizers, integrated use of inorganic and organic nutrient sources. Simultaneously, Climate-smart Water management focuses on improving water use efficiency and reducing emissions of greenhouse gases from paddy fields through a couple of practices such as alternate wetting and drying (AWD), improved irrigation scheduling, and field water budgeting. The synergistic integration of nutrient and water management improves plant nutrient and water uptake, productivity in response to challenging environmental conditions. Adoption of these strategies is vital for achieving sustainable rice production to ensure food availability to growing population under changing climatic conditions.

Keywords- Greenhouse gases, nutrient use efficiency, sustainability, leaching.

Abstract 6**Artificial Intelligence in Drug Discovery: Computational Methods, Tools, and Emerging Applications**Mohd Asif Siddiqui¹, and Indu²¹Department of Life Science, Swami Vivekanand Subharti University, Subhartipuram, NH-58, Delhi-Haridwar Bypass Road, Meerut-250005.²Assistant Professor, School of Arts and Humanities, IIMT University, Meerut

*Corresponding author email: asifsiddiqui82@gmail.com,

Abstract

The pharmaceutical sector has been able to innovate its drug discovery process through the implementation of bioinformatics tools and technologies that enable researchers to explore complex biological systems in ways never possible before. This review summarizes a variety of computational methods that have been developed throughout the modern drug discovery process and have been unified into a singular, holistic analytical framework using AI, AlphaFold-based structure prediction, federated learning, real-world case studies, and other new approaches not found in previously published reviews. The analytic methods described include molecular docking, quantitative structure–activity relationship (QSAR) modeling, pharmacophore modeling, virtual screening, network pharmacology, and AI-based deep learning and generative design. Using comparative analyses of classical versus deep learning-based QSAR models, docking versus AI-assisted virtual screening, and single-target and network pharmacology methods, this review demonstrates that there are specific situations and reasons when one method is preferred over another. The example applications covered include drug discovery paradigms for anticancer, antiviral, neurodegenerative disease, antimicrobial, and rare diseases. Additionally, we discuss current issues surrounding translational bottlenecks that exist between in silico and in vivo predictions, regulatory, and ethical issues associated with using AI approaches to drug discovery, as well as critical issues that the field will face in years to come.

Keywords: bioinformatics, drug discovery, molecular docking, machine learning, virtual screening, QSAR, pharmacophore, network pharmacology, AlphaFold

Abstract 7**An inclusive Review on Fermented Chilli Extract in Sustainable Agriculture:
Biopesticidal Mechanisms, Applications and Future Opportunities**

Priyanshu Rana, Ashwani Kumar*, Aysha pundir, Shagun Tomar, Kanupriya

Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India

*Corresponding author. Email: amritdhra1981@gmail.com

Abstract

The increasing environmental and health concerns associated with the excessive use of synthetic pesticides have intensified the search for sustainable and eco-friendly alternatives in modern agriculture. Fermented plant-based formulations have emerged as promising biopesticidal agents due to their biodegradability, low toxicity, and multifunctional properties. Among these, fermented chilli solution derived primarily from *Capsicum* species has gained attention because of its rich content of bioactive compounds such as capsaicinoids, phenolics, and flavonoids that exhibit strong insecticidal, repellent, antifungal, and antimicrobial activities. This review comprehensively examines the efficacy and potential of fermented chilli solution as a sustainable biopesticide in organic and natural farming systems. The article discusses the biochemical composition of chilli, fermentation processes that enhance the bioavailability of active compounds, and the mechanisms through which fermented chilli formulations act against agricultural pests and pathogens. Additionally, the review highlights the advantages of fermented chilli solution including cost-effectiveness, environmental safety, compatibility with integrated pest management (IPM), and its role in promoting soil and plant health. Current research findings, field applications, and limitations related to formulation stability, standardization, and large-scale adoption are also critically analyzed. Furthermore, future research directions are proposed to optimize fermentation techniques, improve formulation efficiency, and integrate fermented chilli biopesticides into sustainable agricultural practices. Overall, fermented chilli solution represents a promising natural alternative to chemical pesticides and offers significant potential for environmentally responsible pest management.

Keywords: Fermented chilli solution; Biopesticide; *Capsicum* fermentation; Sustainable agriculture; Natural pest control; Organic farming; Plant-based pesticides; Eco-friendly pest management.

Abstract 8**The Efficacy and Potential of Fermented Ginger (*Zingiber officinale*) as a Sustainable Biopesticide: A Comprehensive Review**

Shagun Tomar, Ashwani Kumar*, Aysha pundir, Priyanshu Rana, Kanupriya

Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India

*Corresponding author. Email: amritdhra1981@gmail.com

Abstract:

Research on plant-based biopesticides has increased due to the growing need worldwide for environmental friendly substitutes for chemical based pesticides. There are a lot of plants that can be used in making of biopesticides like Neem, turmeric, tobacco, pyrethrum, garlic, basil, cinnamon, etc. Ginger is one of them due to its high concentration of gingerols, shogaols, terpenes, and oleoresins with potent antibacterial, antifungal, and insecticidal properties. *Zingiber officinale* (ginger) has drawn a lot of interest among phytochemical-rich species. The investigation of plant-based biopesticides has been encouraged by the growing need for eco-friendly farming methods. As a substitute for chemical pesticides, fermented ginger (*Zingiber officinale*) extracts made with a jaggery-water solution can be used. The microbial activity, formulation techniques, phytochemical changes, bioassay effectiveness, storage stability, environmental safety, regulatory issues, and commercialization possibilities of fermented ginger biopesticides are all thoroughly covered in this review. Due to Fermentation volatile terpenes and organic acids, increases the conversion of gingerols to shogaols, and stabilizes bioactive chemicals. Strong insecticidal, larvicidal, antifungal, nematicidal, and repellent properties nano-emulsions. Environmental safety is confirmed by sophisticated toxicological research and risk quotient analyses, and commercialization is supported by regulatory frameworks in the USA, EU, India, and other nations. Advanced formulations, pilot-scale fermentation, and integration into integrated pest management (IPM) systems provide a scalable adoption pathway. To ensure worldwide application, future research should concentrate on fermentation optimization, field validation, metabolomic profiling, and formulation standardization.

Keywords: Fermentation, Jaggery, Biopesticide, Phytochemicals, Integrated Pest Management, Ginger, And Environmental Safety

Abstract 9**Novel Approaches in Drug Discovery: Integrating Natural Bioactives, Nanotechnology, and Computational Methods**

Bhupesh Singh*, Dhanendra Kumar Rai

Department of Life Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India, 250005

*Corresponding Author Email: Bhupesh20011996@gmail.com

Abstract

Recent improvements in how we find new medicines have resulted from two things; 1) there is an increasing demand for safe (nonpoisonous) & effective medicines, and 2) as we learn more about the complexities of how diseases work, it is apparent that traditional methods of developing new medicines are both slow, expensive, and only about 10% of new drugs that make it into the clinic succeed. The current direction of research will be integrating various methods such as using natural products from plants/animals/microorganisms/marine organisms in combination with new technologies (such as nanotechnology) and computer methods to allow quicker identification and development of new medicines. These natural products are a tremendous source of the many different types of bioactive ingredients (active compounds) which have been identified through various methods. Additionally, many of these bioactive compounds have shown that they have the potential to be developed into new medicines based on the fact that they work very well with human cells and tissues and are very effective in treating diseases found in humans. Nanotechnology has recently grown by enhancing the discovery and delivery of drugs and biopharmaceuticals through enhanced solubility, stability, and target drug delivery in patients. Nanoparticle-based systems (i.e., metal nanoparticles & polymer-based nanocarriers) improve drug efficacy via controlled drug release and increased bioavailability (e.g., better pharmacokinetic properties). At the same time, computational methods like molecular docking, virtual screening, and quantitative structure-activity relationships (QSAR) are changing how we do early-stage drug discovery. These in silico tools allow us to efficiently evaluate huge compound databases for potential drug compounds; model interactions between potential drugs and their biological targets; and optimize lead compounds, thereby reducing costs and time required for their laboratory testing.

Keywords: Drug discovery, natural bioactive, nanotechnology, computational methods, molecular docking, Nano medicine.

Abstract 10

A single vendor and multiple buyers integrated inventory policy in demand declining market

Ankit Kumar Goyal

Department of Basic Science, Keral Verma Subharti College of Science, SVSU,
Meerut

Email Id- ankitkumar.goyal@gmail.com

Abstract

In the present study, an inventory policy for single vendor and multiple buyers is developed and studied. The demand function is decreasing with respect to time. It is established numerically that the integrated approach results in significant decrease in the total cost in compared with the independent decision approach by all the buyers. The sensitivity analysis is carried out for all the parameters.

Key words: Inventory policy, Single vendor, Multi buyers, declining market condition

Abstract 11**Nanostructured Metal Oxides as Foliar Modulators of Growth, Photosynthesis, and Seed-Oil Bioactivity in Moringa (*Moringa oleifera* L.)**Anupriya Rana¹, Ashwani Kumar¹, Sarita Rana¹, Ritika Yadav¹, Shachi Tiwari¹¹ Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh.

Email: anupriya.rana05@gmail.com

Abstract

Metallic nano-oxides have gained considerable attention as precision foliar inputs capable of modulating plant physiological processes and secondary metabolite biosynthesis. *Moringa* (*Moringa oleifera* L.), renowned for its exceptional nutritional profile and multipurpose agronomic value, represents an ideal candidate for nano-agronomic interventions aimed at enhancing crop productivity and oil bioactivity. In this study, moringa plants were subjected to foliar applications of zinc oxide (ZnO) and titanium dioxide (TiO₂) nanoparticles across a concentration gradient of 20–80 ppm to evaluate their differential effects on vegetative growth parameters, photosynthetic indices, and seed-oil chemistry. ZnO nanoparticles significantly enhanced plant height, leaf number, and stem diameter, while concurrently promoting elevated chlorophyll accumulation and total protein content, indicative of improved photosynthetic efficiency and anabolic metabolism. In contrast, TiO₂ nanoparticles demonstrated a mild stimulatory response at lower concentrations, transitioning to inhibitory effects at elevated application rates, suggesting concentration-dependent phytotoxic thresholds. Gas chromatography–mass spectrometry profiling of extracted moringa seed oils revealed distinct compositional alterations attributable to each treatment. ZnO exposure enriched long-chain fatty acid esters, including ethyl linoleate and methyl stearate, whereas TiO₂ treatment favored medium-chain fatty acid accumulation alongside tocopherol-associated antioxidant species of notable nutraceutical significance. Collectively, these findings establish that nanostructured metal oxides can serve as effective agronomic tools for fine-tuning growth, metabolic, and oil quality outcomes in moringa, offering a sustainable pathway toward enhanced functional food and phytopharmaceutical applications.

Keywords: *Moringa oleifera*; foliar application; fatty acid profile; tocopherols; nano-agronomy; nutraceuticals; GC-MS analysis

Abstract 12**Application of Spices as Bio preservative in Indian Food**

Mehrukh Iffat

Ph.D. Scholar, Biotechnology, KVSCOS, SVSU, Meerut

Email Id- mehrukhiffat786@gmail.com

Abstract

Increasing population is the root of almost every problem of this era. It leads to increase in demand for food and other life necessities. To meet such huge demands for food, it needs to preserve it from farms to industry or homes. But today methods of preservation are a matter of serious concern because it is done chemically which can lead to serious health issues or incurable ailments like cancer if used beyond permissible limits. Studies reveal that certain food commodities like spices itself can act as strong preservatives against wide varieties of microorganisms. Spices are integral components of Indian cuisine, valued not only for their flavor and aroma but also for their medicinal and preservative properties. God has gifted Asian land with high productivity of certain precious spices and condiments which have given fruitful results in certain aspects of life including health care and preservation. New technologies in food preservation have emerged, leads to a reduction in the level of chemical preservatives and promotes the use of naturally occurring antimicrobial compounds in various spices. Recent research has demonstrated that many spices possess strong antimicrobial, antioxidant, and antifungal activities, making them effective natural alternatives to synthetic food preservatives. Phytochemicals present in spices have potentials to fight and work against microbial, enzymatic or physical factors responsible for spoilage of food. Though spices have certain food compatibility and organoleptic limitations which could be overcome by using combinations of spices.

Keyword: Food, Population, Antifungal, Microbial.

Abstract 13**Hospital Management System**

Ritik Singh (PG Scholar)

Department of Computer Application, Swami Vivekanand Subharti University, Meerut

Author Email Id: ritiksingh9675k@gmail.com

Abstract

The Hospital Management System (HMS) is a computer-based information system designed to manage hospital operations efficiently and effectively. The main objective of this system is to simplify the administrative and clinical activities of hospitals by integrating different departments such as patient registration, doctor management, appointment scheduling, billing, pharmacy, and medical records into a single digital platform. Traditional hospital management processes are mostly manual, which leads to data redundancy, errors, and time-consuming operations. The proposed system aims to overcome these problems by providing a centralized and automated solution. The Hospital Management System allows hospital staff to store, retrieve, and manage patient information in a secure and organized manner. It helps doctors access patient history, diagnosis details, and treatment records quickly. The system also enables easy appointment scheduling, reducing waiting time for patients and improving hospital service quality. In addition, it automates billing and report generation, which enhances accuracy and transparency in hospital transactions. The proposed system can be developed using modern technologies such as web-based platforms, database management systems, and secure authentication methods. It ensures data integrity, quick data processing, and efficient communication between different hospital departments. Furthermore, the system can support future enhancements such as integration with IoT devices, electronic health records, and AI-based diagnostic support. Overall, the Hospital Management System improves hospital productivity, reduces manual workload, enhances patient care, and provides a reliable platform for hospital administration and medical data management.

Keyword: HMS, hospital, AI-based.

Abstract 14**Tracing Lineage and Relations: Ethical AI-Driven Sustainable Forensic Anthropology**

Lalit Panwar

Department of Forensic Science, Faculty of Science, Swami Vivekanand Subharti University,
Meerut 250005, U.P., India

Email Id-lalit.su202500613@subharti.co

Abstract

Forensic anthropology is central to human identification, employing skeletal and biological markers to elucidate ancestry, familial relationships, and individual identity. The advent of artificial intelligence (AI) has transformed this discipline, enabling rapid, precise, and data-driven analyses while reducing human error and bias. This review examines the integration of ethical AI methodologies in forensic anthropology to trace lineage and familial connections, highlighting the delicate balance between technological innovation and moral responsibility. Furthermore, it underscores the importance of sustainable forensic practices—such as minimizing destructive sampling, conserving resources, and preserving biological evidence—and how these can be seamlessly incorporated into AI-driven approaches. By merging traditional anthropological expertise with advanced computational tools, investigators can achieve unprecedented accuracy in complex scenarios, including mass disaster identification, missing persons cases, and historical population studies. The paper also addresses contemporary challenges, including data privacy, algorithmic transparency, and societal implications of automated ancestry determination. Ethical AI-driven forensic anthropology thus represents a forward-looking paradigm, enhancing both criminal and humanitarian investigations while promoting sustainability, responsible data stewardship, and long-term preservation of human biological resources.

Keyword: AI-driven, technological, humanitarian.

Abstract 15**AI-Driven Strategies for Combating New-Age Cybercrime: Towards Sustainable Digital Security**

Pragati Jain

Department of Forensic Science, Faculty of Science, Swami Vivekanand Subharti University,
Meerut 250005, U.P., India

Email Id- pragati.su202400801@subharti.co

Abstract

The rapid evolution of digital technologies has reshaped how individuals, organizations, and governments operate, but it has simultaneously fueled the rise of new-age cybercrime. Contemporary cyber threats—including data breaches, ransomware, identity theft, phishing attacks, and financial fraud—have become increasingly sophisticated, adaptive, and far-reaching, presenting profound social, economic, and ethical challenges. This review critically examines these emerging cybercrime trends and explores sustainable strategies for prevention, mitigation, and long-term resilience. Emphasis is placed on ethical and resource-conscious approaches, including the development of robust digital infrastructures, proactive risk management, cybersecurity education, and comprehensive legal and regulatory frameworks. The study highlights the importance of integrating technological measures with organizational policies and user awareness programs to foster a secure, sustainable, and responsible digital environment. Sustainable cybersecurity not only mitigates immediate threats but also ensures ethical practices, minimizes resource consumption, and builds long-term trust in digital systems. By adopting a holistic and forward-looking approach, stakeholders can strengthen the resilience of digital ecosystems, safeguard sensitive information, and address the evolving landscape of cyber threats. This review offers actionable insights for building ethical, sustainable, and effective cybersecurity practices capable of confronting the challenges of modern cybercrime.

Keyword: cyber, Sustainable, sophisticated.

Abstract 16**Hi-Tech Polyhouse – A True Value of Protected Cultivation**

Mahima Sharma and Saurabh Tyagi

Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University Meerut; (UP)

India

Email Id- srbhtyagi1@gmail.com

Abstract

Protected cultivation has emerged as an important approach to enhance agricultural productivity, quality, and resource-use efficiency in modern horticulture. Among various protected structures, the hi-tech polyhouse represents an advanced system that enables precise control of environmental parameters such as temperature, humidity, light, and irrigation. This technology creates a favorable microclimate for crop growth, allowing year-round cultivation and significantly reducing the impact of adverse weather conditions. Hi-tech polyhouses are equipped with automated systems including drip irrigation, fertigation units, ventilation systems, shading mechanisms, and climate control technologies. These features help optimize plant growth while minimizing water, fertilizer, and pesticide use. As a result, farmers can achieve higher yields, better quality produce, and increased economic returns compared to traditional open-field cultivation. Crops such as capsicum, tomato, cucumber, strawberry, and various flowers perform particularly well under polyhouse conditions. In addition to improving productivity, hi-tech polyhouses contribute to sustainable agriculture by enhancing resource efficiency and reducing environmental stress on crops. They also enable off-season production, which can fetch premium market prices and strengthen farmers' income. Despite the higher initial investment, government subsidies, technological advancements, and growing market demand are encouraging wider adoption of this technology. Therefore, hi-tech poly-house cultivation represents a valuable component of protected agriculture offering a reliable solution for climate-resilient farming efficient resource management and improved profitability for farmers. Its adoption can play a significant role in meeting the increasing demand for high-quality produce while ensuring sustainable agricultural development.

Keywords: Fertigation; agricultural productivity; climate-resilient farming and sustainable development.

Abstract 17**IoT-Based Agriculture: The Future of Indian Farming**

Saurabh Tyagi and Sunil Kumar

Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University

Meerut; (UP) India

Email Id- srbhtyagi1@gmail.com

Abstract:

Agriculture plays a vital role in the economy of India, supporting a large portion of the population and ensuring national food security. However, the sector faces several challenges such as climate variability, inefficient resource use, declining soil fertility, and labor shortages. The integration of the Internet of Things (IoT) in agriculture offers innovative solutions to address these challenges and improve productivity and sustainability. IoT-based agriculture involves the use of smart sensors, connected devices, drones, and automated systems to monitor and manage farming activities in real time. These technologies enable farmers to collect data on soil moisture, temperature, humidity, crop health, and nutrient levels, allowing for precise decision-making and efficient resource management. With IoT-enabled systems, farmers can implement precision agriculture practices such as automated irrigation, smart fertilization, pest detection, and climate monitoring. This leads to optimized water use, reduced input costs, higher crop yields, and improved environmental sustainability. In India, the adoption of IoT technologies has the potential to transform traditional farming into a more efficient, data-driven, and climate-resilient system. Government initiatives and increasing digital infrastructure are further promoting the use of smart agriculture technologies across rural areas. Therefore, IoT-based agriculture represents a promising pathway for enhancing productivity, ensuring food security, and achieving sustainable agricultural development in India.

Keywords: Internet of Things (IoT), Smart Agriculture, Precision Farming, Digital Agriculture, Sensor Technology, Sustainable Farming.

Abstract 18**Climate Smart Agriculture for a Sustainable World**

Saurabh Tyagi and Apurv Kaintura

Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University Meerut; (UP)
India

Email Id- srbhtyagi1@gmail.com

Abstract

Climate change poses serious challenges to global agriculture by affecting crop productivity, soil health, water availability, and food security. Climate-Smart Agriculture (CSA) has emerged as an integrated approach to address these challenges while promoting sustainable agricultural development. Climate-smart agriculture focuses on three major objectives: increasing agricultural productivity, enhancing resilience and adaptation to climate change, and reducing or removing greenhouse gas emissions where possible. CSA promotes the adoption of innovative and resource-efficient practices such as conservation agriculture, integrated nutrient management, efficient water management, agroforestry, climate-resilient crop varieties, and precision farming technologies. These strategies help farmers adapt to changing climatic conditions while maintaining ecosystem balance and ensuring long-term food security. Furthermore, CSA supports sustainable use of natural resources, improves soil fertility, conserves biodiversity, and enhances farmers' livelihoods. The implementation of climate-smart policies, capacity building, and technological innovations plays a crucial role in transforming conventional farming systems into more resilient and sustainable systems. Therefore, integrating climate-smart agricultural practices is essential for achieving global sustainability goals and ensuring food security for the growing population in a changing climate.

Keywords: Climate-smart agriculture, Sustainable agriculture, Climate change adaptation, Mitigation, Food security, Resource conservation, Resilient farming systems.

Abstract 19**Smart Agro-forestry Management for One Health**

Saurabh Tyagi and Neha Pant

Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University, Meerut; (UP)
India

Email Id- srbhtyagi1@gmail.com

Abstract

Smart agroforestry management integrates advanced technologies with traditional agroforestry practices to enhance ecosystem sustainability, agricultural productivity, and human well-being. The One Health approach recognizes the interconnectedness of human health, animal health, and environmental health, emphasizing the need for integrated land management systems. Smart agroforestry utilizes modern tools such as remote sensing, geographic information systems (GIS), Internet of Things (IoT) sensors, and data-driven decision-making to optimize tree–crop–livestock interactions. These systems improve soil fertility, conserve biodiversity, regulate microclimates, and enhance carbon sequestration while providing diversified income sources for farmers. Furthermore, agroforestry landscapes contribute to improved nutrition, reduced environmental degradation, and increased resilience to climate change. By integrating sustainable management practices with digital monitoring and precision agriculture, smart agroforestry supports healthy ecosystems, sustainable food production, and improved rural livelihoods. Therefore, the adoption of smart agroforestry under the One Health framework can play a significant role in achieving sustainable development goals by promoting ecological balance, food security, and public health.

Keywords: Smart agroforestry, One Health, sustainable agriculture, precision farming, ecosystem health, climate resilience, biodiversity conservation, digital agriculture.

Abstract 20**Intelligence-Based Plant Breeding for Improved Food Quality**

Pulkit Sharma and Mahima Sharma

Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University

Meerut; (UP) India

Email Id- srbhtyagi1@gmail.com

Abstract

Improving food quality is a major objective of modern plant breeding in order to meet the nutritional demands of the growing global population. Intelligence-based plant breeding integrates advanced technologies such as artificial intelligence (AI), machine learning, genomics, phenomics, and bioinformatics to accelerate the development of crop varieties with enhanced nutritional value, better taste, improved processing quality, and higher consumer acceptance. These intelligent approaches enable breeders to analyze large datasets related to genetic variation, environmental factors, and crop performance, thereby facilitating precise selection and prediction of desirable traits. By combining genomic selection, marker-assisted breeding, and predictive modeling, breeders can efficiently identify superior genotypes with improved protein content, vitamins, minerals, and other quality parameters. Furthermore, intelligence-driven breeding strategies help in reducing breeding cycles, improving selection accuracy, and enhancing resilience to environmental stresses without compromising food quality. The integration of digital agriculture tools and high-throughput phenotyping platforms also supports real-time monitoring of quality traits during crop development. Therefore, intelligence-based plant breeding represents a promising and sustainable approach for developing high-quality crop varieties that contribute to nutritional security and sustainable agriculture.

Keywords: Artificial Intelligence, Plant Breeding, Food Quality, Genomic Selection, Machine Learning, Nutritional Enhancement, Precision Breeding, Sustainable Agriculture.

Abstract 21**Role and Importance of Smart Botanical Gardens in India**

Satvaan Kumar Singh and Mohd. Rizwan

Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University, Meerut;
(UP) India

Email Id- srbhtyagi1@gmail.com

Abstract

Botanical gardens play a crucial role in the conservation, research, and education of plant diversity. In India, the concept of smart botanical gardens is emerging as an innovative approach that integrates modern technologies such as digital plant databases, sensor-based monitoring systems, GIS mapping, and interactive learning tools. These gardens serve as living laboratories for students, researchers, and scientists to study plant taxonomy, conservation biology, and sustainable horticulture. Smart botanical gardens contribute significantly to the conservation of endangered and indigenous plant species, climate change mitigation, and biodiversity preservation. They also enhance public awareness by providing digital information systems, QR-coded plant labeling, mobile applications, and virtual tours that improve visitor engagement and learning experiences. Furthermore, these gardens support academic research, eco-tourism, and sustainable landscape management. In a country like India, which possesses rich floral diversity, the development of smart botanical gardens can strengthen environmental education, promote green technology, and support national biodiversity conservation goals. Therefore, smart botanical gardens represent an important step toward integrating traditional botanical knowledge with modern technological advancements for sustainable environmental management.

Keywords: Smart Botanical Garden, Plant Biodiversity Conservation, Digital Herbarium, Environmental Education, Sustainable Horticulture, Climate Change Mitigation, Eco-tourism, India.

Abstract 22**Sensor-Based Water Management in Rice–Wheat Cropping System**

Apurv Kaintura and Saurabh Tyagi

Department of Agriculture (KVSCOS) Swami Vivekanand Subharti University Meerut; (UP)
India

Email Id- srbhtyagi1@gmail.com

Abstract

The rice–wheat cropping system is one of the most important agricultural production systems in South Asia, particularly in India, where it plays a crucial role in ensuring food security. However, this system consumes a significant amount of irrigation water, leading to rapid depletion of groundwater resources. Sensor-based water management has emerged as a promising approach to optimize irrigation practices and improve water use efficiency. This study focuses on the application of soil moisture sensors, automated irrigation controllers, and real-time monitoring systems for efficient water management in the rice–wheat cropping system. The sensors continuously monitor soil moisture levels and provide data that help in scheduling irrigation based on crop water requirements rather than traditional calendar-based irrigation. The adoption of sensor-based irrigation techniques can significantly reduce water wastage, enhance crop productivity, and improve resource use efficiency. In rice cultivation, sensors help maintain optimal soil moisture conditions under alternate wetting and drying (AWD) irrigation practices, while in wheat they assist in timely irrigation during critical growth stages. The integration of sensor technology with precision agriculture tools contributes to sustainable crop production, reduced energy consumption, and improved groundwater conservation. Therefore, sensor-based irrigation management has the potential to transform conventional irrigation practices and promote sustainable intensification of the rice–wheat cropping system.

Keywords: Sensor-based irrigation, Soil moisture sensors, Rice–wheat cropping system, Precision agriculture, Water use efficiency, Irrigation scheduling, Sustainable water management.

THEME 3:

**Environmental Science and Climate
Change**

Abstract 1**A Review of The Toxic Effect of Fungicides on Various Physiological Aspects of Fish**Tanya^{1*}, and Neeru Singh^{2*}

¹Ph.D. Scholar, Assistant Professor, Department of Zoology, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut- 250005, U.P.

²Department of Zoology, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut- 250005, U.P.

*Email Id-tanyachaudhary30062002@gmail.com, thatsneeru@yahoo.com

Abstract

Ecotoxicology is the science of the effects of toxic chemicals on biological organisms, especially at the population, community, ecosystem, and biosphere levels. Pesticides, after surface runoff, enter the aquatic system, causing a hazardous condition in the environment. These agrochemicals have been reported to be highly toxic not only to the fish population but to the other organisms as well, which form the food chain of the ecosystem. The contaminations of water result in various adverse effects on the health of the fish by altering their physiological status. The fungicides cause toxic effects on the biochemical, haematological, genetic, enzymatic, protein, and histological status of the organisms. In the course of this review, an attempt has been made to explain the ill effects of the commonly used fungicides on the different species of fish by rating the toxicity levels of the toxicants. fish metabolism is directly affected by different pesticides. They cause different types of toxicity in fish such as changes in fish behaviour, haematological changes, histopathological disturbances, biochemical modifications, endocrine system disruption, changes in antioxidant defence system and alteration of acetylcholinesterase activity. The judicious use of fungicides must be carried out by the farmers. The use of Biopesticides and natural products must be encouraged to avoid the toxic effect of the fungicides. Biocontrol of the pests must be a wise selection as compared to the use of synthetic agrochemicals.

Keywords: Fungicides, Fish Toxicology, Oxidative Stress, Hematological Alterations, Histopathology, Endocrine Disruption, Neurotoxicity, Immunotoxicity, Aquatic Pollution.

Abstract 2**To test the efficacy of some fungal isolates for biodegradation of plastic polymer**Shagun¹, Abhishek Thakur¹ and Shipra Chaudhary¹¹Meerut Institute of Engineering and Technology, Meerut

Email Id-seenushagun@gmail.com

Abstract

Plastic pollution has emerged as a major environmental concern due to the extensive use of synthetic polymers and their resistance to natural degradation processes. Conventional disposal methods such as landfilling and incineration contribute to secondary environmental problems, highlighting the need for eco-friendly alternatives. Microbial biodegradation has gained significant attention as a sustainable approach for the breakdown of plastic polymers. Among microorganisms, filamentous fungi possess remarkable enzymatic capabilities that enable them to degrade complex polymeric structures. The present study focuses on the biodegradation potential of selected fungal species viz. *Aspergillus flavus*, *Aspergillus niger* and *Penicillium* spp. for the degradation of commonly used plastic polymers. Fungal isolates were obtained from plastic containing soil environment and cultivated under controlled laboratory conditions to evaluate their plastic-degrading capacity. In the present study, plastic samples such as Low Density Polyethylene (LDPE) was used as substrate in mineral salt medium to assess fungal degradation activity. The biodegradation process was monitored through weight loss analysis, morphological changes. Results from previous studies indicate the potential role of certain extracellular enzymes including laccase, peroxidase, lipase, esterase, cutinase in oxidative and hydrolytic cleavage polymer chain enzyme facilitate the breakdown of polymer bonds, leading to reduced molecular weight and structural weakening of plastics. The present investigation was carried out with an aim to test the efficacy of biodegradation of plastic polymer by three fungal species as mentioned above. It is expected that the aforementioned fungal species would demonstrate positive result as far as plastic degradation potential is concerned.

Keywords: Plastic biodegradation, *Aspergillus flavus*, *Aspergillus niger*, *Penicillium* spp., laccase, esterase, fungal enzymes.

Abstract 3**Qualitative Screening of Microbial Strains Isolated from Different Sources for Pectin-Degrading Capability**

Misbah Fatima*, Almas Nauseen, Ananya Chaudhary and Dr. Ashima Kathuria

Department of Biotechnology, Meerut Institute of Engineering & Technology, Meerut

Email Id- misbah.fatima.bt.2022@miet.ac.in

Abstract

Industrial enzymes play a crucial role in modern biotechnological and manufacturing processes because of their specificity and efficiency. There is growing interest in industrial biocatalysts owing to their sustainable and cost-effective processing technologies. Among the industrial enzymes, pectinases are most widely exploited in various industries for food processing, textiles, and paper production. Pectinases are a group of enzymes that carry out complete breakdown of pectin, a complex polysaccharide present in plant cell walls, into simpler molecules like galacturonic acid. Pectinase is mainly obtained from microorganisms such as bacteria and fungi. It has diverse applications primarily in food processing industry and also in environmental management and several industrial sectors. In the food industry, pectinase is commonly used in the clarification of fruit juices and in the processing of products like coffee, tea, cocoa, jams, and jellies. The present project work reports the isolation and primary screening of pectinase-producing microbial strains from different sources. Total of twenty-six microbial cultures were obtained from various soil and waste water samples by serial dilution method. Among the isolated cultures, 12 strains exhibited pectin-degrading capability on primary screening by producing zone of pectin hydrolysis around its growth. These pectinolytic strains will be further subjected to quantitative screening for investigating their industrial potential.

Keywords: Pectinase, microbial, fruit juices.

Abstract 4**Microbial Consortia for Rice Stubble Decomposition: Mechanisms, Efficiency, and Environmental Impacts – A Systematic Review**

Ritik Joshi¹, Adesh Kumar^{2*}, Ashwani Kumar² and Ravinder Kumar Jain²

¹Ph.D. Scholar Microbiology, Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut Uttar Pradesh, India, 250005

^{2*}Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut Uttar Pradesh, India, 250005

*Corresponding Author- Dr. Adesh Kumar, adesh.du@gmail.com

Abstract

Rice cultivation produces substantial amounts of crop residues, particularly rice stubble, and its improper disposal often results in open-field burning. This practice contributes significantly to air pollution, greenhouse gas emissions, and deterioration of soil quality. Recently, microbial consortia have gained attention as an effective and sustainable approach for enhancing rice stubble decomposition and improving residue management practices. This systematic review compiles and analyzes current research on the mechanisms, efficiency, and environmental impacts associated with microbial consortia used for rice stubble degradation. It highlights the role of diverse microbial communities, including cellulolytic, hemicellulolytic, and ligninolytic bacteria and fungi, which work synergistically to break down the complex lignocellulosic components of rice residues. Special emphasis is given to enzymatic processes involving cellulases, hemicellulases, ligninases, and other oxidative enzymes responsible for degrading cellulose, hemicellulose, and lignin. The review also assesses the effectiveness of different microbial formulations under both laboratory and field conditions, focusing on decomposition rate, nutrient release, and their integration into agricultural systems. Overall, microbial consortia demonstrate considerable potential to accelerate residue decomposition, enhance soil organic matter dynamics, and promote nutrient recycling. These benefits support improved soil fertility and crop productivity while reducing environmental pollution associated with residue burning.

Keywords: Rice stubble decomposition, Microbial consortia, Lignocellulosic degradation, Greenhouse gas emissions, Soil fertility.

Abstract 5**Phytochemical Screening and Comparative Study of Antioxidant Potential in Different Commercial Brands of Herbal Tea Masala**

Nikhil Kumar and Adesh Kumar

Department of Life Sciences, Keral Verma subharti college of Sciences Subharti University,

Meerut, Uttar Pradesh

Email Id-nikhiledu966@gmail.com

Abstract

In recent years, the consumption of herbal tea masalas has increased significantly due to their perceived health benefits and presence of bioactive compounds. These herbal formulations are often enriched with traditional Indian spices like Ginger, Cardamom, Cinnamon, and Black Pepper, which are known for their therapeutic properties. The present study aims to conduct a systematic phytochemical screening and evaluate the antioxidant potential of three different commercial brands of Herbal Tea Masala available in the local market of Meerut. Aqueous and Ethanolic extracts of the selected samples will be prepared. Standard qualitative chemical tests will be performed to detect the presence of secondary metabolites such as Alkaloids, Flavonoids, Saponins, Tannins, and Phenols. The antioxidant capacity will be analyzed based on the Total Phenolic Content (TPC) and compared across the brands to identify the most potent formulation. The study expects to highlight the variations in phytochemical constituents across different brands, which directly influence their health-promoting efficacy. This research will provide valuable insights for consumers and help in the standardization of herbal formulations for better sustainable health practices.

Keywords: Phytochemicals, Herbal Tea, Antioxidants, Botany, Sustainable Health, Meerut.

Abstract 6**Industrial Enzymes: Empowering Bioeconomy and Environment Sustainability**

Ashima Kathuria and Khushboo Gupta*

Department of Biotechnology, Meerut Institute of Engineering & Technology, Meerut, U.P.

Email Id- khushboo.gupta.mtbt.2025@miet.ac.in

Abstract

Industrial enzymes are the most significant biotechnological products of bioprocess industry. Their utility in almost every industry, encompassing food and beverage, feed, textile, pulp and paper, detergent, pharmaceutical, diagnostic, leather, water treatment and biofuel have been well-proven. The global industrial enzymes market size is growing at a CAGR of 5.6% from 2026 to 2033. Industrial enzymes are experiencing rapid expansion because of enhanced efficiency of industrial processes through their precise catalytic activity. To meet the expanding global demands of biocatalyst they are produced preferably from microbes in comparison to plant and animal sources. The micro-organisms source segment dominated the market and accounted for the largest revenue share of 75.3% in 2025 due to its strong suitability for industrial scale enzyme production. It is because production of microbial enzymes is more convenient at commercial scale in terms of time, efficiency and process optimization. However, their production cost poses a considerable challenge. Parallely, there is another major challenge of an unprecedented increase in agrowaste generation globally, which requires serious attention and sustainable approach. These challenges can be addressed by developing effective strategies, following the principles of circular bioeconomy. The focus of circular economy is promoting waste to resource generation. Thus, the excessive biomass generated from agricultural practices can be used for the production of variety of microbes which can be employed for various applications in food, feed, dairy and pharmaceutical industry. The agro-waste can also be utilized as a low-cost substrate for the fermentative production of industrially important metabolites. These renewable natural wastes can therefore prove to be a highly valuable resource by its effective utilization under planned waste management strategy. Industrial enzyme have been employed for the bioconversion of wastes into biodegradable and even various value-added products that are environmentally friendly, thus contributing to environmental sustainability.

Keywords: Agrowaste management, circular economy, industrial enzymes, microbial enzyme production

Abstract 7**Nano-fertilizer-Mediated Nutrient Delivery for Improved Productivity and Sustainable Cultivation of Soybean and Groundnut**Palak Sharma, Anupriya Rana^{1*}, Ashwani Kumar¹, Sarita Rana¹, Ritika Yadav¹¹ Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh.

Email: anupriya.rana05@gmail.com

Abstract

The growing need for sustainable and efficient agricultural practices has led to the emergence of nanotechnology-based solutions such as nanofertilizers. This study focuses on the design and methodology of nanofertilizers for enhancing the yield and crop development of soybean (*Glycine max*) and groundnut (*Arachis hypogaea*). Nanofertilizers provide improved nutrient use efficiency through controlled release mechanisms and targeted delivery, thereby reducing nutrient loss and environmental contamination compared to conventional fertilizers. In the present work, nutrient-loaded nanoparticles were synthesized using eco-friendly methods and characterized using advanced analytical techniques including Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), and X-ray Diffraction (XRD). The formulated nanofertilizers were applied under controlled experimental and field conditions to assess their impact on germination, plant growth, physiological parameters, and yield attributes. The results demonstrated a significant improvement in seed germination rate, chlorophyll content, root-shoot biomass, and overall crop productivity in both soybean and groundnut. Furthermore, the application of nanofertilizers allowed for reduced dosage while maintaining higher efficiency, contributing to environmental sustainability. The findings suggest that nanofertilizer-based approaches hold great potential for modern agriculture by enhancing crop yield, improving nutrient utilization, and supporting sustainable crop production systems.

Keywords: Nanofertilizers, Soybean, Groundnut, Sustainable agriculture, Nutrient use efficiency

Abstract 8**Biodiversity Loss in the Anthropocene: Challenges and Sustainable Solutions**Asad Chauhan¹, Farhan Khan², Amit Adhikari³Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand
Subharti University, Meerut, Uttar Pradesh, IndiaEmail ID: asadch6132@gmail.com¹, fk92580710@gmail.com²,
adhikariamit0101@gmail.com³**Abstract**

The Anthropocene, a proposed geological epoch defined by humanity's growing dominance over Earth's systems since the mid-20th century, has triggered an unprecedented decline in global biodiversity. Industrialization, deforestation, agricultural intensification, urbanization, and resource overexploitation have collectively driven extinction rates to an estimated 100 to 1,000 times above natural background levels, prompting scientists to recognize this as the sixth mass extinction event. Biodiversity loss rarely stems from a single cause. Habitat destruction, driven by agricultural expansion and urban sprawl, remains the dominant driver of species extinction. Climate change intensifies this crisis by shifting species ranges and disrupting ecological relationships, while pollution, invasive species, and illegal wildlife trade compound the damage. Critically, the interaction among these pressures can magnify extinction risk well beyond what any single threat produces alone. Addressing this crisis demands integrated, cross-sectoral solutions. Key strategies include expanding connected protected area networks, promoting agroecological land-use practices, restoring degraded ecosystems through community-engaged approaches, strengthening enforcement against wildlife trafficking, and redirecting harmful subsidies toward nature-positive investments. Indigenous and local knowledge must be meaningfully incorporated into governance frameworks, and international cooperation through mechanisms such as the Kunming-Montreal Global Biodiversity Framework is essential for coordinated action. Achieving Sustainable Development Goal 15 requires balancing ecological protection with equitable human development. Protecting biodiversity is ultimately inseparable from ensuring climate resilience, food security, and the long-term well-being of future generations.

Keywords: Anthropocene; Biodiversity Loss; Sixth Mass Extinction; Climate Change; Ecosystem Services; SDG 15; Sustainability

THEME 4:
**Sustainable Engineering and
innovation**

Abstract 1**An ab initio Study of Double Perovskite $\text{Cs}_2\text{NaTiBr}_6$ for Solar Cell Application**

Aadi Verma^{1*}, Anshika Sharma¹, Nikki Sharma¹, Sana¹, Aman Kumar²,
Vivek Kumar Nautiyal¹

¹Department of Physics, Chaudhary Charan Singh University Campus, Meerut- 250004,
INDIA

²Department of Physics, KVSCOS, Swami Vivekanand Subharti University, Meerut 250005,
India

*Corresponding author- aadiiv.140@gmail.com

Abstract

Recent advancements and developments in photovoltaic materials have made significant progress owing to the search for efficient and sustainable energy sources. Although lead halide perovskites have demonstrated impressive performance in solar cell applications, they face challenges such as environmental instability and lead toxicity. This study investigates several physical properties of lead-free double halide perovskites, $\text{Cs}_2\text{NaTiBr}_6$ and evaluates their potential for solar cell applications using density functional theory (DFT) and spectroscopic limited maximum efficiency (SLME) approach. The negative formation energy and Born criteria confirm the structural stability of perovskites in the ideal cubic structure. Optoelectronic analyses reveal that $\text{Cs}_2\text{NaTiBr}_6$, with a direct band gap of 0.79, 1.92 and 1.83 eV calculated via PBE-GGA, mBJ and mBJ+SOC method which is in the range of band gap required for solar cells. These findings highlight the potential of lead-free perovskites for next-generation solar cell applications.

Keywords: DFT, SLME, double perovskite

Abstract 2**Continuous Fixed-Bed Column Studies on Cadmium Removal Using Sodium Carbonate–Modified Tea Factory Waste**Samarpita Gupta¹, and Subhrajyoti Deb²¹M.Tech Scholar, Water Resources Engineering, Department of Civil Engineering, The ICFAI University Tripura, India

Email: guptasamarpita07@gmail.com

²Assistant Professor, Department of Civil Engineering, The ICFAI University Tripura, India

Email: subhrajyotideb@iutripura.edu.in

Abstract

Cadmium (Cd(II)) contamination in aquatic environments poses significant environmental and public health risks due to its toxicity, persistence, and bioaccumulative behavior. Tripura, a major tea-producing state in India, generates substantial quantities of tea factory waste (TFW), an underutilized agro-industrial by-product with strong potential for sustainable resource recovery. This study evaluates the feasibility of sodium carbonate–modified tea factory waste (NTW) as a low-cost and sustainable adsorbent for Cd (II) removal in continuous fixed-bed column systems. Raw TFW was chemically treated using Na₂CO₃ to enhance its adsorption properties and characterized through Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM) to examine functional groups and surface morphology. Continuous column experiments were conducted under varying operational parameters, including bed height, influent Cd(II) concentration, and flow rate, to assess dynamic adsorption performance. The modified adsorbent demonstrated a maximum adsorption capacity of 9.20 mg/g. Increasing bed height and decreasing flow rate improved Cd(II) removal efficiency, whereas higher influent concentrations resulted in earlier breakthrough times. Column performance was evaluated using BDST, Thomas, and Yoon–Nelson models, all of which showed strong agreement with experimental data ($R^2 > 0.95$) and minimal prediction error. Regeneration studies confirmed satisfactory reusability over three adsorption–desorption cycles using mild reagents and hot water with minimal energy input. A qualitative life-cycle perspective further indicated low environmental impact and alignment with circular economy principles.

Keywords: Cadmium (Cd (II)); Tea Factory Waste; Fixed-Bed Column; Sustainable Adsorption; Water Resource Management; Circular Economy.

Abstract 3**Eco-Friendly Electricity Generator from Busy Road**Kaushal Pratap Singh¹, and Nitin Verma²¹BN College of Engineering & Technology, Lucknow, U.P.

E-mail: kp92dit@gmail.com

²RV. Institute of Technology, Bijnor, U.P

E-mail: vermanitin504@gmail.com

Abstract

The concept is to capture the normally lost energy surrounding a system and converting it into electrical energy that can be used to extend the lifetime of that system's power supply. So, this is my step to improve the situation of electricity with an innovative and useful concept i.e. Generating Electricity from a Speed breaker. Producing electricity from a speed breaker is a new concept that is undergoing research. The number of vehicles on road is increasing rapidly and if we convert some of the kinetic energy of these vehicles into the rotational motion of roller then we can produce considerable amount of electricity, this is the main concept of this project. In this project, a roller is fitted in between a speed breaker and some kind of a grip is provided on the speed breaker so that when a vehicle passes over speed breaker it rotates the roller. This movement of roller is used to rotate the shaft of D.C. generator by the help of chain drive which is there to provide 1:5 speed ratios. As the shaft of D.C. generator rotates, it produces electricity. This electricity is stored in a battery. Then the output of the battery is used to lighten the streetlamps on the road. Now during daytime, we don't need electricity for lightening the streetlamps, so we are using a control switch which is manually operated. The control switch is connected by wire to the output of the battery. The control switch has ON/OFF mechanism which allows the current to flow when needed.

Keywords – D.C: Direct current, A.C: Alternating current, Generation, Mechanism.

Abstract 4**Comparative Analysis of Phthalocyanine-Based Charge Transport Layers in Lead-Free Perovskite Solar Cells**

Kanishka Choudhary

Research Scholar, Physics Department, SRM Institute of Science and Technology NCR

Campus, Modinagar, Ghaziabad U.P.

Email: kanishkac41@gmail.com

Abstract

This research investigates the development of environmentally benign, lead-free perovskite solar cells (PSCs) by evaluating two distinct device architectures: NiO-MAGeI₃-MASnI₃-BrNiPc and NiPc-MASnI₃-BrNiPc. As the photovoltaic industry faces the dual challenge of toxic lead content and long-term instability, the integration of Methylammonium Tin Iodide (MASnI₃) alongside advanced charge transport layers offers a critical pathway toward sustainable energy. The primary objective of this work is to systematically compare the performance of these architectures, specifically assessing the efficacy of Brominated Nickel Phthalocyanine (BrNiPc) as a robust hole transport layer (HTL) and the comparative influence of Nickel Oxide (NiO) versus Nickel Phthalocyanine (NiPc) as electron transport layers (ETL). The material selection is grounded in specific optoelectronic advantages: BrNiPc provides enhanced hole mobility and a deep-lying HOMO level, which allows for favorable energy alignment with the valence band of MASnI₃, while the MAGeI₃ buffer layer is utilized to modulate the bandgap and bolster the structural integrity of the perovskite lattice against atmospheric degradation. Furthermore, NiO is employed for its superior chemical stability and p-type conductivity, which effectively minimizes interfacial recombination. By characterizing the interface dynamics and device performance metrics of these configurations, this study aims to optimize charge extraction and band alignment, providing a roadmap for developing high-efficiency, stable, and lead-free photovoltaic technologies for future commercial-scale applications.

Keyword: Brominated Nickel Phthalocyanine, lead-free perovskite, solar cells, optoelectronic.

Abstract 5**First-Principle Study of Double Perovskite $\text{Rb}_2\text{NaTiBr}_6$ for Optoelectronics Properties****Anshika Sharma^{1*}, Aadi Verma¹, Nikki Sharma¹, Sana¹, Aman Kumar²,****Vivek Kumar Nautiyal¹**¹Department of Physics, Chaudhary Charan Singh University, Meerut-250004, India²Department of Physics, KVSCOS, Swami Vivekanand Subharti University, Meerut 250005, India

*Corresponding author- sharmaanshika0901@gmail.com

Abstract

The pursuit of effective and sustainable energy sources has led to recent breakthroughs in photovoltaic materials. Lead halide perovskites have shown remarkable performance in solar cell applications; however, they have drawbacks such as lead toxicity and environmental instability. This study investigates several physical properties of lead-free double halide perovskites, $\text{Rb}_2\text{NaTiBr}_6$ and evaluates their potential for solar cell applications using density functional theory (DFT) with the spectroscopic limited maximum efficiency (SLME) approach. The structural stability of perovskites in the ideal cubic structure is confirmed by the Born criteria and negative formation energy. According to optoelectronic analyses, $\text{Rb}_2\text{NaTiBr}_6$ has direct band gaps of 0.79, 2.05, and 1.96 eV, which are within the range of band gaps needed for solar cells and were determined using PBE-GGA, mBJ, and mBJ+SOC methods. These results demonstrate the promise of lead-free perovskites for usage in next-generation solar cells.

Keywords: DFT, SLME, Double Perovskite.

Abstract 6**A DFT study of double perovskite $\text{Cs}_2\text{NaTiCl}_6$ for photovoltaic application**Nikki Sharma^{1*}, Aadi Verma¹, Anshika Sharma¹, Sana¹, Aman Kumar²,Vivek Kumar Nautiyal¹¹Department of Physics, Chaudhary Charan Singh University Campus, Meerut- 250004,

INDIA

²Department of Physics, KVSCOS, Swami Vivekanand Subharti University, Meerut 250005,

India

*Corresponding author- nikkisharma247776@gmail.com

Abstract

Double perovskite materials have gained considerable attention for their potential use in photovoltaic devices due to their good stability and favorable optoelectronic properties. In this study, the structural, electronic, and optical properties of the double perovskite $\text{Cs}_2\text{NaTiCl}_6$ are investigated using Density Functional Theory (DFT). The calculated results provide insight into the stability and electronic behavior of the material. The band structure and density of states indicate semiconducting characteristics, while the optical analysis shows its interaction with visible light. Such insights are important for evaluating its suitability in solar energy conversion technologies. These properties suggest that $\text{Cs}_2\text{NaTiCl}_6$ can be considered a promising candidate for photovoltaic and optoelectronic applications.

Keywords: Density Functional Theory, Double Perovskite, $\text{Cs}_2\text{NaTiCl}_6$, Photovoltaic Applications.

Abstract 7**Recent progresses in design, fabrication and applications of iron-based nanoparticles**

Geetanjali Singh, and Preeti Singh*

Department of Basic Science, Faculty of Science, Swami Vivekanand Subharti University,
Meerut

250005, U.P. India.

*Corresponding author email: preeti.su202300045@subharti.co

Abstract

The utilization of magnetic nanoparticles for the development of magnetically retrievable catalytic system has led to a dramatic expansion of their efficient applications owing to their eco-friendly and sustainable catalytic processes. Growing demand for eco-friendly and sustainable chemical reactions has attracted the attention of nanocomposites. The present study offers a synergistic approach to greener synthesis of nanocomposites in order to focus on their practical utility in the formation of high value chemical products. Nanocomposite will be synthesized using non-toxic solvents, eco-friendly chemicals and aligning with the principles of green chemistry. Combining the metal nanoparticles and biodegradable materials in the formation of nanocomposite enhances the catalytic activity enabling the efficient organic reactions. This study underscores the future of the potential catalyst in the rational design, development of novel, and recyclable nanocatalyst for promoting eco-friendly synthesis of the high value chemicals.

Keyword: Catalytic, Recyclable nanocatalyst, Nanocomposites.

Abstract 8**Chemical Assessment of Major Essential Elements (Na, Mg, K, and Ca) in Groundwater**Shakebul Hasan^{1*}, Venus Dillu²^{1,2}Department of Applied Physics, Gautam Buddha University, Gautam Budh

Nagar, Uttar Pradesh, India - 201312

*Email: hasan.shakeb786@gmail.com

Abstract

Groundwater chemistry is strongly influenced by lithological composition, water–rock interactions, and anthropogenic activities such as landfill leachate infiltration. The present study investigates the distribution of major essential elements—sodium (Na), magnesium (Mg), potassium (K), and calcium (Ca)—in groundwater samples collected from landfill-influenced regions of Delhi, India. Samples were obtained from seven locations including Bhalsawa (S1–S2), Ghazipur (S3–S4), Abul Fazal (S5), Kalindikunj (S6), and Okhla Bird Sanctuary (S7), which are situated in proximity to major municipal waste disposal sites. The concentrations of elements ^{23}Na , ^{24}Mg , ^{39}K , ^{43}Ca , and ^{44}Ca were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), a highly sensitive analytical technique capable of detecting trace-level elemental concentrations in environmental samples. The measured concentrations were expressed in parts per billion (ppb) and showed considerable spatial variation across the study area. Sodium exhibited the largest variability, ranging from approximately 42 ppb to 1501 ppb, suggesting a strong influence of silicate weathering processes and possible ion-exchange reactions within the aquifer matrix. Magnesium concentrations varied between approximately 14 ppb and 176 ppb, reflecting contributions from the dissolution of mafic minerals and weathering of ferromagnesian rock components. Potassium concentrations ranged from about 11 ppb to 28 ppb and are likely associated with the breakdown of potassium-bearing feldspar and mica minerals. Calcium concentrations derived from the isotopes ^{43}Ca and ^{44}Ca showed moderate variation, indicating that carbonate mineral dissolution and silicate weathering are key geochemical processes influencing groundwater composition. The relative enrichment of Ca and Mg suggests dominant carbonate interactions, whereas variations in Na and K indicate secondary ion-exchange mechanisms.

Keywords: ^{23}Na , ^{24}Mg , ^{39}K , ^{43}Ca , and ^{44}Ca , Groundwater contamination, Water quality assessment, ICP-MS, HPI, Landfill leachate, Delhi NCR

Abstract 9**Artificial Intelligence in Ethical and Black Hat Hacking: A Forensic Perspective for Sustainable Digital Development**

Vanshika

Department of Forensic Science, Keral Verma Subharti College of Science

Email: k00951096@gmail.com**Abstract**

In the digital era, technology plays a major role in communication, corporate operations and everyday life. The risk of hacking and cybercrime has significantly increased as digital systems continue to expand. Hacking is no longer only technical exercise; it has become a serious threat to cybersecurity. Legally, ethical hackers find flaws in computer systems and assist companies in strengthening their security. Black hat hackers, on the other hand, take use of these flaws to steal information, commit financial fraud, or do harm. Understanding this distinction is crucial for appropriate investigation and evidence analysis from the standpoint of forensic science. Traditional security measures are insufficient in the face of increasingly sophisticated cyberattacks such as phishing, malware, ransomware, SQL injection, and denial-of-service attacks. These days, artificial intelligence is crucial to bolstering digital forensics and cybersecurity. AI systems help in detecting suspicious activities, analyzing massive amounts of digital data, identifying patterns of attacks and assisting investigators in reconstructing cyber incidents more effectively. Additionally, machine learning techniques aid in the research of hacker behaviour and the distinction between malevolent unauthorized activity and permitted ethical testing. This study compares, from a forensic perspective, the instruments and methods employed by ethical and black hat hackers. It also describes how the development of safe digital infrastructure is aided by the use of artificial intelligence into cybersecurity solutions. AI promotes sustainable digital development by safeguarding private data, averting long-term harm, and enhancing danger detection. Therefore, building a safe and sustainable digital future requires the joint efforts of digital forensics, ethical hacking, and artificial intelligence.

Keywords: Artificial Intelligence, Ethical Hacking, Black Hat Hacking, Digital Forensics, Cybersecurity

Abstract 10**Fixed Point Approximation Using Refined Iterative Method for Enriched Suzuki Mappings in Banach Space**Sumbul Kaneez¹, Faem Ali², and Aftab Alam³^{1,3}Department of Mathematics, Swami Vivekanand Subharti University, Meerut-250005, India²Department of Applied Mathematics, Aligarh Muslim University, Aligarh-202002, India

Email Id-sumbulkaneez97@gmail.com, faemrazaamu@gmail.com and tyagi80aftab@gmail.com

Abstract

This paper investigates the problem of approximating fixed points of a class of nonlinear mappings in Banach spaces. A refined iterative scheme is introduced to study the convergence behavior of enriched nonexpansive-type operators under suitable control conditions. Strong convergence results are established by employing the geometric properties of Banach spaces and appropriate assumptions on the control parameters. The proposed algorithm is shown to generalize and improve several existing iterative methods available in the literature. Furthermore, the stability and effectiveness of the method are demonstrated through theoretical analysis and illustrative examples. The results obtained in this work contribute to the development of fixed-point theory and provide a useful tool for solving nonlinear problems arising in applied mathematics and related fields.

Keywords: Banach spaces, iteration techniques, fixed point theory, Enriched non-expansive mappings, Convergence Analysis, Nonlinear Operates.

Abstract 11**Structural and Optical Response of Ceria to Gamma Irradiation**

Charul Uniyal¹, Akanksha Malik², Anshu Singh^{3*}, Ankur Kumar^{4*}, Manoj Yadav^{1*}

¹Department of Physics, Sri Dev Suman Uttarakhand University Campus Rishikesh,
Uttarakhand- 249201, India

²Department of Physics, Kanya Gurukul Campus, Gurukul Kangri Deemed to be University,
Haridwar, Uttarakhand-249404, India

³Department of Basic Science, Keral Verma Subharti College of Science, Swami Vivekanand
Subharti University, Meerut, Uttar Pradesh-250005, India

⁴Department of Physics, Sri Dev Suman Uttarakhand University Campus Gopeshwar,
Uttarakhand-246401, India

*Email: anshu.singh2105@gmail.com, physicsankur@gmail.com,
drmanojyadav734@gmail.com

Abstract

Present study investigates the effect of gamma irradiation on the structural, morphological and optical properties of CeO₂ nanoparticles synthesized via solid-state reaction method. X-ray diffraction analysis confirms the retention of a single-phase cubic fluorite structure for both pristine and gamma irradiated samples without the formation of any secondary phase, indicating the structural stability of the material under irradiation. However, Raman spectroscopy analysis reveals a slight shift of the characteristic F_{2g} Raman mode towards lower wavenumber after irradiation, suggesting minor radiation-induced lattice modifications. The field-emission scanning electron microscopy (FE-SEM) images demonstrate gradual grain growth with increasing radiation dose. In addition, Optical studies further indicate a slight modulation in the optical bandgap after gamma irradiation. These findings suggest CeO₂ can serve as a promising material for radiation-resistant coatings and protective components in high-radiation environment such as space electronics and nuclear systems.

Keywords: Gamma Irradiation, Radiation tolerance, Structural recovery.

Abstract 12**Impact of Fe Concentration on the Properties of Fe and W co-doped V_2O_5** Akanksha Malik¹, Anshu Singh^{2*}, and Richa Saini^{1*}¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India⁶Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India

*Email: anshu.singh2105@gmail.com, rsaini_11@yahoo.com

Abstract

Fe-W co-doped V_2O_5 samples with compositions 1% Fe-1%W (S_1) and 2%Fe-1%W (S_2) are studied to evaluate the effect of Fe concentration on their structural, morphological, and electrochemical characteristics. Structural analysis indicates that S_2 exhibits a larger crystallite size with reduced diffraction peak intensity, suggesting dopant-induced changes in the crystal structure. However, FE-SEM observations show a morphological transformation from nanorod-like features in S_1 to more compact and agglomerated grains in S_2 . In addition, Cyclic voltammetry measurements reveal a lower current response for S_2 , indicating diminished electrochemical activity. This behavior is mainly attributed to increased crystallite growth and particle aggregation, which reduce the active surface area and limit ion transport. Overall, the results highlight the significant role of Fe content in tuning the microstructure and electrochemical behavior of Fe-W co-doped V_2O_5 .

Keywords: Electrochemical, Agglomeration, Crystallite growth

Abstract 13**The Effect of La doping on Cerium Oxide for the Enhanced Dielectric Performance**Ritul^{1*}, Akanksha Malik¹, Richa Saini^{1*}, Anshu Singh^{2*}

¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar,
Uttarakhand-249404, India

²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University,
Meerut, Uttar Pradesh-250005, India

*Email: anshu.singh2105@gmail.com, rsaini_11@yahoo.com

Abstract

Present study investigates the effect of La-doping on the cerium oxide nanoparticles. These ceria (CeO_2) nanoparticles are prepared using sol-gel method. The X-ray diffraction (XRD) analysis confirmed the formation of FCC structure corresponding to CeO_2 with space group Fm3m. However, after La-doping (1% and 5 %), any impurity peak is not observed in XRD patterns. In addition, scanning electron microscopy (SEM) investigations revealed that the formation of CeO_2 nanoparticles with an average particle size of ~ 15.64 nm. However, Raman measurement confirms the generation of oxygen vacancies with La concentration in CeO_2 . Furthermore, the dielectric measurements are performed as a function of frequency at room temperature shows an enhancement in dielectric constant with La doping.

Keyword: Raman, nanoparticles, dielectric.

Abstract 14**Structural & Optical Properties of Gamma Irradiated CeO₂ Thin Films**Anshu Singh^{1*}, Akanksha Malik², Richa Saini²¹Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India²Department of Physics, Kanya Gurukul Campus, Gurukul Kangri Vishwavidyalaya, Haridwar, Uttarakhand-249404, India

*Email: anshu.singh2105@gmail.com

Abstract

This investigation reports the structural & optical properties of gamma irradiated CeO₂ thin films. These thin films are grown on Si (100) substrate by electron-beam evaporation method and irradiated with gamma (γ) rays having different doses (25 kGy, 50 kGy, 75 kGy and 100 kGy). Grazing incidence X-ray diffraction (GI-XRD) analysis of these films confirm the stable fluorite phase of CeO₂. However, the crystallinity of these films reduces with γ doses. Atomic force microscopy show that surface roughness of these films modified after gamma irradiation. Raman measurement reveals the effect of different doses on CeO₂ structure and presence of defect states. As the gamma doses increase, more oxygen vacancies create and shift the photoluminescence in low energy range leading to the intense PL emission.

Keywords: Nano ceria, Gamma irradiation, Photoluminescence.

Abstract 15**Structural, and Magnetic Properties of Cerium Oxide Nanoparticles Synthesized by Sol-gel Method**

Aditi Chauhan^{1*}, Akanksha Malik¹, Richa Saini^{1*}, Anshu Singh^{2*}

¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India

²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India

*Email: anshu.singh2105@gmail.com, rsaini_11@yahoo.com

Abstract

Ceria (CeO₂) nanoparticles of average size of ~4-6 nm are synthesized using conventional sol-gel method. The prepared compositions of Ce_{1-x}La_xO₂ (x = 0.0, 0.1, and 0.5) are investigated using XRD, FTIR and magnetic measurements. Rietveld Refinement analysis confirmed the formation of FCC structure corresponding to CeO₂ with space group Fm3m. La doping into CeO₂ nanoparticles results in decrease of average crystallite size. In addition, FTIR results further confirm the phase of samples for CeO₂. However, the magnetic properties of these samples are found to be enhanced after La doping.

Keyword: Ceria (CeO₂), sol-gel method, FTIR.

Abstract 16**Structural and Phase Analysis of V_2O_5 via X-ray Diffraction & Rietveld Refinement**Saloni Chauhan^{1*}, Akanksha Malik¹, Richa Saini^{1*}, Anshu Singh^{2*}¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India

*Email: anshu.singh2105@gmail.com, rsaini_11@yahoo.com

Abstract

In the present work, vanadium pentoxide (V_2O_5) is successfully synthesized using a sol–gel method. The synthesized samples are characterized using X-ray diffraction (XRD) and electron density (ED) mapping to study their structural and microstructural behaviour. However, Rietveld refinement analysis confirmed the formation of the orthorhombic α -phase, V_2O_5 with lattice parameters closely matching standard JCPDS data. Broad diffraction peaks indicated nanoscale crystallite size, and slight variations in lattice constants suggested the presence of internal strain or defect-induced modifications. Electron density mapping provided further insight into the structural characteristics of the material. These findings highlight the influence of microstructural inhomogeneities on electron distribution, which play a significant role in determining the functional properties of V_2O_5 for applications in catalysis, energy storage, and sensing devices.

Keyword: vanadium pentoxide, JCPDS, XRD, electron density.

Abstract 17**In Vitro Assessment of Sodium Chloride-Induced Salinity Stress on Germination and Seedling Development in *Dalbergia sissoo* Roxb.**Nikhil Chand¹, Ritika Yadav¹, Dhanendra Kumar Rai¹, Sarita Rana¹¹Department of Biotechnology, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut-250005 (INDIA).

Email: nikhilchand6@gmail.com

Abstract

This study investigates the influence of sodium chloride (NaCl)-induced salinity stress on seed germination and seedling vigor index of *Dalbergia sissoo* Roxb. under in vitro conditions. Seeds were cultured on filter paper, semi-solid, and liquid Murashige and Skoog (MS) media to assess viability and germination efficiency. Liquid MS medium yielded the highest germination percentage (67.53%), followed by semi-solid (57.14%) and filter paper (47%). To evaluate the impact of salt stress, seedlings were exposed to increasing NaCl concentrations (0–200 mMol). A significant, concentration-dependent decline was observed in germination rate, seedling height, shoot/root length, seedling vigour index, and biomass accumulation. Optimal growth was achieved at 0 mMol NaCl, while 200 mMol NaCl led to substantial physiological suppression. The findings highlight *D. sissoo*'s sensitivity to salinity and support the application of optimized in vitro culture systems for screening salt-tolerant genotypes.

Keywords: *Dalbergia sissoo*, salinity stress, seed germination, NaCl, in vitro culture, seedling vigor, MS medium, oxidative stress.

Abstract 18**A Comprehensive Theoretical Analysis of Cs_2KGaX_6 ($\text{X} = \text{Cl, Br, I}$): for Green Energy Solutions**

Aman Kumar

Department of Physics, K.V. Subharti College of Science, Swami Vivekanand Subharti University, Meerut, 250005, India.

Corresponding Author: 01amankumar@gmail.com

Abstract

Researchers have identified double perovskites as promising materials for thermoelectric and optoelectronic technologies, owing to their versatility in energy-related applications. This research is mostly about the compounds Cs_2KGaX_6 [$\text{X} = \text{Cl, Br, I}$]. It uses advanced computer programs called Wien2K and BoltzTraP to investigate their structure, electronic, optical, and thermoelectric properties. Structural analysis confirms the stability of these compounds through energy versus volume curve evaluations. The calculated band gaps for $\text{Cs}_2\text{KGaCl}_6$, $\text{Cs}_2\text{KGaBr}_6$, and Cs_2KGaI_6 are 4.938 eV, 3.449 eV, and 2.924 eV, respectively. These values indicate that the materials can absorb light in both the visible and ultraviolet regions. The study of optical properties shows that Cs_2KGaX_6 [$\text{X} = \text{Cl, Br, I}$] has strong light absorption, high electrical conductivity, interesting dielectric constants, optical reflectivity, and interesting refractive indices. These properties make it a great choice for photovoltaic uses. We meticulously evaluated the transport properties, including the Seebeck coefficient, as well as the thermal and electrical conductivities. The results highlight the strong potential of these materials for thermoelectric generators. The Cs_2KGaX_6 [$\text{X} = \text{Cl, Br, I}$] compounds demonstrate exceptional properties, solidifying their viability as sustainable energy materials, particularly for photovoltaic and thermoelectric applications.

Keyword: WIEN2K, BoltzTraP, Seebeck coefficient, Double perovskites.

Abstract 19**Optimization of Fe Doping in V₂O₅ Nanoparticles for Improved Structural and Optical Properties**

Divyanshi Giri¹, Akanksha Malik¹, Richa Saini^{1*}, Anshu Singh^{2*}

¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India

²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India

*Email: rsaini_11@yahoo.com, anshu.singh2105@gmail.com,

Abstract

This work presents the effect of Fe doping (5% and 10%) on the structural, optical, and morphological properties of V₂O₅ nanoparticles synthesized by the sol-gel method. X-ray diffraction (XRD) confirmed orthorhombic V₂O₅ with reduced crystallite size after doping, indicating Fe incorporation and lattice strain. Photoluminescence (PL) analyses shows structural distortion and reduced emission intensity, suggesting improved charge carrier separation. However, Field emission scanning electron microscopy (FE-SEM) reveals improved and more uniform morphology in doped samples. Among the samples, 5% Fe doped sample shows better crystallinity and enhanced optical properties compared to 10% doping, which caused excess lattice distortion. Overall, controlled Fe doping, particularly at 5%, improves the properties of V₂O₅ for potential applications in photocatalytic applications.

Keywords: photocatalytic, lattice distortion, crystallite size.

Abstract 20**Review on Biochemical Characterization of Enzymes in Biofuel-Producing Cyanobacteria: Mechanisms, Applications and Future Perspectives**

¹Jigyasa Yadav, ^{2*}Ashwani Kumar, ³Punjab Singh Malik, and ²Sarita Rana

¹Ph.D Scholar Biochemistry, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

^{2*}Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

³Department of Botany, Meerut College Meerut, Uttar Pradesh, India

*Corresponding Author- amritdhra1981@gmail.com

Abstract:

The increasing demand for sustainable and renewable energy sources has intensified research on microbial biofuel production, particularly through photosynthetic microorganisms such as cyanobacteria. Cyanobacteria possess remarkable metabolic versatility and the ability to convert solar energy and carbon dioxide into valuable biofuels including bioethanol, biodiesel, biohydrogen, and biobutanol. The efficiency of these processes is largely governed by the activity and regulation of key metabolic enzymes involved in carbon fixation, lipid biosynthesis, hydrogen production, and fermentation pathways. Biochemical characterization of these enzymes plays a critical role in understanding their catalytic properties, substrate specificity, kinetic parameters, structural stability, and regulatory mechanisms. Enzymes such as RuBisCO, hydrogenases, nitrogenases, acetyl-CoA carboxylase, and alcohol dehydrogenases are central to metabolic pathways leading to biofuel synthesis. Recent advances in biochemical assays, proteomics, and molecular biology techniques have significantly enhanced the understanding of enzyme structure–function relationships in cyanobacteria. These insights enable metabolic engineering strategies aimed at improving enzyme efficiency and optimizing biofuel yields. This review summarizes the current knowledge on the biochemical characterization of enzymes involved in cyanobacterial biofuel production, highlighting their catalytic mechanisms, metabolic roles, and potential applications in bioenergy development.

Keywords: Cyanobacteria, Biofuel production, Enzyme characterization, Hydrogenases, RuBisCO, Lipid biosynthesis, Metabolic engineering, Renewable energy.

Abstract 21**Stability Analysis of Thermal Convection in a Rivlin –Ericksen Nanofluid Induced by Thermophoresis with Nanoparticle Transport Between Parallel Plates**

Aftab Alam

Department of Basic Science, Keral Verma Subharti College of Science, Swami Vivekanand
Subharti University, Meerut

*Corresponding author: tyagi80aftab@gmail.com,

Abstract:

This study examines the stability of a Rivlin–Ericksen nanofluid layer that is saturated in a continuous medium and placed between two infinite horizontal plates. The energy equation is modified by including the effects of Brownian motion and thermophoresis of nanoparticles. Both linear and nonlinear stability analyses are carried out by applying boundary conditions that are suitable for the physical model. In addition, boundary conditions related to the nanoparticle mass flux are considered, assuming passive behaviour of nanoparticles similar to the temperature conditions at the boundaries. The results show that stationary convection can occur for both positive and negative values of the concentration Rayleigh number (R_n). It is also found that convection begins earlier compared to the case of a porous medium. Unlike Newtonian nanofluids, where oscillatory convection does not occur, the Rivlin–Ericksen nanofluid allows oscillatory convection when the value of R_n is negative. This situation arises when the density of the base fluid is greater than the density of the nanoparticles. However, the viscoelastic parameter of the Rivlin–Ericksen fluid reduces the instability caused by oscillatory convection. For the nonlinear stability analysis, a truncated Fourier series method is used to calculate the parameters related to heat and mass transfer. The results indicate that for certain values of parameters, the rates of heat transfer and mass transfer increase significantly. The outcomes of the study are presented graphically and are also confirmed through numerical calculations.

Keywords: Thermophoretic, Rivlin–Ericksen nanofluid, Nanoparticles, Buoyancy Forces.

Abstract 22**Modification of the Structural and Luminescence Properties of Ni doped V2O5 Nanoparticles**

Harshita Verma¹, Akanksha Malik¹, Richa Saini^{1*}, and Anshu Singh^{2*}

¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India

²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India

*Email: anshu.singh2105@gmail.com rsaini_11@yahoo.com

Abstract

In this work, nickel-doped vanadium pentoxide (V2O5) nanoparticles were prepared using the sol-gel method, a simple and cost-effective approach for producing uniform nanomaterials. Different doping percentage were used to study to investigate modification in structural and optical behavior of V2O5. Structural analysis using X-ray diffraction (XRD) confirmed the formation of the expected orthorhombic V2O5 phase, with noticeable changes in crystallite size and peak intensity as the Ni content increased. Field emission scanning electron microscopy (FE-SEM) revealed well-dispersed particles and subtle changes in surface morphology, especially at higher doping levels. Photoluminescence (PL) measurements showed that Ni doping altered the emission properties of the nanoparticles, likely due to the introduction of new defect states and changes in the band gap. Overall, the study shows that nickel doping can effectively tune the structural and optical properties of V2O5 nanoparticles, making them promising materials for applications in areas like sensing, photocatalysis, and optoelectronics.

Keywords: Nanoparticles, Photoluminescence, photocatalysis

Abstract 23**Fe dopant Tuned the Properties of Vanadium Pentoxide Nanoparticles**

Jahanvi Kukreti¹, Akanksha Malik¹, Richa Saini^{1*}, and Anshu Singh^{2*}

¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India

²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India

*Email: rsaini_11@yahoo.com, anshu.singh2105@gmail.com,

Abstract

This study investigates the effect of iron (Fe) doping on the structural, morphological, and optical properties of vanadium pentoxide (V_2O_5) nanoparticles. Pure and Fe-doped V_2O_5 samples (3% and 10%) are analysed using X-ray diffraction (XRD), Photoluminescence (PL), and Field emission scanning electron microscopy (FE-SEM) techniques. XRD results confirm that Fe doping induces lattice distortions and increases structural disorder while maintaining the orthorhombic V_2O_5 phase. Photoluminescence analysis reveals reduced charge carrier recombination with Fe incorporation, indicating improved optoelectronic behavior. FESEM shows noticeable modifications in surface morphology and grain size reveals change in V oxidation states. These findings demonstrate that Fe doping effectively tunes the structural and optical properties of V_2O_5 for potential applications in sensing and optoelectronic devices.

Keywords: Nanoparticles, surface morphology, sensors

Abstract 24**Applications of Smart Technologies In Healthcare: The Role Of Ai And Machine Learning**Deepshikha Hudda^{*2} and Aftab Alam¹¹Department of Basic Science, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut¹*Corresponding author: deepshikhahudda001@gmail.com,**Abstract**

This paper examines the role of AI and ML in enhancing patient care through faster decision-making, personalized treatments, and proactive healthcare delivery. Key applications include predictive analytics, medical imaging diagnostics, natural language processing, clinical decision support systems, robotic surgery, virtual health assistants and remote patient monitoring. By analysing current advancements and future trends, the study highlights how AI-driven technologies can improve accessibility, reduce costs, and enhance patient outcomes, while emphasizing the need to address technical, ethical, and operational challenges to achieve intelligent, patient-centred healthcare.

Keywords: Machine Learning, Artificial Intelligence, AI and ML, Healthcare.

Abstract 25**Effect of W Doping on the Structural and Optical Properties of V₂O₅ Nanoparticles for Thermoelectric Applications**

Nikita Pundir¹, Akanksha Malik¹, Richa Saini^{1*}, Anshu Singh^{2*}

¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India

²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India

*Email: rsaini_11@yahoo.com, anshu.singh2105@gmail.com,

Abstract

This work presents the W doped V₂O₅ nanoparticles with 3% and 5% concentrations were synthesized to study their potential for thermoelectric applications. X-ray diffraction (XRD) analysis confirmed orthorhombic V₂O₅ with a reduction in crystallite size after W doping, indicating successful incorporation and lattice strain. Photoluminescence (PL) results shows decrease emission intensity in doped samples, suggesting reduced charge carrier recombination. Morphological studies reveals a decrease in grain size compared to pristine V₂O₅. These structural and microstructural changes can enhance phonon scattering and reduce thermal conductivity, making W-doped V₂O₅ a promising material for thermoelectric applications.

Keywords: Thermoelectric, Nanoparticle, lattice strain.

Abstract 26**Review on Role of Nutrition in Preventing Lifestyle Diseases**

Ashwani Kumar*, Shagun Sharma, Anupriya Rana, Adesh Kumar

Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India

*Corresponding author. Email: amritdhra1981@gmail.com

Abstract

Lifestyle diseases are becoming a major public health concern worldwide due to unhealthy dietary habits, physical inactivity, and stress. Proper nutrition plays a vital role in preventing and managing these diseases by maintaining overall health and strengthening the immune system. A balanced diet rich in fruits, vegetables, whole grains, proteins, vitamins, and minerals helps regulate body functions and reduces the risk of chronic illnesses. Poor dietary patterns, including excessive consumption of processed foods, sugar, and saturated fats, are strongly associated with diseases such as Type 2 Diabetes, Hypertension, and Obesity. Nutrients like dietary fiber, antioxidants, and essential fatty acids play an important role in maintaining metabolic balance and reducing inflammation. In addition, proper nutritional awareness and healthy eating habits can significantly lower the burden of lifestyle-related disorders. Preventive strategies focusing on balanced nutrition, along with regular physical activity, can improve quality of life and reduce healthcare costs. Therefore, promoting healthy dietary practices is essential for the prevention and long-term management of lifestyle diseases and for achieving sustainable public health outcomes.

Keywords: Lifestyle diseases, Nutrition, balanced diet, sustainable public health,

Abstract 27**Correlation of Structural and Morphological Properties in W-Doped V_2O_5 for Thermoelectric Applications**

Bhawana Joshi¹, Akanksha Malik¹, Richa Saini^{1*}, Anshu Singh^{2*}

¹Department of Physics, Kanya Gurukul Haridwar, Gurukul Kangri (Deemed to be University), Haridwar, Uttarakhand-249404, India

²Department of Basic Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh-250005, India

*Email: rsaini_11@yahoo.com, anshu.singh2105@gmail.com,

Abstract

Tungsten (W) doped vanadium pentoxide (V_2O_5) nanoparticles with doping concentrations of 5% and 10% are synthesized to investigate their potential for thermoelectric applications. X-ray diffraction (XRD) analysis confirmed the formation of orthorhombic V_2O_5 and revealed a reduction in crystallite size with increasing W concentration, indicating successful incorporation of W ions and the introduction of lattice strain. Raman spectroscopy showed noticeable changes in vibrational modes, further suggesting structural modifications induced by W doping. Morphological analysis demonstrated a decrease in grain size in the doped samples compared to pristine V_2O_5 , leading to a more refined microstructure. The correlation between reduced crystallite size and smaller grain morphology is expected to enhance phonon scattering, which can lower thermal conductivity. It is an important factor for improving thermoelectric efficiency. Therefore, these structural and morphological modifications indicate that W-doped V_2O_5 is a promising candidate for thermoelectric applications.

Keywords: phonon scattering, grain size, nanoparticle

Abstract 28**Investigating Noise-Resilient Circuit Topologies for Variational Quantum Eigen solvers**

Dr. Amit Kumar

Department of Basic Sciences, KVSCOS, SVSU, Meerut.

Abstract:

As the Noisy Intermediate-Scale Quantum (NISQ) era progresses, the Variational Quantum Eigensolvers (VQE) remains a primary candidate for demonstrating quantum utility in molecular simulations. However, the high error rates of CNOT gates in superconducting architectures present significant challenges for achieving chemical accuracy. This research proposes a comparative framework to evaluate sparsified circuit topologies designed to minimize entangling gate depth for small molecular systems such as H₂. Using the Qiskit Aer simulator, the study aims to characterize the trade-offs between circuit expressibility and susceptibility to hardware-inspired noise models. Preliminary analysis suggests that strategic gate reduction may mitigate decoherence effects; however, the extent of this improvement under varying noise regimes remains an area of ongoing investigation. This work provides a foundation for developing hardware-efficient ansatzes and sets the stage for further optimization of hybrid quantum-classical workflows.

Keyword: Noisy, VQE, CNOT gates, Qiskit Aer simulator.

Abstract 29**Use of Bioinformatics Tools for Early Detection and Prediction of Genetic Diseases**Surya Saini¹, Manshi¹, Nikhil Chand², Dhanendra Kumar Rai²¹Department of Life Science, Keral Verma Subharti College of Science, Swami Vivekananda Subharti University, Meerut.²Assistant Professor, Department of Life Science, Keral Verma Subharti College of Science, Swami Vivekananda Subharti University, Meerut.

Email-teotiamanshi586@gmail.com

Abstract

Mutations and variations of the human genome create genetic diseases when normal biological functions are disrupted. Identifying genetic diseases at their earliest point has been an ongoing challenge in the field of clinical medicine. New opportunities to identify disease-causing genetic markers prior to disease onset exist due to rapid developments in the area of genomic technologies and the expanding field of bioinformatics. The bioinformatic field is an important connection or link between genomic data (raw sequence data) and usable or clinically useful medical data. This study will review and evaluate the role of bioinformatic tools and computational method development for the early detection and prediction of genetic disorders via analysis of genomic data. To achieve these objectives, a review of concept and literature was performed based on an analysis of studies published in peer-reviewed journals, publicly accessible genomic databases, established bioinformatics platforms (e.g., NCBI, OMIM, Ensembl, ClinVar) and commonly used bioinformatic tools (BLAST, GATK) and several variant annotation pipelines. The analysis focused on the workflows currently used for genomic variant calling, biomarker discovery, and assessing disease association. Bioinformatics is being used to systematically analyze large-scale genomic data sets to identify variations in genetic sequences such as single nucleotide polymorphisms (SNPs) and other variants associated with hereditary diseases, and deposited in the OMIM and ClinVar databases to provide a catalogue of validated relationships between genetic mutations and diseases that are included in predictive model and enhance the accuracy of prediction through the application of machine learning methods to genomic analysis workflow. These approaches can also facilitate early diagnosis of conditions and consequently assist in the provision of more targeted and individualized therapy, tailored to a patient's genetic make-up.

Keywords: Bioinformatics, Genomics, Genetic Diseases, Biomarkers, Personalized Medicine, Early Detection

Abstract 30**MnO₂/MWCNT Nanocomposites as High-Performance Supercapacitor Electrodes**Riya Gaur^{1*}, Sonia Zeba Hashmi¹,

Department of Chemistry, Banasthali Vidyapith, Rajasthan, 304022, India

Email: gaurriya453@gmail.com

Abstract

MnO₂/MWCNT nanocomposites were synthesized via a hydrothermal method for supercapacitor electrode applications. Structural and morphological characterization using XRD, FTIR, FE-SEM, and EDX confirmed successful composite formation and uniform MnO₂ distribution on the MWCNT network. Electrochemical performance was evaluated using cyclic voltammetry and galvanostatic charge–discharge measurements in 1 M KOH electrolyte. The 1 wt.% MWCNT/MnO₂ nanocomposite exhibited superior electrochemical performance, delivering a specific capacitance of 729.8 F g⁻¹ (CV) and 405.5 F g⁻¹ (GCD). The enhanced capacitive behavior is attributed to the synergistic effect of MnO₂ pseudocapacitance and improved electrical conductivity of MWCNTs.

Keywords: MnO₂/MWCNT nanocomposites; Supercapacitors; Hydrothermal synthesis; Electrochemical performance; Energy storage.

Abstract 31**Highly Sensitive Hydrogen Gas Detection using Magnetron Sputtered Pt-Decorated 2D MoSe₂ Nanostructured Thin Film Sensor**Pawan kumar¹, and Anuj Kumar^{1,*}¹ Molecular Simulation and Energy Storage Laboratory, Department of Physics, Chaudhary Charan Singh University, Meerut, 250001, Uttar Pradesh, India.¹ Email: pawanphysics.iitr@gmail.com

* Corresponding author; Email: dranujkumarccsu@gmail.com

Abstract:

Hydrogen (H₂) is considered one of the most promising clean energy carriers for the future. However, its colourless nature, high flammability, and extremely low ignition limit make it potentially hazardous, thereby requiring highly sensitive and reliable detection systems. Conventional MoSe₂-based gas sensors often face challenges such as slow response, incomplete recovery, and limited selectivity, especially in humid environments, which restrict their practical deployment. In the present study, a Pt-decorated MoSe₂ thin film gas sensor was developed on porous silicon (n-type, <100>) substrates using the DC magnetron sputtering technique. Detailed structural, morphological, and compositional analyses were carried out using XRD, FE-SEM, EDAX, and XPS. The results confirmed the successful formation of well-oriented, highly crystalline, and phase-pure Pt–MoSe₂ nanostructured thin films. The fabricated sensor exhibited remarkable gas sensing performance, including high sensitivity, fast response and recovery times, excellent repeatability, and strong selectivity towards hydrogen across a broad concentration range. Notably, the device was capable of detecting hydrogen concentrations as low as 5 ppm in dry air under near room temperature conditions, demonstrating a rapid and stable sensing response. These findings suggest that Pt-functionalized MoSe₂ thin films can serve as an efficient, low-power sensing platform for trace-level hydrogen detection. Furthermore, the study highlights the significant advantages of integrating noble metal functionalization with two-dimensional semiconductor materials for the advancement of next-generation hydrogen sensing technologies.

Keywords: 2D TMDs materials; Porous Silicon, Molybdenum diselenide (MoSe₂); Magnetron sputtering; Nanostructured thin films; Hydrogen gas sensor.

Abstract 32**Mathematical Modeling on Hedge Fund Investment Strategies in Emerging Markets under Geopolitical and ESG-Related Crises**Vikas Kumar¹ and Amita²¹Department of Basic Sciences, Keral Verma Subharti College of Science Swami Vivekanand Subharti University, Meerut²Research Scholar, Department of Basic Sciences, Keral Verma Subharti College of Science Swami Vivekanand Subharti University

Email Id- Hod.bs@subharti.org, amita.su202400335@subharti.co

Abstract

Hedge funds operate in highly dynamic financial environments and often adopt sophisticated investment strategies to manage risk and generate returns. In recent years, geopolitical instability and Environmental, Social, and Governance (ESG) related crises have emerged as major sources of uncertainty affecting global capital markets, particularly in emerging economies. These disruptions influence market volatility, capital flows, and investor confidence, thereby creating complex challenges for hedge fund managers when allocating assets and designing risk mitigation strategies. This study focuses on the development of a mathematical modeling framework to analyze and optimize hedge fund investment strategies in emerging markets during periods of geopolitical and ESG-related crises. The research integrates quantitative techniques such as time-series econometric models, volatility modeling, and optimization methods to evaluate how hedge fund portfolios respond to sudden geopolitical shocks and ESG risk events. By incorporating indicators such as geopolitical risk indices, ESG performance scores, and market volatility measures, the proposed model aims to forecast strategy performance and identify optimal portfolio adjustments under uncertain conditions. The study seeks to examine the effectiveness of mathematical models in capturing the interaction between geopolitical instability, ESG disruptions, and hedge fund returns in emerging markets. It also investigates whether incorporating ESG risk variables into forecasting models improves predictive accuracy and investment decision-making. The findings are expected to contribute to the literature on alternative investments, sustainable finance, and quantitative risk management by providing a structured analytical approach to hedge fund strategy optimization under crisis conditions.

Keyword: ESG, accuracy, policymakers.

Abstract 33**A Review of Graphs Associated with Finite Groups**Vikas Kumar¹ and Sonia²¹Department of Basic Sciences Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut²Research Scholar, Department of Basic Sciences, Keral Verma Subharti College of Science Swami Vivekanand Subharti University, Meerut

Email Id-hod.bs@subharti.org, soniapunia403@gmail.com

Abstract

The study of graphs associated with finite groups represents an important intersection between group theory and graph theory, providing a useful framework for understanding algebraic structures through combinatorial and visual methods. Finite group theory, a fundamental branch of abstract algebra, deals with groups that contain a finite number of elements and satisfy the basic group axioms of closure, associativity, identity, and invertibility. Although group operations are defined algebraically, representing relationships between group elements using graphs allows researchers to analyze these structures more intuitively and apply graph-theoretic techniques to solve algebraic problems. In this context, a graph associated with a finite group typically represents group elements as vertices and defines edges according to specific algebraic relations among those elements. One of the most significant examples is the Cayley graph, where each vertex corresponds to a group element and edges connect elements based on multiplication by a fixed generating set; Cayley graphs are widely studied because of their high degree of symmetry and their applications in network design, interconnection networks, and geometric group theory. Another important construction is the commuting graph, whose vertices represent non-central elements of a group and whose edges connect pairs of elements that commute with each other; this graph provides insights into the commutativity structure of a group and helps analyze centralizers and the center of the group. In addition, the non-commuting graph focuses on pairs of elements that do not commute, offering complementary information about the internal structure and interaction of group elements. The power graph is another widely studied example in which vertices represent group elements and edges connect two elements whenever one is a power of the other; this graph captures cyclic relationships among elements and often reveals whether the underlying group has cyclic properties.

Keywords: Finite Groups, Cayley Graphs, Commuting Graphs, Power Graphs

Abstract 34

Forecasting of Hedge Fund Strategies by Mathematical Models in Capital Markets

Vikas Kumar

Department of Basic Sciences, SVSU

Email: hod.bs@subharti.org

Abstract

This research examines the effects of geopolitical instability and political crises on the capital markets of India with a particular emphasis on hedge fund strategies. We create mathematical models aimed at predicting hedge fund performance and portfolio modifications during times of political uncertainty. The study integrates geopolitical event analysis, time-series financial modeling, and machine learning methodologies to comprehend and anticipate hedge fund actions in the face of volatile circumstances in India.

Keywords: Hedge Funds, Geopolitical Instability, India Capital Markets, Political Crises, Mathematical Modeling, Forecasting, Time-Series Analysis

THEME 5:

Advances in Biological Sciences

Abstract 1**The Separated Self: Human-Nature Disconnection as the Unaddressed Root Driver of Anthropocene Destabilization**

Amit Adhikari

Environmental Science, Department of Life Science, Swami Vivekanand Subharti University,
Meerut, Uttar Pradesh, India

Email: adhikariamit0101@gmail.com

Abstract

Despite three decades of scientific agreement, policy efforts, and technological progress, the disruption of Earth's systems is speeding up. This review suggests that mainstream research on the Anthropocene has accurately identified the symptoms of the environmental crisis but has overlooked its core cause: the deep-seated belief that separates humans from nature, rooted in the psychological and philosophical ideas that form modern civilization. The paper brings together findings from planetary boundaries science, Deep Ecology, eco-psychology, Terror Management Theory, and non-dual philosophies like Advaita Vedanta to show that the idea of humans as separate from and superior to nature isn't just a cultural view but it's the force that drives our most destructive habits. Existing models, whether economic, political, or technological, see humans as rational beings who need better incentives but don't look at the deeper structures of desire and tendency to identify ourselves with something external which lead to destructive behavior. At the heart of this problem sits Cartesian dualism, the old split between mind and body, human and nature. Industrial modernity took this split and built a civilization around it. The result is what this paper calls as "inner hollow" (i.e. a sense of lack that pushes people to consume and accumulate in a search for meaning or wholeness). This is not merely a private wound. It scales up, shaping societies and causing shallow remediation to fail. What is needed instead? The paper argues for an "internal ecology" framework: not merely more rules or smarter gadgets, but a focus on the inner landscape. Research shows that when people practice mindfulness or deepen their connection to nature, their blind desire to consume and identify with it drops.

Keywords: Anthropocene, human-nature relationship, internal ecology, ontological separation, environmental psychology, Advaita Vedanta

Abstract 2**Multi-Omics Integration Reveals Microbial Consortia-Driven Sugarcane Trash Decomposition for Sustainable Agriculture: A Review**¹Anuradha Sinha, ²Adesh Kumar^{1,2} Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India, 250005¹Corresponding Author Email/ID: anuradhasinha505@gmail.com**Abstract**

Growing sugarcane produces a lot of leftover plant material, called sugarcane trash, which is often burned, causing pollution and nutrient loss. Managing this waste in an eco-friendly way by breaking it down with helpful microbes can improve soil and recycle nutrients. New technology lets us better study which microbes are present and how they help break down this plant matter. This research uses three scientific approaches to look at the microbes that decompose sugarcane trash. The study found many types of microbes, such as *Bacillus*, *Pseudomonas*, *Streptomyces*, and *Trichoderma*, which produce proteins to break down plant materials like cellulose and lignin. The study also identifies important natural processes and enzymes that these microbes use. Tests of the chemical changes during breakdown confirms formation of new compounds, showing the plant material breaks down. This combined approach shows how microbes work together to speed up decomposition. These results suggest that using chosen groups of microbes could help recycle sugarcane trash, improve soil, and support sustainable farming.

Keywords: Sugarcane trash, microbial consortia, multi-omics, metagenomics, sustainable agriculture, lignocellulose degradation.

Abstract 3**Toxicity and Recovery Response of Malathion on Biochemical, Physiological, and Genotoxic Parameters in *Channa punctatus* from the Meerut Region**Gauri Sharma^{1*} and Dr. Dheer Pal Singh²^{1,2}Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut

*Corresponding Author Email/ID: sharmagauri0878@gmail.com

Abstract

Agricultural intensification has significantly increased the application of chemical pesticides, particularly organophosphates, carbamates, and synthetic pyrethroids, resulting in their frequent runoff into freshwater ecosystems. In agrarian regions such as the Indo-Gangetic plains, pesticide residues contaminate ponds, canals, and reservoirs, posing serious ecological risks to non-target aquatic organisms, especially fish. The present literature survey comprehensively reviews acute toxicity, biochemical, enzymatic, and genotoxic impacts of various pesticides on freshwater fish species. Acute toxicity studies indicate wide variation in 96-h LC50 values depending on pesticide type and fish species, with synthetic pyrethroids such as cypermethrin and lambda-cyhalothrin exhibiting higher toxicity at microgram levels compared to several organophosphates. Sublethal exposures consistently alter key biochemical parameters, with total protein emerging as the most sensitive biomarker, followed by lipids, carbohydrates, and triglycerides. Stress biomarkers such as glucose, cortisol, and cholesterol often show elevation, indicating metabolic disruption and physiological stress responses. Enzymatic assessments reveal significant inhibition of membrane-bound ATPases (Na^+/K^+ -ATPase, Mg^{2+} -ATPase, Ca^{2+} -ATPase), acetylcholinesterase (AChE), and alterations in acid and alkaline phosphatases across multiple tissues including gills, liver, kidney, muscle, and brain. AChE inhibition is particularly pronounced in organophosphate exposure, confirming neurotoxic mechanisms. Recovery studies demonstrate partial and organ-specific restoration following transfer to pesticide-free water; however, complete recovery is often delayed or incomplete, indicating persistent physiological impairment.

Keywords: Pesticide toxicity; Freshwater fish; LC50; Biochemical biomarkers; Na^+/K^+ -ATPase; Acetylcholinesterase (AChE); Acid phosphatase (ACP)

Astract 4**Green Synthesis and Characterization of Bioplastics for A Sustainable Environment**Harshita Nagar^{1*}, and Sangeeta Dayal²¹Research scholar, Department of Life Science, Swami Vivekanand Subharti University,
Meerut²Department of Life Science, Swami Vivekanand Subarctic University, Meerut

*Corresponding Author Email/ID: hnagar936@gmail.com

Abstract

The growing environmental impact of petroleum-based plastics has increased the demand for sustainable and biodegradable alternatives. Bio plastics derived from renewable plant resources have attracted considerable attention as an eco-friendly option for reducing plastic pollution. This review summarizes recent developments in the green synthesis and characterization of bio plastics produced from low-cost agricultural feed stocks such as starch, cellulose, and various aggro-wastes. Common preparation techniques including solution casting, melt blending, and microbial fermentation are discussed with emphasis on their environmental compatibility and efficiency. In addition, key characterization methods such as mechanical testing, thermal analysis (TGA and DSC), structural analysis (FTIR and XRD), and biodegradability studies are examined to evaluate the performance of these materials. Studies indicate that bio plastics derived from agricultural residues including banana peel, cassava starch, and rice straw show tensile strengths ranging from 0.42 to 74.16 MPa and bio degradation rates of 37–96% within 60 days. These materials have potential applications in food packaging, agricultural films, and consumer products. Despite these advantages, challenges related to large-scale production, mechanical stability, and economic feasibility remain. Future research should focus on process optimization, material reinforcement, and sustainable production strategies to enhance the commercial potential of plant-based bio plastics.

Keywords: Bio-plastics, green synthesis, Agricultural waste, Starch, Cellulose, Biodegradability, Sustainability, Characterization.

Abstract 5**Sustainable Plant-Based Innovation in Cancer Therapeutics: Proposed In-Vitro
Evaluation of *Ocimum sanctum* Leaf Extract**Shweta Chaudhary^{1*}, and Mohd Asif Siddiqui²¹Ph.D. Research Scholar, Department of Life Sciences, Keral Verma Faculty of Science,
Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India²Department of Life Sciences, Keral Verma Faculty of Science, Swami Vivekanand Subharti
University, Meerut, Uttar Pradesh, India

*Corresponding Author Email: shweta0110ulb@gmail.com

Abstract

Around the world various people are affected from the disease of Cancer. Treatment that are not just safe and affordable but also environment friendly is the need of the hour. The available treatments are though working well but are subject to the strong side effects as they can stop working overtime (drug resistance) and can be very expensive. Due to these reasons only the scientists are making constant attempts to find new form of medicines from plants. As plants are natural and can be grown again and again are better for the environment. Out of the various plant they are studying *Ocimum sanctum* (also called Tulsi) is one of them. Tulsi is one of the most common medicinal plants used in traditional medicine. Tulsi has Various natural substances that may protect the body from damage, reduce swelling, and possibly slow down the growth of cancer cells. Author through this study aims to evaluate the in-vitro anti-cancer potential of *Ocimum sanctum* leaf extract against selected cancer cell lines using standard cytotoxicity assays. The author in this study will collect, authenticate, shade dry, the fresh leaves which will be subjected to solvent extraction. The author will in this study will conduct the Preliminary phytochemical screening to identify major bioactive constituents such as flavonoids, phenolics, alkaloids and terpenoids. Cytotoxic effects of the extract will also be assessed in this study through in-vitro assays to determine its inhibitory impact on cancer cell viability. The research integrates sustainable resource utilisation with biomedical innovation, contributing to eco-friendly drug discovery strategies. The expected findings of this study may provide scientific validation for the therapeutic potential of *Ocimum sanctum* and support its translational application in sustainable cancer management.

Keywords: Cancer Therapeutics, Green Innovation, In-vitro Cytotoxicity, Medicinal Plants, *Ocimum sanctum*, Sustainable Drug Discovery.

Abstract 6**Quality Assessment of Raw Milk and Dairy Products through Biochemical and Microbiological Analysis**Abhishek kumar^{1*}, Rekha Yadav¹¹Department of Biotechnology and microbiology, Meerut Institute of Engineering and Technology, Meerut.

Email Id- as7652798@gmail.com

Abstract

The consumption of raw milk and its derivatives pose considerable health risks, especially in warm climates where microbial growth is accelerated. The spoilage process in milk involves the breakdown of its primary components carbohydrates, proteins, and fats by various microorganisms, which results in the accumulation of harmful metabolic by-products that compromise both safety and quality. Lactic acid bacteria, such as *Lactococcus* spp. and *Streptococcus* spp, play a central role in milk souring by fermenting lactose into lactic acid, thereby lowering the pH and altering the product's sensory attributes. However, spoilage is not limited to these bacteria; Gram-negative psychrotrophic bacteria, coliforms, yeasts, and molds also contribute to the deterioration of milk, each introducing distinct biochemical changes that can lead to off-flavors, texture defects, and potential toxin production. Beyond spoilage, milk and dairy products can act as vehicles for pathogenic bacteria that threaten public health. Pathogens such as *Salmonella* spp., *Listeria monocytogenes*, *Campylobacter jejuni*, *Yersinia enterocolitica*, pathogenic *Escherichia coli* strains, and enterotoxigenic *Staphylococcus aureus* are frequently implicated in foodborne outbreaks linked to dairy consumption. Accurate detection and differentiation of these microorganisms are critical for ensuring food safety and public health protection. Biochemical assays, including the citrate utilization test, methyl red (MR) test, and Voges–Proskauer (VP) test, are instrumental in this regard.

Keywords: Citrate test, Methyl red (MR) test, Voges–Proskauer (VP) test, *Lactobacillus*, Coliforms, Psychrotrophic bacteria Raw milk, Dairy product.

Abstract 7**Biodegradation of Low Density Polyethylene by Indigenously Isolated
Microbial Consortia**Megha Verma^{1*}, Mohd Asif Siddiqui¹¹Department of Life Sciences, Keral Verma Faculty of Science, Swami Vivekanand Subharti
University, Meerut, Uttar Pradesh, India

Email Id- meghaverma0636@gmail.com

Abstract

The widespread use of low-density polyethylene (LDPE) in packaging, agriculture, and consumer products has led to significant environmental challenges due to its resistance to degradation, low recycling rates, and accumulation in terrestrial and marine ecosystems. Conventional waste management methods, including landfilling, incineration, and recycling, offer limited effectiveness and often generate secondary environmental burdens. Biodegradation has emerged as a sustainable alternative, leveraging microbial and enzymatic pathways to depolymerize LDPE into less harmful compounds. This research provides a comprehensive examination of current biodegradation strategies, encompassing bacterial, fungal, algal, and actinomycete contributions, as well as the enzymatic mechanisms underlying polymer breakdown. In this study, the biodegradation capacity of locally isolated microbial consortia against LDPE is examined in a controlled laboratory setting. LDPE was used as the only carbon source to enhance microbial strains that were isolated from soil samples polluted by plastic. To evaluate their diversity and synergistic interactions, the formed consortia were morphologically, biochemically, and molecularly described. Pre-treatment methods—such as UV irradiation, thermal processing, and chemical oxidation—are discussed for their role in enhancing microbial accessibility. Advanced analytical tools including FTIR, SEM, and GC–MS are highlighted for evaluating degradation efficiency. Weight loss analysis, surface morphological changes using scanning electron microscopy (SEM), functional group modifications using Fourier-transform infrared spectroscopy (FTIR), and changes in tensile strength were used to assess the biodegradation effectiveness. Following incubation, notable changes in the surface topology of LDPE, the emergence of carbonyl and hydroxyl groups, and a discernible decrease in polymer weight were noted, all of which pointed to active microbial breakdown.

Keyword: UV irradiation, FTIR, SEM, LDPE.

Abstract 8**In Silico Approaches for the Identification of Anticancer Bioactive Compounds from Medicinal Mushrooms**Anjali Verma ¹, Krishna Sundari Sattiraju*Department of Biotechnology, Jaypee Institute of Information Technology, A-10, Sector-62,
201309, Noida, Uttar Pradesh

Email: s.krishna.sundari@mail.jit.ac.in

Abstract

Cancer remains one of the leading causes of mortality worldwide and continues to pose a significant challenge for the development of effective therapeutic strategies. Natural products have long been recognized as a valuable source of pharmacologically active molecules, and medicinal mushrooms have gained considerable attention due to their diverse bioactive metabolites with potential anticancer properties. Compounds such as cordycepin, hispolon, and other phenolic and secondary metabolites derived from medicinal mushrooms have demonstrated promising biological activities in various experimental studies. In recent years, in silico approaches have emerged as powerful tools in modern drug discovery, enabling the rapid screening and evaluation of bioactive compounds against specific molecular targets. Computational techniques including molecular docking, virtual screening, molecular interaction analysis, and pharmacokinetic prediction (ADME) play a crucial role in identifying potential lead molecules and understanding their interaction with cancer-related proteins. Several studies have reported significant binding affinity of mushroom-derived compounds with key proteins involved in cancer progression, including AKT1, TP53, STAT3, EGFR, and IGF1R. These computational strategies not only accelerate the drug discovery process but also provide valuable insights into the structural and functional aspects of ligand–protein interactions. Furthermore, in silico analysis assists in predicting drug-likeness, bioavailability, and toxicity profiles of potential compounds, thereby reducing time and cost in early-stage drug development. Overall, the integration of medicinal mushroom research with advanced computational approaches represents a promising strategy for the discovery of novel anticancer agents. However, further experimental validation through in vitro and in vivo studies is necessary to confirm their therapeutic potential and clinical applicability.

Keywords: Medicinal mushrooms, In silico analysis, Molecular docking, Anticancer compounds, Drug discovery.

Abstract 9**Antimicrobial Activity of Turmeric against Biofilm Forming *Staphylococcus Aureus*
Isolate from Cow Milk**Shudanshu Sharma¹, Ravindra Kumar Jain^{1*}¹Department of Biotechnology, Keral Verma Subharti College of Science, Swami Vivekanand
Subharti University, Meerut, U.P. India – 250005

*Corresponding author: rkjbiotech20@gmail.com

Abstract

Staphylococcus aureus is a well-known pathogen capable of producing enterotoxins during bacterial growth in contaminated milk, causing mastitis in dairy cattle and the ingestion of such preformed toxins is one of the major causes of food poisoning around the world. The capacity of *S. aureus* to produce biofilms increases its antibiotic resistance, posing a considerable challenge to dairy hygiene and public health. This research explored the antimicrobial activity of turmeric (*Curcuma longa*) extracts towards biofilm-producing *S. aureus* isolated from cow's milk. Milk samples were collected from dairy farms and screened to microbiological analysis for the isolation and identification of *S. aureus* by using selective culture media, morphological, and biochemical methods. The biofilm-forming ability of the isolates was determined by using Congo Red Agar method and the microtiter plate assay. Ethanolic turmeric extract was prepared using appropriate maceration extraction methods and tested for antimicrobial activity against confirmed biofilm-forming *S. aureus* isolates using the agar well diffusion and disk diffusion method. The research results revealed that turmeric extract had strong inhibitory effects against *S. aureus* isolates, with clear zones of inhibition observed at various concentrations. In turmeric the bioactive compounds like curcumin may damage bacterial cell walls and reduce biofilm formation. In conclusion, turmeric has shown strong antimicrobial activity against biofilm-forming *Staphylococcus aureus* isolated from cow milk. These findings suggest that turmeric may act as a potential natural alternative for controlling *S. aureus* infections and enhancing microbial safety in dairy products.

Keywords: Antimicrobial activity, Bio-Film forming microbes, Congo Red Agar, Dairy Milk, microtiter plate, turmeric extract.

Abstract 10**A Comparative Analysis of Antimicrobial Resistance Patterns among *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus***Sushil Giri ^{1,2}, Umesh² and Adesh Kumar¹¹Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut Uttar Pradesh, India, 250005²Department of Microbiology, Govt. Medical College Haldwani, Nainital, Uttarakhand-263139

Email Id- sushilgiri256@gmail.com

Abstract

The rapid rise of antimicrobial resistance (AMR) has emerged as a major global health concern, driven by the increasing prevalence of multidrug resistant (MDR) bacterial pathogens in both community and hospital settings. Gram-negative bacteria such as *E. coli* and *P. aeruginosa* and Gram-positive *S. aureus* are among the most frequently isolated pathogens in clinical microbiology laboratories. These organisms are commonly indicated in surgical site and wound infection and are known for their enhanced virulence, biofilm-forming ability, and evolving resistance to multiple antibiotics. The growing incidence of MDR strains significantly complicates therapeutic management and infection control practices. In this context, the present study was designed to comparatively evaluate the MDR patterns of *E. coli*, *P. aeruginosa* and *S. aureus* against commonly prescribed antimicrobial agents. The current study reveals a high prevalence of antimicrobial resistance among isolates from wound infections, with MDR *E. coli* and *P. aeruginosa* predominating. A notable percentage of *S. aureus* isolates were methicillin resistant. Resistance to carbapenem, fluoroquinolones and cephalosporins, highlight a significant treatment problem. These findings highlight the need for continuous surveillance and strengthened antimicrobial stewardship practices.

Keywords: Antimicrobial Resistant (AMR), Antibiotic Stewardship, Biofilm Formation, Multi-Drug Resistant (MDR), Surgical Site Infection (SSI),

Abstract 11**TLC based Comparative Analysis of Qualitative Phytochemical Characteristics of
Eclipta alba and *Eclipta prostrata***Anuj¹, Ashwani Kumar^{*2}, Ravindra Kumar Jain², and Nikhil Chand²¹Research Scholar, Biotechnology, Swami Vivekanand Subharti University, Meerut, India²Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India

*Corresponding author. Email: amritdhra1981@gmail.com

Abstract

The present study focuses on the qualitative and quantitative phytochemical analysis of *Eclipta alba* and *Eclipta prostrata*—two medicinally important species traditionally used in Ayurvedic and ethnobotanical systems. These plants, known for their diverse pharmacological properties, were analyzed to determine the presence and concentration of key bioactive constituents. Qualitative phytochemical screening of methanolic and aqueous extracts revealed the presence of major secondary metabolites such as alkaloids, flavonoids, phenolics, saponins, tannins, terpenoids, and glycosides in both species, with slight variations in intensity. Quantitative estimation demonstrated that *Eclipta alba* contained higher concentrations of total phenolic content (TPC) and total flavonoid content (TFC) compared to *Eclipta prostrata*, suggesting a stronger potential for antioxidant and therapeutic applications. The findings provide comparative insight into the phytoconstituent profiles of these botanicals and support their continued exploration for the development of plant-based pharmaceutical and nutraceutical formulations. Further studies including chromatographic profiling and biological assays are recommended to validate their therapeutic efficacy and identify active compounds.

Key words: TLC, Qualitative Phytochemical analysis, *Eclipta alba* and *Eclipta prostrata*

Abstract 12**Therapeutic Potential of Naringin in the Prevention of Age-Related Disorders-A
Systematic Review**

¹Shrashti Teja, ²*Ashwani Kumar, ²Ravindra Kumar Jain, ²Adesh Kumar

¹Ph.D Scholar Biotechnology, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

² Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

*Corresponding Author- Dr. Ashwani Kumar, amritdhra1981@gmail.com

Abstract

Aging is a complex and inevitable biological process characterized by progressive physiological decline, reduced cellular repair capacity, and increased susceptibility to chronic diseases. Natural bioactive compounds derived from plants have gained considerable attention for their potential to mitigate age-related functional deterioration. Among these compounds, naringin, a prominent flavanone glycoside predominantly found in citrus fruits, has emerged as a promising candidate due to its diverse pharmacological properties. Upon enzymatic hydrolysis by naringinase, naringin is converted into its aglycone form, naringenin, which exhibits enhanced bioavailability and biological activity. Recent experimental studies involving cellular models and organisms such as yeast, *Caenorhabditis elegans*, and mammals indicate that naringin may influence multiple hallmarks of aging, including oxidative stress, mitochondrial dysfunction, chronic inflammation, impaired protein homeostasis, and dysregulated nutrient signaling pathways. Through its antioxidant, anti-inflammatory, and metabolic regulatory activities, naringin demonstrates protective effects against several age-associated disorders, including neurodegenerative diseases, metabolic syndrome, pulmonary aging, and cardiovascular complications. Citrus fruits represent an abundant and sustainable source of flavonoids with significant therapeutic potential. In particular, naringin has attracted attention for its role in nutraceutical development and functional food formulations aimed at promoting healthy aging.

Keywords: Naringin, Citrus flavonoids, Anti-aging, Oxidative stress, Nutraceuticals, Secondary metabolites

Abstract 13**Plant-Derived Bioenzymes: Efficacy, Extraction Strategies, and Versatile Applications –
A Comprehensive Review**

¹Unaiza Hashmi, ^{2*}Ashwani Kumar, ²Ravindra Kumar Jain, ²Dheer Pal Singh, ²Neeru Singh, ²Anchal Sharma

¹Ph.D Scholar Biotechnology, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

²Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

*Corresponding Author- Dr. Ashwani Kumar, amritdhra1981@gmail.com

Abstract

Bioenzymes derived from plant components have emerged as sustainable and economically viable alternatives to microbial and animal-derived enzymes for a wide range of industrial, biotechnological, and environmental applications. This comprehensive review summarizes recent advancements (2020–2025) in the extraction, purification, characterization, and utilization of plant-derived bioenzymes. Major enzyme classes such as proteases (e.g., bromelain and papain), oxidoreductases (including peroxidases and polyphenol oxidases), phosphatases, and lyases are discussed with emphasis on their botanical sources, biochemical properties, catalytic efficiency, and functional performance. Recent studies demonstrate improved extraction and purification strategies capable of achieving enzyme recovery yields ranging from 60–93% with purification levels of approximately 4–7 folds. Advances in biochemical characterization have also provided insights into optimal operational conditions, including pH, temperature stability, and substrate specificity. Furthermore, the review highlights diverse applications of plant bioenzymes in detergent formulation, wastewater bioremediation, food processing, pharmaceutical production, and fine chemical synthesis. Particular attention is given to the valorization of agricultural and agro-industrial residues, such as pineapple peels and cabbage processing waste, as cost-effective and sustainable sources of bioenzymes. Despite these promising developments, several challenges remain, including the need for standardized activity assays, improved enzyme stability, and economic feasibility for large-scale production.

Keywords: Bioenzymes; Plant-derived enzymes; Proteases; Oxidoreductases; Enzyme purification; Industrial biotechnology; Waste valorization; Sustainable bioprocessing

Abstract 14**Waste to Wealth: Converting Plant Residues into Sustainable Bioplastic for a Plastic-Free Future**Harshita Nagar¹, and Sangeeta Dayal²¹Research scholar, Department of Life Science, Swami Vivekanand Subharti University,
Meerut²Department of Life Science, Swami Vivekanand Subarctic University, Meerut, UP, India
Email Id- hnagar936@gmail.com**Abstract**

The growing environmental impact of petroleum-based plastics has increased the demand for sustainable and also the demand for biodegradable alternatives. Bio plastics derived particularly from renewable plant resources have attracted considerable attention as an eco-friendly option for reducing plastic pollution. This review summarizes recent developments in the green synthesis and characterization of bio plastics produced from low-cost agricultural feed stocks for instance starch, cellulose, and various aggro-wastes. Common preparation techniques among them solution casting, melt blending, and microbial fermentation are discussed with emphasis on their environmental compatibility and efficiency. In addition, key characterization methods which include mechanical testing, thermal analysis (TGA and DSC), structural analysis (FTIR and XRD), and biodegradability studies are examined to evaluate the performance of these materials. Studies indicate that bio plastics derived from agricultural residues including banana peel, cassava starch, and rice straw show tensile strengths ranging from 0.42 to 74.16 MPa and bio degradation rates of 37–96% within 60 days. These materials have potential applications in food packaging, agricultural films, and consumer products. Nevertheless, issues related to large-scale production, mechanical strength, and cost-effectiveness remain unresolved. Further studies are required to understand process optimization, material reinforcement, and sustainable production strategies to enhance the commercial potential of plant-based bio plastics.

Keywords: Bioplastics, green synthesis, Agricultural waste, Starch, Cellulose, Biodegradability, Sustainability, Characterization

Abstract 15**Resveratrol as a Promising Antitumor Phytochemical: Mechanisms, Therapeutic Potential, and Future Perspectives**

¹Damini Rajora, ^{2*}Ashwani Kumar, ²Ravi Kumar, ³Shlok Jindal

¹Ph.D Scholar Biotechnology, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

^{2*}Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

³CRS Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

*Corresponding Author- amritdhra1981@gmail.com

Abstract

Cancer remains one of the leading causes of morbidity and mortality worldwide, necessitating the exploration of safer and more effective therapeutic agents. Natural bioactive compounds have gained significant attention due to their pharmacological potential and minimal side effects. Resveratrol (3,5,4'-trihydroxy-trans-stilbene), a polyphenolic compound predominantly found in grapes, berries, peanuts, and red wine, has emerged as a potent anticancer agent with diverse biological activities. This review highlights the antitumor properties of resveratrol and its underlying molecular mechanisms. Resveratrol exerts its anticancer effects through multiple pathways, including inhibition of tumor cell proliferation, induction of apoptosis, suppression of angiogenesis, and modulation of key signaling pathways such as NF- κ B, PI3K/Akt, MAPK, and p53. Additionally, it demonstrates strong antioxidant and anti-inflammatory properties that contribute to its chemopreventive potential. Recent studies have also emphasized its role in regulating cell cycle arrest, inhibiting metastasis, and enhancing the efficacy of conventional chemotherapeutic drugs. Despite its promising therapeutic benefits, limitations such as low bioavailability and rapid metabolism remain challenges for clinical application. Advances in nanoformulations, drug delivery systems, and structural modifications are being explored to overcome these limitations and improve its therapeutic efficacy. Overall, resveratrol represents a promising natural compound with significant potential in cancer prevention and treatment. Further preclinical and clinical studies are required to validate its safety, optimal dosage, and effectiveness in anticancer therapy.

Keywords: Resveratrol, Antitumor activity, Phytochemicals, Apoptosis, Antioxidant, Cell signaling pathways, Chemoprevention.

Abstract 16**Phytochemical Analysis and Potential Bioactive Properties of Turmeric Leaves Bioenzyme**

Aysha pundir, Ashwani Kumar*, Shagun Tomar, Priyanshu Rana, Kanupriya

Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India

*Corresponding author. Email: amritdhra1981@gmail.com

Abstract:

Turmeric (*Curcuma longa*) is globally recognized for the therapeutic potential of its rhizomes; however, the aerial leaves are frequently discarded as agricultural waste. This study explores the valorization of these leaves through the production of a bioenzyme—a complex crude extract obtained via the traditional fermentation of turmeric leaves, molasses, and water. The research focuses on the phytochemical profiling and assessment of the bioactive properties of the resulting fermented solution. Preliminary phytochemical screening revealed a rich presence of secondary metabolites, including flavonoids, tannins, saponins, and terpenoids. Notably, the fermentation process appears to enhance the bioavailability of phenolic compounds compared to aqueous leaf extracts. The findings suggest that turmeric leaf bioenzyme serves as a potent, eco-friendly source of bioactive compounds. This study provides a sustainable pathway for converting agricultural by-products into high-value functional liquids with applications in biomedicine, sustainable agriculture, and green chemistry.

Keywords: *Curcuma longa*, Bioenzyme, Phytochemicals, Fermentation, Antioxidant, Circular Economy.

Abstract 17**Phytochemical Analysis and Potential Bioactive Properties of Garlic (*Allium sativum*) Bioenzyme**

Kanupriya, Ashwani Kumar*, Shagun Tomar, Priyanshu Rana, Aysha pundir

Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India

*Corresponding author. Email: amritdhra1981@gmail.com

Abstract:

Garlic (*Allium sativum*) is widely recognized for its medicinal and antimicrobial properties due to the presence of various bioactive phytochemicals. The present study focuses on the phytochemical analysis of garlic-derived bioenzyme produced through the fermentation of garlic with jaggery and water under controlled conditions. Bioenzymes are natural organic solutions obtained through enzymatic fermentation of plant materials and are known for their eco-friendly and multifunctional applications. In this study, garlic bioenzyme was prepared using a standard fermentation process for a period of three months. After fermentation, the extract was subjected to qualitative phytochemical screening to identify the presence of important secondary metabolites. The analysis revealed the presence of major phytochemicals such as alkaloids, flavonoids, phenolics, tannins, saponins, glycosides, and sulfur-containing compounds. These bioactive constituents are known to contribute to antimicrobial, antioxidant, and anti-inflammatory activities. The results suggest that garlic bioenzyme is a rich source of biologically active compounds that may have potential applications in agriculture, environmental management, and health-related fields. The study highlights the importance of fermentation in enhancing the phytochemical profile of garlic and supports the development of natural, sustainable bioenzyme-based formulations for various applications.

Key words: Garlic bioenzyme, *Allium sativum*, phytochemical screening, fermentation, bioactive compounds, eco-friendly formulation.

Abstract 18**Isolation of Antibiotic-Resistant Bacteria from Municipal Sewage Water**

Ashwani Kumar*, Shubham Raj, Anupriya Rana, Ritika Yadav

Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India

*Corresponding author. Email: amritdhra1981@gmail.com

Abstract:

Bacteria were isolated from sewage water collected from different urban locations to evaluate the presence and spread of antibiotic resistance in the environment. The membrane filtration technique was applied, and the isolates were cultured on selective media including MacConkey agar, Salmonella–Shigella agar, Sodium azide agar, Mannitol salt agar, and Pseudomonas isolation agar. Identification of the microorganisms was carried out using Gram staining, observation of colony morphology and color, motility test, sugar utilization tests, and other biochemical assays. The bacterial isolates were identified as *Escherichia coli*, *Enterobacter* spp., *Klebsiella* spp., *Proteus* spp., *Pseudomonas aeruginosa*, & *Enterococcus faecalis*. Antibiotic susceptibility was tested using trimethoprim, streptomycin, rifampin, erythromycin, cephalothin, ciprofloxacin, carbenicillin, amoxiclav, amoxicillin, and ampicillin. The isolates demonstrated 50–100% resistance to the antibiotics tested; all isolates were resistant to rifampin, amoxiclav, and amoxicillin, while *Pseudomonas aeruginosa* showed resistance to all antibiotics used. These findings suggest a significant level of antibiotic resistance in sewage water, which could pose challenges in treating infections if such multidrug-resistant bacteria spread to human and animal pathogens. Municipal sewage water is an important reservoir of diverse microorganisms, including antibiotic-resistant bacteria that may pose a risk to public health. These findings indicate that municipal sewage water may act as a significant source of antibiotic-resistant bacteria, which could contribute to the spread of resistance to human and animal pathogens and create challenges in the treatment of infectious diseases.

Key words: Salmonella–Shigella, Antibiotic-Resistant Bacteria, Municipal Sewage Water, multidrug-resistant

Abstract 19**Novel Approaches in Drug Discovery and Development: A Multidisciplinary Perspective**

Tosha, Sarita Rana, Dhanendra Kumar Rai

Department of Life Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh,
India

Email Id-toshadhatirya290305@gmail.com

Abstract

Drug discovery and development are intricate and time-consuming procedures that require a convergence of various scientific disciplines like medicinal chemistry, molecular biology, pharmacology, computational biology, and biotechnology. The traditional drug discovery process has been a time-consuming process that involves long experimentation procedures. In addition, a large percentage of failures are observed during clinical trials. However, during the past few years, advances in computational technologies, artificial intelligence, high-throughput screening, and systems biology have significantly improved drug discovery. These novel drug discovery techniques are efficient for identifying drug targets, screening drug candidates, and predicting drug efficacy. In addition, research on natural products, nanotechnology, and personalized medicine is also contributing to the development of more effective drug discovery strategies. The present review focuses on various novel drug discovery strategies that are employed during drug development. The novel drug discovery strategies are a convergence of various disciplines like computational technologies, omics technologies, natural products, and drug delivery systems. These novel drug discovery strategies are expected to accelerate drug development and discover novel therapeutics for various diseases.

Keywords: Drug discovery, computational drug design, artificial intelligence, natural products, omics technologies, nanotechnology.

Abstract 20**Antibacterial and Phytochemical Exploration of *Moringa* Leaves:**

Sweta Kumari ,Sanjana Kumari , Dhanendra Kumar Rai

Department of Life Science, Swami Vivekanand Subharti University, Meerut, India

Email: sweta294ray@gmail.com

Abstract:

Moringa oleifera, commonly known as the drumstick tree, is a plant well known for its nutritional and medicinal value. The present study aims to explore the phytochemical composition and antibacterial activity of *Moringa* leaves. Fresh leaves were collected, washed, dried, and ground into powder. The powdered leaves were then used to prepare extracts using suitable solvents. These extracts were analyzed through phytochemical screening to identify the presence of important bioactive compounds. The phytochemical analysis showed the presence of alkaloids, flavonoids, tannins, saponins, phenols, and glycosides. These compounds are known for their biological activities and play the leaf extracts was tested against selected bacterial strains using the agar well diffusion method. The results showed that the extracts produced clear zones of inhibition, which indicates their ability to prevent the growth of bacteria. The findings of this study suggest that *Moringa oleifera* leaves possess significant antibacterial properties due to the presence of various phytochemicals. Therefore, *Moringa* leaves can be considered a potential natural source for developing plant-based antibacterial medicines. Further research is needed to isolate and identify the specific active compounds responsible for these antibacterial effects.

Keywords: *Moringa oleifera*, phytochemical screening, antibacterial activity, medicinal plants, leaf extract, bioactive compounds, natural antibiotics.

Abstract 21**Isolation and characterization of Cellulose producing microorganisms
from soil sample**

Mariva Shehzad¹, Anuradha Sinha¹, Adesh Kumar¹, Ravinder Kumar Jain¹

¹Department of Life Sciences, Swami Vivekanand Subharti, University, Meerut, India

*Corresponding author. Email: adesh.du@gmail.com

Abstract

Cellulose is the most abundant natural biopolymer and a major structural component of plant biomass. The microbial degradation of cellulose plays a vital role in carbon cycling and has wide industrial applications. Thermostable celluloses are of particular interest because they remain active and stable at high temperatures, which improves enzymatic efficiency and reduces the risk of microbial contamination during industrial processes. The present study was conducted to isolate and characterize thermostable cellulose-producing microorganisms from soil samples. Soil samples were collected from sites rich in decaying plant materials, which are known to harbour diverse cellulolytic microorganisms. Isolation of microorganisms was carried out using serial dilution and spread plate techniques on selective media containing carboxymethyl cellulose as the sole carbon source. Primary screening for cellulose activity was performed using Congo red staining to identify clear zones of cellulose hydrolysis around microbial colonies. Promising isolates showing significant cellulolytic activity were selected for further analysis. These isolates were characterized based on their morphological, biochemical, and physiological characteristics. The thermostability of cellulose, enzymes was evaluated by determining enzyme activity at elevated temperature ranges. The study revealed the presence of efficient thermostable cellulose producing microorganisms capable of degrading cellulose under high temperature conditions. These microorganisms have potential applications in various industrial sectors including biofuel production, agricultural waste management, textile processing, and paper and pulp industries.

Keywords: Cellulose. Thermostable enzymes, Cellulolytic microorganisms, Soil microorganisms, Carboxymethyl cellulose, Congo red assay.

Abstract 22**Discovery of Bioactive Phytochemicals with Antibacterial Activity from *Azadirachta indica* Leaves**

Sanjana Kumari, Sweta Kumari, Dhanendra Kumar Rai

Department of Life Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India

Corresponding Author-:chhayakumarinm555@gmail.com

Abstract

Medicinal plants are important sources of various therapeutic agents. Among various medicinal plants, the neem tree is well known for its various pharmacological activities. The current research work was conducted to explore the phytochemical screening of various phytoconstituents present in neem leaves extracts for their potential antimicrobial activities against some pathogenic bacteria. The neem leaves were collected from various sources, dried, and extracted using suitable organic solvents. The preliminary phytochemical screening of neem leaves extracts revealed that various important phytoconstituents like alkaloids, flavonoids, tannins, saponins, glycosides, and terpenoids are present in neem leaves extracts. The antimicrobial activity of neem leaves extracts was studied by using the agar well diffusion method against various pathogenic bacteria like *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*. The results revealed that neem leaves extracts show significant antimicrobial activity against various pathogenic bacteria. The results revealed that as the concentration of neem leaves extracts increases, the zone of inhibition also increases. The antimicrobial activity of neem leaves extracts is due to the presence of various phytoconstituents that are responsible for inhibiting the growth of various pathogenic bacteria.

Keywords: *Azadirachta indica*, phytochemicals, antibacterial activity, medicinal plants, bioactive compounds

Abstract 23**Microbiome–Immunity Axis: Emerging Insights into the Role of the Human
Microbiome in Human Health and Disease**

Anupriya Kumari*, Dhanendra Kumar Rai, Nikhil Chand

Department of Life Science, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh,
India

Corresponding Author-: anumehta.332003@gmail.com

Abstract

The human microbiome is composed of various microorganisms that colonize different parts of the body. The parts of the body that the human microbiome colonizes include the gastrointestinal tract, skin, oral cavity, and respiratory tract. The role of the microbial community in the body is essential in maintaining physiological homeostasis and the development of the immune system. Recent advances in the field of molecular biology and metagenomic sequencing have provided better insight into the role of the microbiome in the body. The microbial community in the body is responsible for various biological activities. The activities include nutrient metabolism, immune system function, pathogen defense mechanisms, and the maintenance of the intestinal barrier. Disruption of the microbial community in the body is responsible for various diseases. The disruption of the microbial community is known as dysbiosis. Diseases that have been linked to dysbiosis include inflammatory bowel disease, metabolic disease, autoimmune disease, and infections. This review aims to highlight the role of the human microbiome in the regulation of the immune system and the maintenance of health and disease. Additionally, the role of various therapeutic strategies in the maintenance of health and disease will be discussed.

Keywords: Human microbiome, immunity, gut microbiota, dysbiosis, probiotics, host–microbe interaction.

Abstract 24**Using AI and Bioinformatics to Track Antimicrobial Resistance (AMR) and discover new drugs target**¹Kirti, and ²Nikhil Chand¹Research scholar, Department of Life science, Swami Vivekanad Subharti University,
Meerut²Department of Life Science, Swami Vivekanand Subharti University, Meerut

Email Id- kirti0307singh@gmail.com

Abstract:

Antimicrobial Resistance (AMR) is a big global problem because many bacteria are becoming "superbugs" that medicine cannot kill. To solve this, we need faster and better ways to study them. My research uses Artificial Intelligence (AI) and Bioinformatics to look at the Genomics and Proteomics (DNA and Proteins) of these bacteria. Instead of only doing slow laboratory tests, I will use computer programs to find out how bacteria change to survive antibiotics. This method helps us identify new targets for Drug Discovery much faster than before. It also helps in Personalized Medicine, where doctors can choose the right treatment for a patient based on the specific type of bacteria they have. By using these modern digital tools, we can better understand the Microbiome and stop the spread of resistance. This research provides a simple yet powerful way to use technology to save lives and make healthcare more effective worldwide.

Keywords: AMR, AI, Bioinformatics, DNA, New Drugs, Superbugs, Healthcare.

Abstract 25**Optimization of Biofilm-Forming Microbial Consortia for Textile Effluent Treatment**

Komal Sharma, and Ravindra Kumar Jain*

Department of Biotechnology, Keral Verma Subharti College of Science, Swami Vivekanand
Subharti University, Meerut, U.P. India – 250005

*Corresponding author Email- komalsharma06114@gmail.com, rkjbiotech20@gmail.com

Abstract:

Industrial development plays an important role in enhancing a nation's economy, but it also leads to the release of substantial volumes of wastewater. This wastewater often contains a mixture of harmful substances, including heavy metals, synthetic dyes, hydrocarbons, phenolic compounds and pharmaceutical traces. These harmful substances can cause significant harm to the environment. Microorganisms such as specific strains of bacteria, fungi and algae have the capacity to naturally degrade those harmful substances into simpler ones without secreting any harmful by product. Microorganisms are a very powerful agent of bioremediation and some of the microbes can be very effective when they work as a group in the form of microbial consortia and not as a single specific strain. Microbial consortia can be used as a very effective tool for the natural degradation of the harmful substances that are present in the wastewater of various industries. We're working on fine-tuning microbial consortia to create effective biofilms for treating textile industry wastewater. Our research focuses on optimizing the mix of bacteria and fungi to break down complex pollutants efficiently. We've identified key factors influencing biofilm formation and pollutant degradation, including pH, temperature, and nutrient levels. By tweaking these parameters, we'll achieve significant improvements in color and COD removal - up to 95% in just 48 hours. The optimized consortia demonstrate robust biofilm formation on various support materials, including activated carbon and ceramic beads, enabling stable performance in varying conditions. The goal is to develop a cost-effective, eco-friendly solution for textile wastewater treatment that can be easily adopted by industries. We're also exploring ways to enhance the consortia's adaptability to varying pollutant loads and types. With further optimization, we believe this biofilm-based technology can make a significant impact in reducing industrial wastewater pollution and promoting sustainable water management practices globally.

Keywords: Biofilm, Textile Effluent, Microbial Consortia, Bioremediation, Wastewater Treatment.

Abstract 26**Comparative Stress Responses of Salt-Sensitive and Salt-Tolerant Wheat under NaCl and PEG-Induced Osmotic Stress**

Amit Kumar

Faculty of Science, Swami Vivekanand Subharti University, Meerut, U.P. India – 250005

E-mail-amit.abiotech1581@gmail.com

Abstract

Salt stress is a major abiotic constraint globally limiting wheat (*Triticum aestivum* L.) productivity. This study investigated the differential physiological and biochemical responses of a salt-sensitive cultivar (K-9006) and a salt-tolerant cultivar (KRL-19) to NaCl (50 and 100 mmol L⁻¹) and iso-osmotic polyethylene glycol (PEG) stress, applied at equivalent osmotic potentials, to dissect the relative contributions of ionic toxicity versus osmotic stress. Key parameters—malondialdehyde (MDA) content, superoxide dismutase (SOD) activity, net photosynthetic rate, and leaf respiration rate—were assessed in roots and leaves after five days of stress treatment. MDA content increased significantly more in K-9006 than KRL-19 under NaCl, with greater increases under NaCl than iso-osmotic PEG stress, confirming dominant ionic toxicity. SOD activity declined progressively in K-9006 but was maintained or upregulated in KRL-19 at low NaCl. Photosynthetic rate was significantly stimulated in KRL-19 at low NaCl and maintained at high NaCl, while it declined markedly in K-9006 at 100 mmol L⁻¹ NaCl. Respiration rate was markedly elevated in K-9006 under NaCl but not under iso-osmotic PEG, implicating Na⁺ ion toxicity as the primary driver. Salt tolerance was positively correlated with SOD activity and photosynthetic rate, and negatively correlated with MDA content and respiration rate. These findings provide a physiological basis for discriminating osmotic from ionic stress components and offer insights for screening and breeding salt-tolerant wheat varieties.

Keywords: Bread Wheat, Malondialdehyde (MDA), Superoxide dismutase (SOD), Photosynthesis, Respiration, Osmotic stress, Ion toxicity, PEG; Sodium Chloride, Salt tolerance

Abstract 27**Recent Developments in Microbial Enzymes for Industrial and Biotechnological Applications**

Sarita Rana, Anu Chauhan, Ritika Yadav, Dhanendra Kumar Rai, Ashwini kumar

Department of Life Sciences, Swami Vivekanand Subharti University, Meerut

Email Id-sarita.su202500080@subharti.co

Abstract

Recent advancements in enzyme engineering, metagenomics, and synthetic biology have significantly expanded the potential of microbial enzymes. The discovery of extremozymes derived from extremophilic microorganisms has enabled enzymatic processes to function efficiently under harsh industrial conditions such as high temperatures, extreme pH levels, and high salinity. In addition, modern genetic tools, including recombinant DNA technology and CRISPR-based systems, have enhanced enzyme production, stability, and functionality, enabling the development of highly efficient biocatalysts. With the increasing global focus on green chemistry and sustainable development, microbial enzymes provide promising solutions by reducing energy consumption, minimizing waste generation, and supporting circular bioeconomy initiatives. Despite their significant potential, several challenges limit the large-scale industrial application of microbial enzymes. These include reduced enzyme stability under industrial conditions, high production costs, and limited catalytic efficiency toward non-natural substrates. Furthermore, the discovery and optimization of novel enzymes remain complex and time-intensive when relying solely on traditional screening techniques. Addressing these challenges requires innovative approaches that integrate advanced enzyme engineering, high-throughput screening technologies, and synthetic biology tools to improve enzyme performance, scalability, and cost-effectiveness. The present research focus aims to explore emerging strategies to enhance microbial enzyme applications in biotechnology. Key objectives include advancing enzyme engineering techniques such as directed evolution, rational design, and machine learning-assisted optimization to improve catalytic activity, stability, and substrate specificity.

Keywords: Microbial Enzymes, Biocatalysis, Industrial Biotechnology, Enzyme Engineering, Environmental Biotechnology, Sustainable Bioprocessing.

Abstract 28**Drug Discovery, Delivery, and Development: Modern Approaches in Pharmaceutical and Biotechnology Research**

Varnika Ahalawat and Nikhil Chand

Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh,
India

Email: varnikaahalawat99@gmail.com

Abstract

Drug discovery, delivery, and development are essential processes in modern pharmaceutical and biotechnology research aimed at identifying and producing effective therapeutic agents. Drug discovery involves the identification of biological targets, screening of potential compounds, and optimization of lead molecules to create effective drugs. Once a promising drug candidate is identified, drug development focuses on preclinical studies, clinical trials, safety evaluation, and regulatory approval to ensure the drug's efficacy and safety for human use. Drug delivery systems play a crucial role in improving the therapeutic efficiency of drugs by enabling targeted delivery, controlled release, and reduced side effects. Advanced technologies such as nanotechnology, bioinformatics, and biotechnology have significantly accelerated the drug discovery process and improved drug delivery strategies. These integrated approaches contribute to the development of safer, more efficient, and personalized medicines for the treatment of various diseases, including cancer, infectious diseases, and genetic disorders.

Keywords: Drug discovery, Drug delivery systems, Drug development, Targeted drug delivery, Nanotechnology, Pharmacokinetics, Biotechnology

Abstract 29**EV Recharge: Finding the Nearest Electric Vehicle Charging Station**

Manish Dayal Nishad

Department of Computer Application, Swami Vivekanand Subharti University, Meerut

Email: mn6341232@gmail.com

Abstract:

The rapid growth of electric vehicles (EVs) has increased the demand for efficient and easily accessible charging infrastructure. One of the major challenges faced by EV users is locating nearby charging stations, especially in unfamiliar areas or during emergencies when the battery level is low. This project proposes the development of an intelligent mobile and web-based application called EV Recharge, designed to help users quickly find the nearest EV charging station or “charging bunk”. The system uses GPS and location-based services to detect the user's current position and identify nearby charging stations in real time. By integrating mapping technologies and a centralized database of charging stations, the application provides information such as station distance, availability of charging points, charging type, operating hours, and navigation routes. Users can also receive alerts when their battery level is low and view the most optimal charging station based on distance and availability. The proposed system aims to improve convenience for EV users while promoting the adoption of sustainable transportation. Additionally, the platform can assist charging station providers in managing their services more efficiently by updating availability and operational status. Overall, the EV Recharge system contributes to building a smarter and more reliable EV ecosystem by connecting drivers with nearby charging infrastructure quickly and effectively.

Keyword: EV, GPS, Recharge.

Abstract 30**Online Complaint Registration and Management System**

Mohd Shahvej

Department of Computer Application, Swami Vivekanand Subharti University, Meerut, India

Email: saif.shavej@gmail.com

Abstract

The Online Complaint Registration and Management System is a web-based application developed to provide a structured and efficient platform for registering and managing complaints. In many organizations, traditional complaint handling processes are manual and time-consuming, which often results in delays and lack of transparency. This project aims to digitize the complaint management process and provide a user-friendly system where users can easily submit complaints and track their progress online. The system allows users to register, log in securely, and submit complaints through an intuitive web interface. Each complaint is stored in a centralized database and assigned a unique identification number, which helps users track the status of their complaints. The administrator has access to an admin dashboard where complaints can be viewed, updated, and resolved efficiently. This improves communication between users and administrators and ensures proper complaint management. The system is developed using HTML, Tailwind CSS, and JavaScript for the frontend interface, while the backend is built using ASP.NET Core. Data storage and management are handled using Microsoft SQL Server, ensuring reliability and efficient data handling. The application includes essential features such as user authentication, complaint submission, complaint tracking, status updates, and administrative management. Overall, the Online Complaint Registration and Management System help reduce paperwork, improve efficiency, and increase transparency in complaint handling. The system can be effectively implemented in educational institutions, government offices, and private organizations to streamline the complaint resolution process and enhance service quality.

Keyword: Microsoft SQL, ASP.NET, JavaScript.

Abstract 31**Proposed Energy-Efficient Renewable Energy Framework for Sustainable Development**

Mukul Sharma

Department of Computer application, KVSCOS, Swami Vivekanand Subharti University,
Meerut

Email Id-mukuls0201@gmail.com

Abstract

Sustainable development has become a critical global priority due to increasing energy demand, environmental degradation, and rising carbon emissions. Traditional energy systems that rely heavily on fossil fuels contribute significantly to greenhouse gas emissions and climate change. Therefore, the integration of renewable energy sources with energy-efficient technologies has become essential for achieving long-term environmental sustainability. This study proposes an energy-efficient renewable energy framework designed to support sustainable development by optimizing the use of renewable resources while minimizing energy consumption and environmental impact. The proposed framework focuses on integrating renewable energy sources such as solar, wind, and hydro power with advanced energy management strategies. It emphasizes efficient energy generation, intelligent resource allocation, and optimized consumption through smart technologies. The framework also incorporates modern computational techniques, including intelligent scheduling algorithms and energy-aware resource management, to improve system efficiency and reduce overall energy waste. Furthermore, the framework aims to address key challenges in renewable energy adoption, including energy intermittency, resource optimization, and infrastructure limitations. By implementing energy-efficient strategies and renewable-aware scheduling mechanisms, the proposed system enhances the reliability and stability of energy supply. The integration of monitoring and control mechanisms also enables better decision-making and efficient utilization of available renewable energy resources. This research contributes to sustainable development by promoting green energy solutions that reduce carbon footprints and support environmentally responsible technological growth. The proposed framework can be applied in various domains such as smart grids, cloud computing environments, and sustainable infrastructure systems.

Keyword: Energy-efficient, Renewable energy, Technologies

Abstract 32**AI-Based Early Flood Prediction System Using Edge Computing**

Ritika goel

MCA, Department of Computer Applications, KVSCOS, Swami Vivekanand Subharti

University, Meerut, India

Email Id- ritikagoel2912@gmail.com

Abstract

Floods remain one of the most destructive natural disasters worldwide, causing severe damage to infrastructure, agriculture, and human life. Traditional flood monitoring systems rely heavily on centralized cloud-based data processing, which often introduces latency and limits real-time responsiveness in critical situations. This research proposes an AI-Based Early Flood Prediction System using Edge Computing that enables faster, decentralized, and intelligent flood detection and prediction. The proposed system integrates IoT sensors, edge computing devices, and machine learning algorithms to monitor environmental parameters such as rainfall intensity, river water level, soil moisture, and flow velocity. Data collected from distributed sensor nodes is processed locally at edge nodes, reducing communication delay and dependency on cloud infrastructure. An AI prediction model trained using historical hydrological and meteorological datasets performs real-time analysis to forecast potential flooding events before they occur. Edge devices execute lightweight machine learning models such as Random Forest, LSTM, or Gradient Boosting to detect abnormal water level patterns and predict flood risk levels. If the system detects a high-risk condition, it immediately triggers automated alerts to disaster management authorities and local communities via mobile applications, SMS gateways, or public warning systems. The proposed architecture improves prediction accuracy, response time, and system scalability while reducing bandwidth consumption and cloud dependency. Additionally, integrating GIS-based mapping allows visualization of flood-prone areas and risk levels in real time. Experimental evaluation using simulated flood datasets demonstrates that the edge-based prediction system significantly reduces prediction latency and improves early warning capabilities compared to conventional centralized systems.

Keyword: Natural disasters, GIS-based mapping, SMS gateways.

Abstract 33

Environmental pollution: its effects on life and its remedies

Ruqayya saleem & Dheer Pal singh

Department of Life science K.V subharti college of science, Swami Vivekanand Subharti
university, Meerut U.P (INDIA)

Email id :- khansila111@gmail.com

Abstract

Environment pollution is a wide-reaching problem and it is likely to influence the health of human populations is great. This paper provides the insight view about the affects of environment pollution in the perspective of air pollution, water and land/soil waste pollution on human by diseases and problems, animals and trees/plants. Study finds that these kinds of pollutions are not only seriously affecting the human by diseases and problems but also the animals and trees/plants. According to author, still time left in the hands of global institutions, governments and local bodies to use the advance resources to balance the environment for living and initiates the breathed intellectuals to live friendly with environment. As effective reply to contamination is largely base on human appraisal of the problem from every age group and contamination control program evolves as a nationwide fixed cost-sharing effort relying upon voluntary participation (Sharp & Bromley, 1979).

Keywords: - Environmental pollution, Soil pollution, Air pollution, Water pollution and Land pollution remedies.

Abstract 34**First-Principles Insights into Structural, Optical, and Thermoelectric Characteristics of BaTiO₃ for Multifunctional Applications**

Aarzoo Chaudhary, and Aman Kumar

Department of Basic Sciences, (Physics), KVSCOS, Swami Vivekanand Subharti University,
Meerut-250005, India.

Corresponding Author: aarzoochaudhary94@gmail.com

Abstract

This research investigates the structural, electrical, optical, and thermoelectric characteristics of barium titanate using density functional theory under the GGA and mBJ-GGA frameworks. Structural optimization using the Birch-Murnaghan equation of state demonstrates significant concordance with experimental lattice parameters (4.0207 Å) and bulk modulus (165.85 GPa), hence validating computational precision. The electronic band structure indicates a direct band gap of around 2.7 eV using mBJ-GGA, which corresponds well with experimental measurements. The optical characteristics, including dielectric function, absorption coefficient, and refractive index, demonstrate BaTiO₃ suitability for visible and UV optoelectronic applications. Thermoelectric characteristics, assessed using Boltzmann transport theory, indicate that electrical conductivity and the Seebeck coefficient may be adjusted by doping and temperature variations. The extensive band gap of BaTiO₃ constrains the power factor ($PF = S^2\sigma$), hence diminishing its thermoelectric efficiency relative to conventional materials such. The findings underscore the potential of BaTiO₃ for energy storage, sensing, and hybrid solar device applications via compositional and structural engineering.

Keywords: Sensor Technologies, mBJ-GGA, BaTiO₃, density functional theory, electrical conductivity, solar device applications.

Abstract 35**Autonomous Symbiotic Resource Network (ASRN), An AI-Driven Closed-Loop Framework for Sustainable and Resilient Urban Infrastructure**

Sharad Yadav

Swami Vivekanand Subharti University, Meerut, India

Email Id- sharadzh123@gmail.com

Abstract

The accelerating growth of urban populations has intensified systemic challenges related to resource depletion, inefficient waste management, and fragmented energy–water–waste infrastructures. Conventional smart city solutions often operate in silos, limiting their ability to achieve holistic sustainability and adaptive resource optimization. This project introduces the Autonomous Symbiotic Resource Network (ASRN), a unified, AI-driven framework designed to transform urban environments into self-regulating, resource-efficient ecosystems.

ASRN is based on a closed-loop, symbiotic model in which waste streams are dynamically converted into reusable resources, emulating natural metabolic processes. The system integrates Internet of Things (IoT) sensors, edge-level data processing, and machine learning algorithms to continuously monitor resource consumption, predict demand patterns, and optimize distribution in real time. Key functional modules include organic waste-to-energy conversion (biogas generation), decentralized wastewater treatment and reuse, and renewable energy harvesting with intelligent load balancing and peer-to-peer resource sharing.

The proposed framework incorporates adaptive feedback mechanisms that enable predictive decision-making and autonomous system optimization. A prototype-scale implementation demonstrates the feasibility of integrating multi-resource circularity within a localized urban setting, highlighting reductions in waste output, improved energy efficiency, and enhanced resource resilience. By shifting from linear consumption models to regenerative infrastructure, ASRN represents a paradigm advancement toward sustainable urban development. The framework offers a scalable and modular solution capable of supporting next-generation smart cities, particularly in resource-constrained and rapidly urbanizing regions.

Keyword: ASRN, IoT, energy efficiency.

Abstract 36**Eco-Friendly Materials and Sustainable Processes for Environmental Protection**

Sonia Choudhary* and Dheer Pal Singh

Department of Life Science, K. V. Subharti College of Science, Swami Vivekanand Subharti

University, Meerut (U.P.), India

Email: murshidanawaj@gmail.com

Abstract

Environmental pollution caused by rapid industrialization and excessive use of synthetic chemicals has become a major global concern. The present study highlights the importance of eco-friendly materials and sustainable processes in reducing environmental damage and promoting long-term ecological balance. Eco-friendly materials such as biodegradable polymers, natural fibers, plant-based products and green composites are emerging as effective alternatives to conventional synthetic materials that often lead to environmental toxicity. The study emphasizes the role of sustainable and environmentally safe production processes including green chemistry, waste minimization, recycling technologies and energy-efficient manufacturing systems. These processes significantly reduce hazardous emissions and help in conserving natural resources. Adoption of eco-friendly materials not only minimizes environmental pollution but also supports sustainable development in various sectors such as agriculture, packaging, textile and biomedical industries. Furthermore, sustainable processing techniques encourage the use of renewable resources and improve environmental management strategies. The integration of eco-friendly materials with green production technologies can play a crucial role in environmental protection and climate change mitigation. Therefore, promoting sustainable materials and eco-friendly industrial practices is essential for achieving environmental sustainability and ensuring a healthier ecosystem for future generations.

Key words: Eco-friendly materials, sustainable processes, green technology, environmental sustainability, biodegradable materials.

Abstract 37**Data Visualization Dashboard for University**

Vikas Dhaka

Department of Computer Application, Swami Vivekanand Subharti University, Meerut

Email: dhakavikas24@gmail.com

Abstract

In modern universities, a large amount of academic and administrative data is generated every semester, including student performance, attendance records, course details, and departmental statistics. However, most institutions store this information in traditional databases or spreadsheets which makes it difficult to analyze and interpret the data effectively. To address this issue, this project focuses on developing a Data Visualization Dashboard for University that converts complex educational data into meaningful visual insights. The main objective of this project is to design an interactive dashboard that helps university administrators, faculty members, and management teams to monitor and analyze academic data easily. The system uses modern data visualization techniques to represent information through charts, graphs, and dashboards, allowing users to understand trends and patterns quickly. The dashboard integrates different data sources and presents information such as student performance analysis, department-wise statistics, attendance trends, and course performance in a clear and user-friendly interface. Tools like Power BI and Excel datasets are used to create interactive visual reports that support better academic decision-making. This project demonstrates how data visualization can simplify complex datasets and provide actionable insights for educational institutions. By implementing this dashboard, universities can improve academic monitoring, enhance data transparency, and support data-driven decision-making for better educational outcomes.

Keyword: Data Visualization, Power BI, University.

Abstract 38**Exploring The Role of Human Micro Biome And Plant Based Antimicrobials for Improving Human Health**

Vanshika tyagi, Sangeeta Dayal

Department of life science, swami vivekanand subharti university, Meerut, UP, India

Email Id-vanshikakumari678@gmail.com

Abstract:

The human microbiome represents one of the most complex biological systems influencing host physiology, immune regulation, and disease susceptibility. Recent advances in microbiome research have revealed that disruptions in microbial diversity and composition are closely associated with several human disorders, including gastrointestinal infections, metabolic diseases, and immune-related conditions. Concurrently, the global rise in antimicrobial resistance has created an urgent demand for alternative and sustainable therapeutic strategies. In this context, medicinal plants, which are rich in diverse bioactive phytochemicals, have emerged as promising natural sources of antimicrobial compounds capable of modulating microbial communities and suppressing pathogenic microorganisms. Despite growing interest in both microbiome research and plant-derived antimicrobials, a significant research gap remains in understanding the molecular interactions between phytochemicals and microbial targets within the human microbiome. Integrating plant science with microbial genomics through computational approaches can provide new insights into these complex interactions. The present study aims to explore the potential of plant-based antimicrobial compounds in regulating human microbiome dynamics using an integrative bioinformatics framework. Publicly available human microbiome datasets and microbial genomic resources will be analyzed to identify key microbial taxa associated with health and disease states. Simultaneously, phytochemical databases of medicinal plants will be screened to identify potential antimicrobial compounds. Advanced computational tools such as molecular docking, comparative genomics, and pathway analysis will be employed to predict interactions between plant-derived metabolites and microbial molecular targets involved in pathogenicity and resistance mechanisms.

Keywords: Human microbiome, Medicinal plants, Phytochemicals, Plant-based antimicrobials, Bioinformatics, Microbial genomics, Antimicrobial resistance.

Abstract 39**Role of Beneficial Microorganisms in Accelerated Composting and Plant Disease Control**

Vishwajit kumar and Amit Kumar

Department of Agriculture, Keral Verma Subharti College of Science

Email ID: - kumarvishwajit056@gmail.com

Abstract

Rapid urbanization and high-intensity practices of agriculture have resulted in the accumulation of organic wastes and the excessive use of fertilizers and pesticides, which have caused environmental and ecological problems. Therefore, sustainable alternatives are the need of the hour to efficiently manage organic wastes and maintain the health of the plants. Microorganisms play a vital role in accelerating the composting process and plant health through various biotechnological approaches. Accelerated composting involves the use of efficient microbial consortia that include bacteria, fungi, and actinomycetes. These microorganisms play a significant role in the efficient degradation of organic matter, thereby reducing the composting time and improving the quality of the final compost. Microbial inoculums that include species of *Bacillus*, *Pseudomonas*, *Trichoderma*, and *Aspergillus* play a significant role in the rapid degradation of lignocellulosic matter, thereby producing stable compost that is free from pathogens and is rich in nutrients. In addition to the management of organic wastes, the application of beneficial microorganisms as plant growth-promoting microorganisms (PGPMs) is useful in improving the health of the plants. In addition, the application of beneficial microorganisms as biological control agents is useful in reducing the use of chemical pesticides. The integration of microbial biotechnology in composting and plant disease management not only supports sustainable agriculture but also contributes to environmental protection and circular bioeconomy. This approach offers an eco-friendly strategy for efficient waste recycling, soil fertility improvement, and long-term plant health protection. Overall, the application of beneficial microorganisms in accelerated composting and plant health management represents a promising biotechnological solution for sustainable agricultural development and environmental conservation.

Keywords: Accelerated composting, Microbial biotechnology, Plant health protection, Biocontrol agents, Sustainable agriculture, Organic waste management.

Abstract 40**Feed Hope- A Web-Based Platform for Sustainable Food and Resource Distribution**

Yash Kaushik

Swami Vivekanand Subharti University, Meerut

Email: Kaushiky145@gmail.com

Abstract

In today's world, a large amount of food and useful items go to waste every day, while many people still struggle to meet their basic needs. This gap between availability and accessibility highlights the need for a simple and effective solution. This paper introduces "Feed Hope," a web-based platform created to help connect people who have extra resources with those who need them. The platform allows users to donate food, clothes, books, and other essentials through an easy-to-use interface. It is developed using HTML, CSS, and JavaScript, with Google Forms used for collecting and managing data. The main focus of the system is to keep it simple so that anyone can use it without technical difficulty. By encouraging people to share their extra resources, the platform helps reduce waste and supports those in need. It also promotes a sense of social responsibility within the community. In the future, the system can be improved by adding features like a mobile app, real-time updates, and smarter ways to match donors with recipients.

Keyword: World, HTML, CSS.

Abstract 41**Experimental Analysis of Bamboo Fibre Reinforced Concrete**

Daud Chauhan

Ph.D. Scholar, Civil Engineering Department

Glocal School of Science and Technology, The Glocal University

Email id-daudchauhan8080@gmail.com

Abstract:

Due to the demand for sustainable, eco-friendly building materials, research has begun investigating whether natural fibers can serve as an alternative to traditional forms of cement and/or other materials. The purpose of this study was to conduct an experimental analysis of concrete reinforced with bamboo fiber (or BFRC) to evaluate the mechanical properties & durability of this new composite material. To do so, various amounts of the very strong tensile, inexpensive, and biodegradable bamboo fibers were mixed into several sets of concrete samples. These samples were then subjected to compressive tests, split tensile tests, and flexural tests as per industry standards to determine their performance with respect to each criterion over varying time periods. The findings of this research indicated that adding the bamboo fibers would improve concrete's tensile strength and flexural strength; however, there was only a slight increase in compression strength. Additionally, the bamboo fibers reduced crack propagation, while also improving ductility and the workability of concrete. For proper concrete mix design, it may be necessary to make adjustments based on the amount of bamboo fibers used in a given mix. Ultimately, this study shows that bamboo fibers have the potential to be used as an environmentally sound building material for low-cost construction in rural regions. Due to these properties and performance characteristics, concrete reinforced with bamboo fibers could serve as an alternative to standard composite materials in future construction projects.

Keywords:

Bamboo fibre, Reinforced concrete, Sustainable materials, Eco-friendly construction, Crack resistance, Durability

Abstract 42**Synergistic Antibacterial Activity of Selected Herbal Plant Extracts combined with Antibiotics Against Carbapenem-Resistant *Escherichia coli***

Sandhya, Amit Kumar

Department of Microbiology, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, NH 58, Subhartipuram, Meerut-250005, U.P. (INDIA)

E-mail: sandhyasingh0710@gmail.com

Abstract

The rapid emergence and global dissemination of carbapenem-resistant *Escherichia coli* (CREC) have become a major public health concern due to the limited therapeutic options available for treating infections caused by these multidrug-resistant (MDR) pathogens. Carbapenems are used as last-line agents for severe infections caused by Gram-negative bacteria; however, the dramatic rise in carbapenem resistance is significantly reducing the clinical efficacy of these agents. Researchers are investigating alternatives to the use of carbapenems as the sole treatment option through herbal extracts and plant-derived pharmaceutical substances, with proven efficacy against these bacteria. Many plant-derived phytochemicals have been found to possess antibacterial activity and enhance the effectiveness of conventional antibiotics (e.g., carbapenems and colistin). These compounds exert their antimicrobial effects through diverse and complex mechanisms, primarily by targeting multiple pathways involved in bacterial survival, growth, and antimicrobial resistance. Nevertheless, many challenges must still be overcome before the clinical practice of using plant-based antimicrobials can occur. Some of the main obstacles are limited human clinical trials that are rigorously designed, variability in methods of plant extraction and purification, variable dosing regimens, and limited information on pharmacokinetics and toxicity. Additionally, due to the heterogeneous nature of many phytochemical mixtures, the lack of standard protocols to assess the antimicrobial activity of phytochemicals will continue to hinder the development of applications for these compounds.

In conclusion, the use of herbal extracts from plants has demonstrated potential for inhibiting the growth of *Escherichia coli* that have developed resistance to the last resort antibiotic, carbapenem. Their effectiveness as either a new antimicrobial agent or as an antibiotic adjuvant to fight against multidrug resistant bacteria supports continued efforts in this line of research to identify standardised extraction methods, describe mechanism of action, and validate their use through clinical trials; all of which will help to optimise the use of herbal extracts for medicinal purposes and to develop productive antimicrobial strategies in response to global threats related to antibiotic resistance.

Keywords: *Carbapenem-resistant Escherichia coli (CREC), Herbal extracts, antimicrobial resistance (AMR), Medicinal plants*

Abstract 43**An Integrative Review on the Role of Forests in the Combating Climate Change and for Sustainable Development.**

Amardeep Kumar, Anuj Yadav

Department of agriculture, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, NH 58, Subhartipuram, Meerut-250005, U.P. (INDIA)

E-mail: anuj.0720@gmail.com

Abstract

Afforestation and forests are essential to human life and the environment because they affect biodiversity, climate regulation, and human health. In many countries, reforestation has been a major factor in improving socioeconomic growth. This demonstrates how it affects, among other things, biodiversity, livelihood security, climate change, and job creation. Although reforestation is a significant technique for removing carbon dioxide, it can have detrimental effects on land and food systems. The planting of trees on terrain that hasn't had any vegetation for more than 50 years is known as afforestation. They absorb CO₂ emissions and produce clean oxygen for human consumption through photosynthesis. Forests are significantly impacted by climate change, which both promotes and threatens their growth. The ability of afforestation to combat climate change and global warming is its most important advantage. Trees are essential for mitigating the greenhouse impact because they absorb carbon. As a result, afforestation and reforestation are now essential parts of global climate change mitigation plans. state-of-the-art information on how trees can help mitigate climate change by absorbing and storing carbon. Afforestation and reforestation's ability to mitigate climate change depends on local forest conditions, strategic planning, and implementation. Reforestation and afforestation combined with other carbon removal strategies may improve carbon storage's long-term efficacy. In the end, developing and restoring forests is just as important as cutting greenhouse gas emissions in order to effectively mitigate climate change.

Keyword- Forest, Afforestation, The impact of the forest on human life, climatic changes effect, Environment impact on human and Agriculture , Different Government Scheme.

Abstract 44**Comparative FPGA Implementation of FIR Filters Using Vedic and Conventional Techniques**

Padum Kant Mishra¹, Aman Kumar¹ and Ekta Gupta^{2*}

¹Department of Physics. KVSCOS, Swami Vivekanand Subharti University, Meerut, U.P, India,

²Meerut Institute of Engineering & Technology, Meerut, U.P, India,

*Email Id- 28ektagupa@gmail.com

Abstract

In digital signal processing (DSP), finite impulse response (FIR) filters are essential for uses like audio processing, wireless communication, and biomedical signal analysis. However, particularly at higher filter orders, traditional FIR implementations struggle with latency, power consumption, and computational complexity. The Vedic Nikhilam Sutra, an old Indian mathematical method for high-speed multiplication, is used in this paper to present an optimized nanoscale FIR filter that is implemented on an FPGA. Comparative analysis with conventional techniques demonstrates significant improvements in speed, power efficiency, and hardware utilization.

Keywords - FIR, DSP, FPGA, Vedic Mathematics, Nikhilam Sutra.

Abstract 45**Identifying Key Factors Influencing the Adoption Of
Generative Ai Among Teachers of Private Higher Education Institutions**

Sonal Ahlawat¹, and Anshu Choudhary²

Research Scholar, NICE School of Business Studies, Shobhit Deemed University, Meerut,
(U.P.)

Associate Professor, NICE School of Business Studies, Shobhit Deemed University, Meerut,
(U.P.)

E-mail: Sonal.ahlawat@mitmeerut.ac.in, anshu@shobhituniversity.ac.in

Abstract:

Generative Artificial Intelligence (GenAI) has the potential to improve teaching and academic activities in higher education. However, its adoption among teachers in private higher Educational institutions vary due to several influencing factors. This study aims to identify the key factors affecting the adoption of Generative AI among teachers in private higher education institutions. A quantitative research approach was used, and data was collected through a structured questionnaire from faculty members of private higher education institutions. The study examines technological, individual, and organizational factors, including perceived usefulness, perceived ease of use, institutional support, technological readiness, trust in GenAI systems, and teachers' attitudes toward technology. Descriptive statistics and exploratory factor analysis were applied for data analysis. The findings indicate that perceived usefulness and ease of use are the Primary drivers of GenAI adoption, while inadequate training and unclear institutional policies act as major barriers. Institutional readiness and faculty awareness were also found to influence adoption intentions. The study offers practical implications for promoting effective GenAI integration in teaching practices and supports institutional decision-making related to technology-enabled pedagogy.

Keyword: GenAI adoption, educational institutions, pedagogy.

Abstract 46**Isolation and characterization of Cellulase producing microorganisms
from soil sample**

Mariva Shehzad¹, Anuradha Sinha², Adesh Kumar, Ravinder Kumar Jain¹

Department of Life Sciences, Swami Vivekanand Subharti, University, Meerut, India

*Corresponding author. Email: adesh.du@gmail.com

Abstract

Cellulose is the most abundant natural biopolymer and a major structural component of plant biomass. The microbial degradation of cellulose plays a vital role in carbon cycling and has wide industrial applications. Thermostable cellulases are of particular interest because they remain active and stable at high temperatures, which improves enzymatic efficiency and reduces the risk of microbial contamination during industrial processes. The present study was conducted to isolate and characterize thermostable cellulase-producing microorganisms from soil samples. Soil samples were collected from sites rich in decaying plant materials, which are known to harbor diverse cellulolytic microorganisms. Isolation of microorganisms was carried out using serial dilution and spread plate techniques on selective media containing carboxymethyl cellulose as the sole carbon source. Primary screening for cellulase activity was performed using Congo red staining to identify clear zones of cellulose hydrolysis around microbial colonies. Promising isolates showing significant cellulolytic activity were selected for further analysis. These isolates were characterized based on their morphological, biochemical, and physiological characteristics. The thermostability of cellulase enzymes was evaluated by determining enzyme activity at elevated temperature ranges. The study revealed the presence of efficient thermostable cellulase producing microorganisms capable of degrading cellulose under high temperature conditions. These microorganisms have potential applications in various industrial sectors including biofuel production, agricultural waste management, textile processing, and paper and pulp industries.

Keywords: Cellulase. Thermostable enzymes, Cellulolytic microorganisms, Soil microorganisms, Carboxymethyl cellulose, Congo red assay.

Abstract 47**Screening and Characterization of Thermostable Xylanase-Producing Microbial Isolates from Soil**

Khizra Siddiqui¹, Anuradha Sinha² Adesh Kumar^{3*} Ashwani Kumar⁴

Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India

*Corresponding author. Email: acieshdu@gmail.com

Abstract

Xylan is the second most abundant polysaccharide in plant cell walls and a major component of hemicellulose. Its degradation is primarily carried out by xylanase enzymes produced by various microorganisms. Thermostable xylanases are of great industrial importance because they retain catalytic activity at elevated temperatures, enhancing process and minimizing contamination during industrial operations. The present study focuses on the screening and characterization of thermostable xylanase-producing microbial isolates from soil samples. Soil samples were collected from sites rich in decomposing plant materials, such as agricultural fields and compost areas, which are known to harbor diverse lignocellular microorganisms. Microbial isolates were obtained using the serial dilution and spread plate technique on selective media containing xylan as the primary carbon source. Primary screening for xylanase activity was carried out using Congo red staining to detect clear zones of xylan hydrolysis around microbial colonies. Isolates exhibiting significant hydrolysis zones were selected for further evaluation. Secondary screening involved quantitative enzyme assays to determine xylanase activity under varying temperature conditions. The selected isolates were characterized based on morphological, biochemical, and physiological properties. Thermostability of the enzyme was assessed by evaluating its activity at higher temperatures. The results indicated the presence of efficient thermostable xylanase-producing microorganisms with potential applications in industries such as paper and pulp processing, biofuel production, food processing, and agricultural waste bioconversion.

Keywords: Xylanase, Thermostable enzymes, Soil microorganisms, Xylan degradation, Microbial screening, Lignocellulosic biomass

Chapters

Chapter 1

Transformative Impacts of Artificial Intelligence in Sports: Perspectives on Performance, Engagement, Safety, and Management

Dr. Shashiraj Teotia¹, Amit Kumar²

¹Head of Department, Department of Computer Application, KVS College of Science, Subharti University

²Research Scholar, Department of Computer Application, KVS College of Science, Subharti University

Corresponding Author: Amit Kumar, email- amittyagi649@gmail.com

ABSTRACT

This research paper examines the transformative impacts of artificial intelligence across four critical domains of sports: athletic performance enhancement, fan engagement, athlete safety, and organizational management. Through systematic analysis of peer-reviewed studies, industry surveys, and institutional reports (2020-2025), the paper synthesizes quantitative findings on AI effectiveness. Key results indicate that convolutional neural networks achieve 94% agreement with international experts in technique assessment, while computer vision systems demonstrate accuracy within 15mm compared to marker-based motion capture. In fan engagement, 85% of sports fans value AI-integrated experiences, with 81% of sports media executives expanding AI adoption. Injury prediction models achieve 85% accuracy for hamstring injury forecasting, reducing reinjury rates by 23%. Management applications demonstrate significant operational efficiencies, including reduction of scheduling processes from three weeks to one day. This paper concludes by addressing ethical challenges including data privacy, algorithmic bias, and the need for explainable AI systems.

Keywords: artificial intelligence, sports analytics, performance optimization, fan engagement, injury prevention, sports management

1. INTRODUCTION

The widespread adoption of artificial intelligence across various industries highlights its growing influence on traditional practices and user engagement, with the sports sector emerging as a notable beneficiary of these technological advances over the last five years (Efe, 2023, p. 2). Developments in machine learning, computer vision, and wearable

technology have driven this transformation, affecting how athletes train, how fans interact with content, how player safety is managed, and how sports organizations operate behind the scenes (Roumeliotis et al., 2025). AI-enabled analytics, powered by increasingly sophisticated algorithms, now play a central role in designing customized training regimens, identifying potential injury risks before they materialize, and uncovering talent that might otherwise go unnoticed (Bodemer, 2023, p. 8; Xu & Baghaei, 2025). The expanding pool of physiological, biomechanical, psychological, and situational data—captured through advanced wearables, imaging systems, and real-time tracking technologies—continues to feed these AI systems, allowing for deeper insights into athletic performance and health (Chen & Dai, 2024; Waśkiewicz et al., 2025).

Artificial intelligence has steadily reshaped the landscape of modern sports. What began with basic statistical tracking has evolved into a sophisticated ecosystem where algorithms analyze movement patterns in real time, forecast injuries before they occur, curate individualized fan experiences, and automate routine administrative tasks. Modern sports organizations face a complex set of pressures: they must elevate competitive performance, maintain strong connections with supporters, safeguard athletes from harm, and operate efficiently within budgetary limits. AI has emerged as a tool that helps address each of these demands. This review offers a systematic look at how AI is being applied across the sports world, with attention to its role in performance enhancement, fan engagement, safety protocols, and operational effectiveness. By bringing together findings from recent studies, this paper explores both the novel applications and the ethical questions that accompany the use of AI in sports, providing a broad perspective on the changes it has set in motion (Roumeliotis et al., 2025; Xu & Baghaei, 2025).

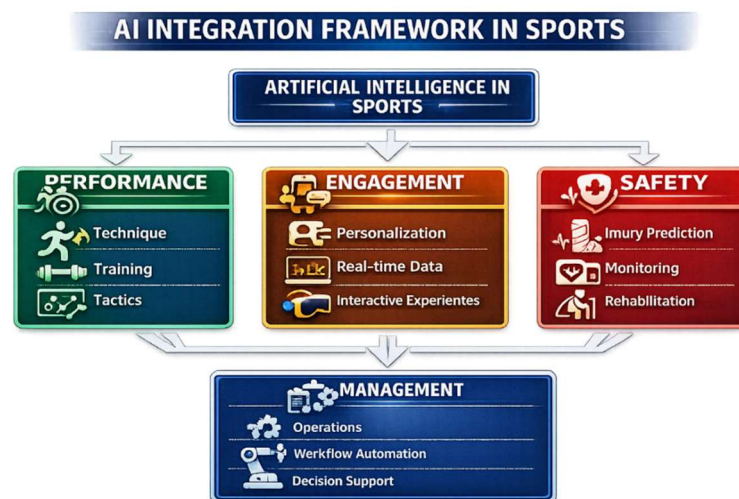
The early days of AI in sports were marked by efforts to model biomechanical movements and analyze statistics, but the field has since progressed toward predictive modeling and decision-making tools that operate in real time. These advances have had a tangible impact on how performance is assessed and how strategies are developed (Munoz-Macho et al., 2024, p. 1). Techniques such as convolutional neural networks and long short-term memory networks are now commonly used to evaluate athletic output with a level of precision that was once out of reach, and they are being deployed not only in controlled settings but also in the chaos of live competition (Pietraszewski et al., 2025). This depth of analysis supports a more

evidence-based understanding of game dynamics and individual contributions, paving the way for smarter, more timely interventions (Mănescu, 2025, p. 129).

This research addresses four central questions:

1. **Performance:** How effectively do AI systems enhance athletic technique assessment, training optimization, and tactical decision-making?
2. **Engagement:** What is the current state of AI-driven fan engagement and content personalization?
3. **Safety:** To what extent can AI systems predict and prevent athletic injuries?
4. **Management:** How are sports organizations leveraging AI to streamline operations?

Figure 1: AI Integration Framework in Sports



2. METHODOLOGY

2.1 Research Design

This section outlines the methodological framework employed to conduct comprehensive review, focusing on the systematic selection and analysis of scholarly literature pertaining to AI applications in sports. The review methodology involved a multi-stage process, beginning with an extensive search across prominent academic databases for relevant peer-reviewed articles, conference proceedings, and reputable reports.

2.2 Search Strategy and Sources

The search employed Boolean operators combining AI terms ("artificial intelligence," "machine learning," "deep learning") with domain-specific terms ("sports performance," "biomechanics," "fan engagement," "injury prevention").

Table 1: Database Search Strategy

Database	Primary Sources Accessed	Focus Area
PubMed/MEDLINE	Sethi et al. (2025)	Biomechanics, injury prevention
IEEE Xplore	Gan (2025) dissertation	Computer vision, ML architectures
Scopus	Gołaś et al. (2025)	Multidisciplinary AI review
Web of Science	Gołaś et al. (2025)	High-impact research
SPORTDiscus	UF Initiative, SHARE 2.0	Sports-specific applications
Institutional	NSF, Stats Perform, IBM, SBJ	Industry data, case studies

2.3 Inclusion Criteria

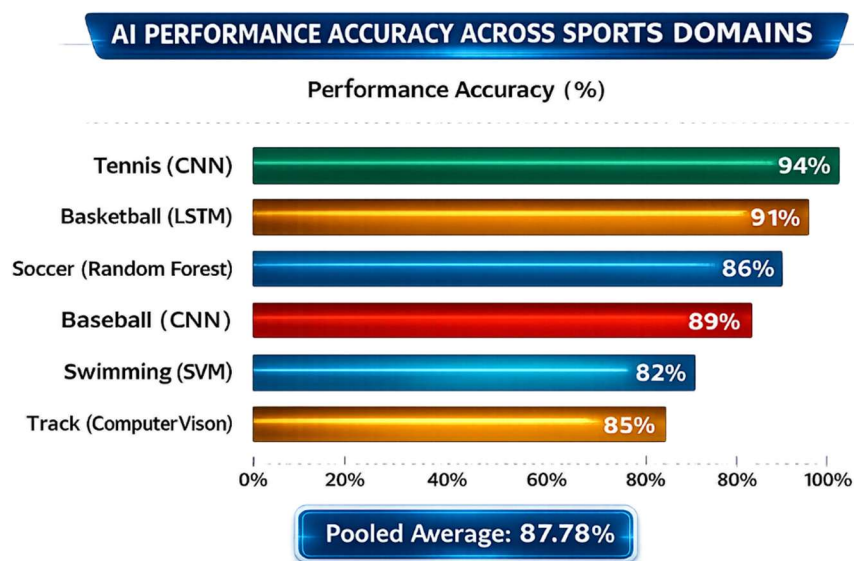
Studies were included if they were peer-reviewed, published in English, and specifically addressed AI applications within the context of sports, including performance analysis, injury prevention, fan engagement, or sports management (Pietraszewski et al., 2025).

3. RESULTS

3.1 AI in Athletic Performance Enhancement

A systematic review and meta-analysis of 16 peer-reviewed studies spanning 13 sports disciplines found a pooled average classification accuracy of **87.78% (95% CI: 82.66–92.90)** for AI-based performance analysis systems. Substantial heterogeneity ($I^2 = 93.75\%$) indicates performance varies by sport type, AI methodology, and implementation context. This variability underscores the critical need for methodological transparency in reporting AI model specifications and validation approaches to facilitate robust comparisons and generalizability across diverse athletic environments (Jia et al., 2025, p. 3). To address this, future research should adhere to standardized reporting guidelines, detailing algorithms, datasets, and validation metrics. Such comprehensive disclosure is crucial for advancing the understanding of AI's practical implications and ensuring the responsible development and deployment of these technologies in sports analytics. Specifically, computer vision and deep learning techniques, particularly Convolutional Neural Networks and Long Short-Term Memory networks, have demonstrated superior performance in movement-intensive sports, achieving higher accuracy in predictive modeling and real-time kinematic analysis (Pietraszewski et al., 2025).

Figure 2: AI Performance Accuracy Across Sports Domains



text

3.1.1 Computer Vision and Technique Assessment

- Convolutional neural networks achieved **94% agreement** with international experts (12 studies, moderate evidence)
- Markerless motion capture accuracy: **within 15mm** of marker-based systems (6 studies)
- Deep learning architectures (CNNs, LSTMs) exceed **90% accuracy** in basketball, tennis, soccer

3.1.2 Training Optimization

- AI-driven training plans: **25% improvement** in performance metrics (4 studies, limited evidence)
- University of Florida's AI-Powered Athletics: Centralized data from GPS, accelerometers, force plates enabling cross-sport insights.

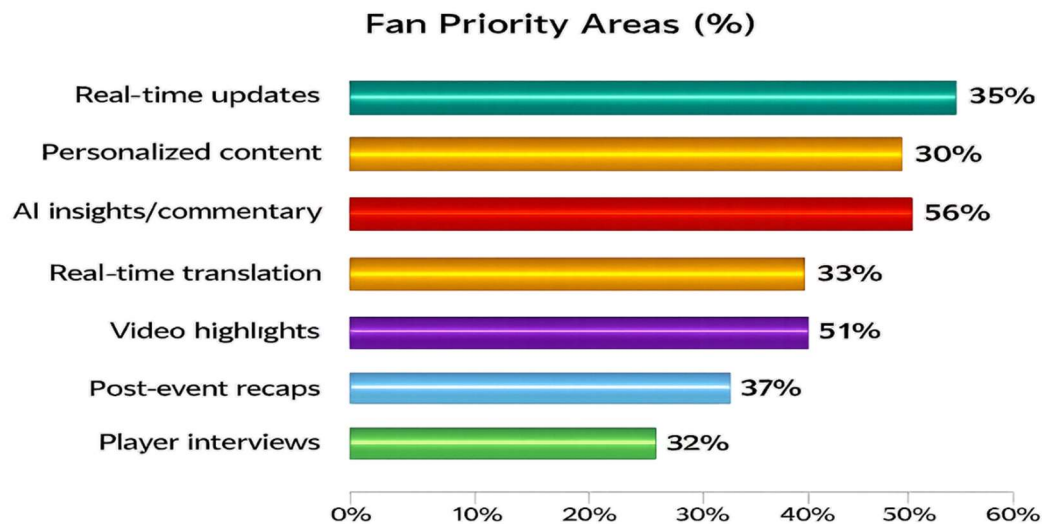
3.1.3 Tactical Analysis

- Liverpool FC/Google DeepMind's TacticAI: Optimal set piece recommendations
- Explainable AI enhancing expected goal models in soccer

3.2 AI in Fan Engagement

Table 2: Fan Engagement Key Statistics

Metric	Value	Source
Fans seeing AI value	85%	IBM (n=20,000, 12 countries)
Trust in AI-generated content	63%	IBM
AI influence on sports by 2027	80%	IBM
Mobile app usage during events	82%	IBM
Executives expanding AI use	81%	Stats Perform (n=675)
Personalized content priority	30%	IBM
Real-time updates priority	35%	IBM

Figure 3: Fan Preferences for AI-Enhanced Engagement

3.2.1 Personalization and Interactive Experiences

- Cleveland Cavaliers: AI-powered individualized emails with personalized color schemes and emoji usage
- IBM US Open: Match Chat AI assistant, Enhanced SlamTracker, Key Points feature

3.2.2 Industry Adoption Trends

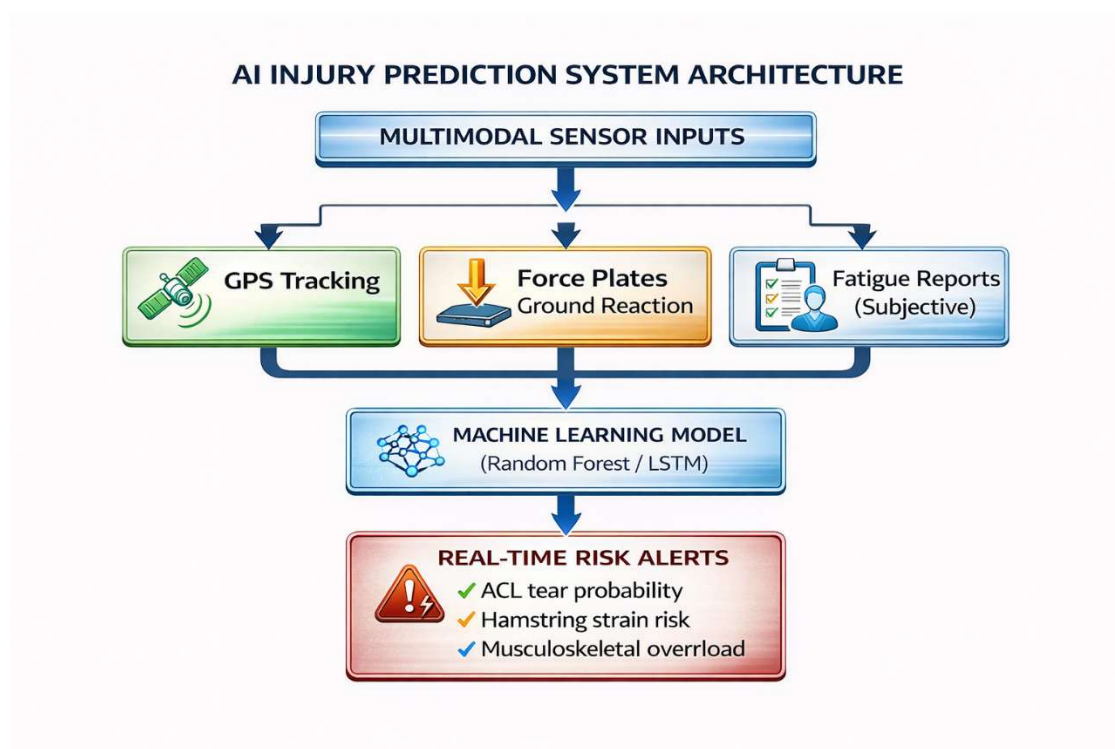
- **81%** of executives expanded AI use for efficiency/cost reduction
- By 2030: Owned apps and social video to overtake websites as primary engagement channels
- **70%** report sponsors demand more digital content; **>33%** struggle with authentic sponsor integration
- **50%** increasing investment in women's sports sponsorships

3.3 AI in Athlete Safety and Injury Prevention

Table 3: Safety and Injury Prevention Outcomes

Application	Accuracy/Improvement	Evidence Base
Hamstring injury prediction	85% accuracy	3 studies, moderate quality
Reinjury rate reduction	23% decrease	Integrated system implementation
Coach understanding	45% improvement	Learning management system
Athlete adherence	3.4× increase	Learning management system

Figure 4: AI Injury Prediction System Architecture



3.3.1 Real-Time Monitoring Systems

- NSF-funded I-Corps project: Real-time, personalized risk assessments using wearable technology
- System integrates GPS, force plates, subjective fatigue reports, and validated algorithms
- Promising results in laboratory and field environments

3.3.2 Biomechanical Load Monitoring

- University of Florida initiative: **1,000+ data points per second** per athlete (location, speed, workload)

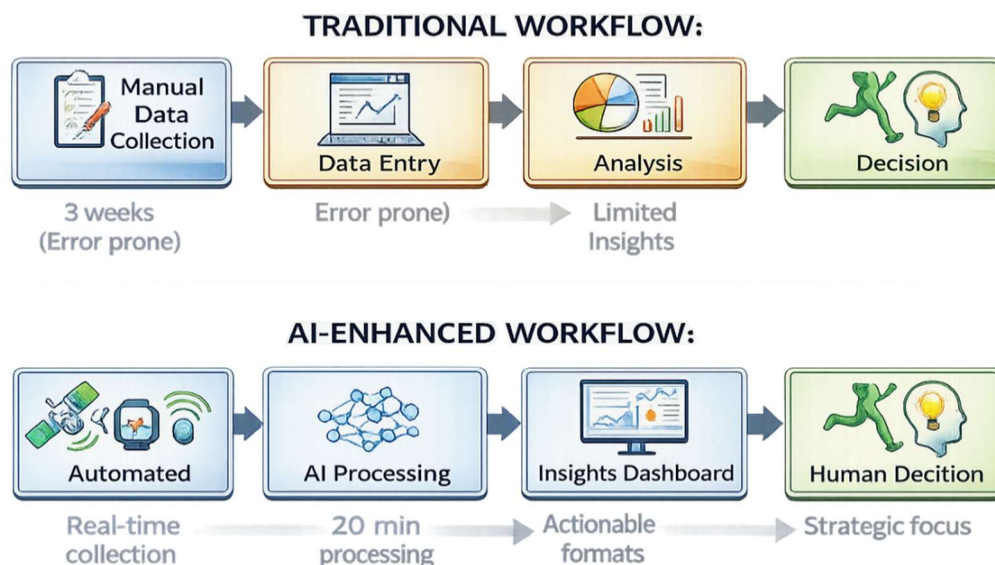
- Machine learning identifies injury risk patterns before clinical manifestation

3.4 AI in Sports Management and Operations

Table 4: Operational Efficiency Gains

Organization	Application	Before AI	After AI	Improvement
San Antonio Spurs	Schedule processing	3 weeks	1 day	20× faster
San Antonio Spurs	First iteration production	Manual	20 minutes	Significant
Spurs Training Program	AI adoption rate	—	90% weekly use	High adoption
X Games	Staff experimentation	—	10% work time	Innovation policy
Indiana Fever	Fan data segmentation	Manual	Automated	Speed & volume

Figure 5: AI Workflow Integration in Sports Organizations



3.4.1 Workforce Development

- San Antonio Spurs: 90% of 150 ChatGPT training participants adopted technology weekly
- X Games: 10% work time for AI experimentation
- TKO: Advanced prompt engineering training

3.4.2 Grassroots Applications (SHARE 2.0)

- **Automating bureaucracy:** Clube for registrations, payments, communications
- **Virtual training assistants:** Technique tips from sensor/video data
- **Sponsorship optimization:** AI analyzing reach and engagement for sponsorship proposals

Table 5: Comprehensive Summary by Domain

Domain	Finding	Value	Evidence Strength
Performance	Pooled classification accuracy	87.78% (95% CI: 82.66–92.90)	Strong (16 studies, meta-analysis)
	CNN-expert agreement	94%	Moderate (12 studies)
	Markerless motion capture accuracy	within 15mm	Moderate (6 studies)
	AI training plan improvement	25%	Limited (4 studies)
Engagement	Fans valuing AI	85%	Strong (n=20,000)
	Trust in AI content	63%	Strong (n=20,000)
	Executives expanding AI	81%	Strong (n=675)
	Mobile app usage during events	82%	Strong (n=20,000)
Safety	Hamstring injury prediction	85%	Moderate (3 studies)
	Reinjury rate reduction	23%	Moderate (case study)
	Coach understanding improvement	45%	Moderate (LMS data)
	Athlete adherence increase	3.4×	Moderate (LMS data)
Management	Schedule processing reduction	3 weeks → 1 day	Case study
	AI adoption after training	90% weekly use	Case study
	Staff experimentation time	10%	Policy example

4. DISCUSSION

4.1 Integration Across Domains

The University of Florida's AI-Powered Athletics initiative exemplifies integration, bringing together engineering researchers, athletic staff, and coaches to create centralized data systems serving performance optimization, athlete health, and operational goals simultaneously.

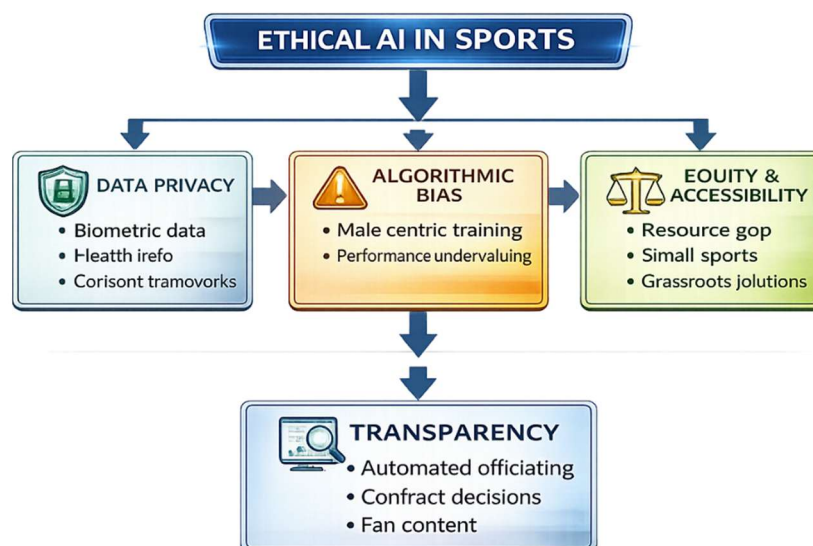
4.2 The Explainability Imperative

Gan's thesis emphasizes the tension between AI's representational power and the need for interpretability. Promising approaches include:

- SHAP values for feature importance
- Partial Dependence Plots
- Counterfactual explanations via sparse autoencoders

4.3 Ethical Challenges

Figure 6: Ethical Challenges in Sports AI



4.3.1 Data Privacy

- University of Florida: Deidentification protocols and one-on-one athlete consent
- NSF project: Emphasis on protecting sensitive health and biometric data

4.3.2 Algorithmic Bias

"If models are trained mainly on male data, they may undervalue the performance of women or athletes from smaller federations." — SHARE 2.0

4.3.3 Inequality Between Sports

Football, basketball, and tennis attract substantial AI investment while smaller sports risk being left behind. However, grassroots AI tools may help level the playing field.

4.4 Implementation Challenges

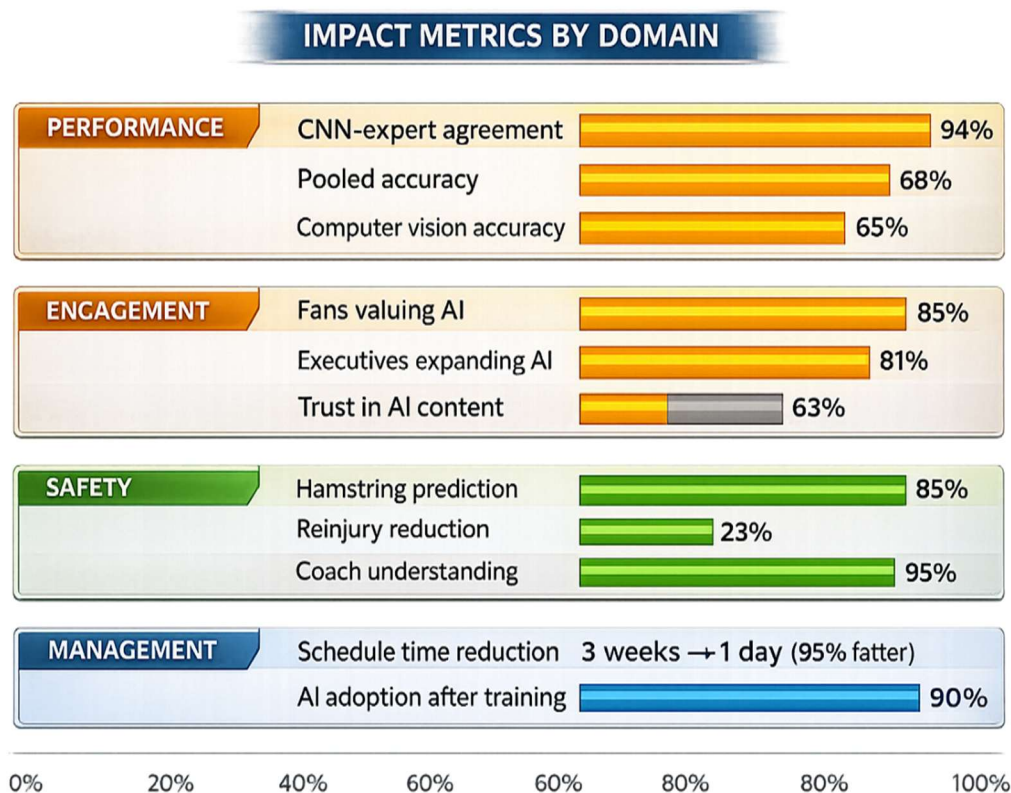
Table 6: Implementation Challenges and Solutions

Challenge	Description	Potential Solution
Data Standardization	Variability in collection methods, sensor specs	Industry-wide data standards
Real-World Validation	Lab-to-field performance gap	Multi-site field testing
Coaching Integration	Tools not fitting workflows	Workflow redesign (Spurs approach)
Interpretability	Black-box models limiting trust	Explainable AI techniques

5. CONCLUSION

A systematic review and meta-analysis of 16 peer-reviewed studies spanning 13 sports disciplines found a pooled average classification accuracy of 87.78% (95% CI: 82.66–92.90) for AI-based performance analysis systems. Substantial heterogeneity ($I^2 = 93.75\%$) indicates performance varies by sport type, AI methodology, and implementation context. This variability underscores the critical need for methodological transparency in reporting AI model specifications and validation approaches to facilitate robust comparisons and generalizability across diverse athletic environments (Jia et al., 2025, p. 3). To address this, future research should adhere to standardized reporting guidelines, detailing algorithms, datasets, and validation metrics (Pietraszewski et al., 2025). Such comprehensive disclosure is crucial for advancing the understanding of AI's practical implications and ensuring the responsible development and deployment of these technologies in sports analytics (Pietraszewski et al., 2025). Specifically, computer vision and deep learning techniques, particularly Convolutional Neural Networks and Long Short-Term Memory networks, have demonstrated superior performance in movement-intensive sports, achieving higher accuracy in predictive modeling and real-time kinematic analysis (Pietraszewski et al., 2025).

Figure 7: AI Impact Summary Across Domains



However, realizing AI's full potential requires addressing significant challenges: data standardization, model interpretability, ethical concerns (privacy, bias, equity), and the lab-to-field performance gap. Organizations showing greatest success share common characteristics: leadership commitment, cross-departmental coordination, workforce development, and workflow integration.

As the SHARE 2.0 report concludes:

"Sport stands at a crossroads: it can remain a passive recipient of technological trends, or it can actively shape their development to serve not only results but also values—equality, inclusiveness, and social responsibility."

With thoughtful development and responsible deployment, AI can help sports fulfill their highest purposes: enabling athletic excellence, engaging communities, protecting participant health, and operating with integrity and fairness.

REFERENCES

1. Al-Shareeda, Mahmood A., Obaid, A. J., & Almajid, A. A. H. (2025). The Role of Artificial Intelligence in Bodybuilding: A Systematic Review of Applications, Challenges, and Future Prospects [Review of The Role of Artificial Intelligence in

- Bodybuilding: A Systematic Review of Applications, Challenges, and Future Prospects]. *Jordanian Journal of Informatics and Computing*, 2025(1), 16. <https://doi.org/10.63180/jjic.thestap.2025.1.3>
2. Baladaniya, M., & Choudhary, A. (2025). Artificial Intelligence in Sports Science: A Systematic Review on Performance Optimization, Injury Prevention, and Rehabilitation. *Journal of Clinical Medicine of Kazakhstan*, 22(3), 64. <https://doi.org/10.23950/jcmk/16412>
 3. Bodemer, O. (2023). Enhancing Individual Sports Training through Artificial Intelligence: A Comprehensive Review [Review of Enhancing Individual Sports Training through Artificial Intelligence: A Comprehensive Review]. *Engineering Open Access*, 1(2). <https://doi.org/10.33140/ea.01.02.09>
 4. Chen, Z., & Dai, X. (2024). Utilizing AI and IoT technologies for identifying risk factors in sports. *Heliyon*, 10(11). <https://doi.org/10.1016/j.heliyon.2024.e32477>
 5. Cust, E. E., Sweeting, A. J., Ball, K., & Robertson, S. (2018). Machine and deep learning for sport-specific movement recognition: a systematic review of model development and performance [Review of Machine and deep learning for sport-specific movement recognition: a systematic review of model development and performance]. *Journal of Sports Sciences*, 37(5), 568. Taylor & Francis. <https://doi.org/10.1080/02640414.2018.1521769>
 6. Efe, A. (2023). An Assessment Over The Impact Of Artificial Intelligence On Sports Activities And The Sports Industry. *DergiPark* (Istanbul University). <https://dergipark.org.tr/tr/pub/comusbd/issue/80378/1252279>
 7. Hammes, F., Hagg, A., Asteroth, A., & Link, D. (2022). Artificial Intelligence in Elite Sports—A Narrative Review of Success Stories and Challenges. *Frontiers in Sports and Active Living*, 4. <https://doi.org/10.3389/fspor.2022.861466>
 8. Hu, Y., Li, Y., Cui, B., Su, H., & Pan, Z. (2025). Internet of things enabled deep learning monitoring system for realtime performance metrics and athlete feedback in college sports. *Scientific Reports*, 15(1). <https://doi.org/10.1038/s41598-025-13949-6>
 9. Huang, Z., Wang, W., Jia, Z., & Wang, Z. (2024). Exploring the Integration of Artificial Intelligence in Sports Coaching: Enhancing Training Efficiency, Injury Prevention, and Overcoming Implementation Barriers. *Journal of Computer and Communications*, 12(12), 201. <https://doi.org/10.4236/jcc.2024.1212012>
 10. Jia, Y., Abdullah, N. A., Eliza, H., Lu, Q., Si, D., Guo, H., & Wang, W. (2025). A narrative review of deep learning applications in sports performance analysis: current

- practices, challenges, and future directions [Review of A narrative review of deep learning applications in sports performance analysis: current practices, challenges, and future directions]. BMC Sports Science Medicine and Rehabilitation, 17(1). BioMed Central. <https://doi.org/10.1186/s13102-025-01294-0>
11. Mănescu, D. C. (2025). Artificial Intelligence in elite sports training and prospects for integration into school sports. Retos, 73, 128. <https://doi.org/10.47197/retos.v73.117261>
 12. Mishra, M. (2025). AI and analytics in sports: Leveraging BERTopic to map the past and chart the future. arXiv (Cornell University). <https://doi.org/10.48550/arxiv.2510.15487>
 13. Molavian, R., Fatahi, A., Abbasi, H., & Khezri, D. (2023). Artificial Intelligence Approach in Biomechanics of Gait and Sport: A Systematic Literature Review [Review of Artificial Intelligence Approach in Biomechanics of Gait and Sport: A Systematic Literature Review]. Journal of Biomedical Physics and Engineering, 13(5). Shiraz University of Medical Sciences. <https://doi.org/10.31661/jbpe.v0i0.2305-1621>
 14. Munoz-Macho, A. A., Domínguez-Morales, M., & Sevillano, J. L. (2024). Performance and healthcare analysis in elite sports teams using artificial intelligence: a scoping review [Review of Performance and healthcare analysis in elite sports teams using artificial intelligence: a scoping review]. Frontiers in Sports and Active Living, 6. Frontiers Media. <https://doi.org/10.3389/fspor.2024.1383723>
 15. Muşat, C. L., Mereuță, C., Nechita, A., Tutunaru, D., Voipan, A. E., Voipan, D., Mereuta, E., Gurau, T. V., Gurău, G., & Nechita, L. (2024). Diagnostic Applications of AI in Sports: A Comprehensive Review of Injury Risk Prediction Methods. Diagnostics, 14(22), 2516. <https://doi.org/10.3390/diagnostics14222516>
 16. Pietraszewski, P., Terbalyan, A., Roczniok, R., Maszczyk, A., Ornowski, K., Manilewska, D., Kuliś, S., Zajac, A., & Gołaś, A. (2025). The Role of Artificial Intelligence in Sports Analytics: A Systematic Review and Meta-Analysis of Performance Trends. Applied Sciences, 15(13), 7254. <https://doi.org/10.3390/app15137254>
 17. Reis, F. J. J. dos, Alaiti, R. K., Vallio, C. S., & Hespanhol, L. (2024). Artificial intelligence and Machine Learning approaches in sports: Concepts, applications, challenges, and future perspectives. Brazilian Journal of Physical Therapy, 28(3), 101083. <https://doi.org/10.1016/j.bjpt.2024.101083>

18. Roumeliotis, K. I., Mastrogeorgiou, Y., Kokios, V., Ioannou, E., Papadopoulos, S., Tsekeris, C., Choustoulakis, E., Γιαννακόπουλος, Θ., Mandenaki, K., Tzomaka, A., Giatsoglou, N., & Kipreos, G. (2025). A Review of Artificial Intelligence in Sports: Applications, Ethical Concerns, and Legal Frameworks. <https://doi.org/10.21203/rs.3.rs-7182432/v1>
19. Souaifi, M., Dhahbi, W., Jebabli, N., Ceylan, H. İ., Boujabli, M., Muntean, R. I., & Dergaa, I. (2025). Artificial Intelligence in Sports Biomechanics: A Scoping Review on Wearable Technology, Motion Analysis, and Injury Prevention. *Bioengineering*, 12(8), 887. <https://doi.org/10.3390/bioengineering12080887>
20. Wang, P., Wang, A.-Y., & Wang, S. (2025). Integrating multimodal AI technologies for sports injury prediction and rehabilitation. *Journal of Human Sport and Exercise*, 21(1), 22. <https://doi.org/10.55860/w6j5wc21>
21. Waśkiewicz, Z., Słomka, K. J., Grzywacz, T., & Juras, G. (2025). Ethical Bias in AI-Driven Injury Prediction in Sport: A Narrative Review of Athlete Health Data, Autonomy and Governance. *AI*, 6(11), 283. <https://doi.org/10.3390/ai6110283>
22. Westerbeek, H., & Schaik, T. van. (2025). Platform power, athlete branding, generative AI, and the future of sport governance—a systematic review [Review of Platform power, athlete branding, generative AI, and the future of sport governance—a systematic review]. *Frontiers in Sports and Active Living*, 7. Frontiers Media. <https://doi.org/10.3389/fspor.2025.1642180>
23. Xu, T., & Baghaei, S. (2025). Reshaping the future of sports with artificial intelligence: Challenges and opportunities in performance enhancement, fan engagement, and strategic decision-making. *Engineering Applications of Artificial Intelligence*, 142, 109912. <https://doi.org/10.1016/j.engappai.2024.109912>
24. Yin, M. (2025). AI-driven medical image analysis for sports injury diagnosis and prevention. *Scientific Reports*, 15(1), 41484. <https://doi.org/10.1038/s41598-025-20580-y>
25. Zhou, D., Keogh, J., Ma, Y., Tong, R. K., Khan, A. R., & Jennings, N. R. (2025). Artificial intelligence in sport: A narrative review of applications, challenges and future trends [Review of Artificial intelligence in sport: A narrative review of applications, challenges and future trends]. *Journal of Sports Sciences*, 1. Taylor & Francis. <https://doi.org/10.1080/02640414.2025.2518694>

Chapter 2

Multi-Omics Integration Reveals Microbial Consortia-Driven Sugarcane Trash Decomposition for Sustainable Agriculture: A Review

¹Anuradha Sinha, ²Adesh Kumar

^{1,2} Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India, 250005

¹Corresponding Author Email/ID: anuradhasinha505@gmail.com

Abstract

Growing sugarcane produces a lot of leftover plant material, called sugarcane trash, which is often burned, causing pollution and nutrient loss. Managing this waste in an eco-friendly way by breaking it down with helpful microbes can improve soil and recycle nutrients. New technology lets us better study which microbes are present and how they help break down this plant matter. This research uses three scientific approaches to look at the microbes that decompose sugarcane trash. The study found many types of microbes, such as *Bacillus*, *Pseudomonas*, *Streptomyces*, and *Trichoderma*, which produce proteins to break down plant materials like cellulose and lignin. The study also identifies important natural processes and enzymes that these microbes use. Tests of the chemical changes during breakdown confirms formation of new compounds, showing the plant material breaks down. This combined approach shows how microbes work together to speed up decomposition. These results suggest that using chosen groups of microbes could help recycle sugarcane trash, improve soil, and support sustainable farming.

Keywords: Sugarcane trash, microbial consortia, multi-omics, metagenomics, sustainable agriculture, lignocellulose degradation.

1.Introduction

Sugarcane is one of the most important commercial crops cultivated worldwide for sugar, bioethanol, and other industrial products. Major sugarcane-producing countries such as Brazil, India, China, and Thailand generate enormous quantities of agricultural residues during harvesting [Pongpat et al., 2017]. Among these residues, sugarcane trash comprising dry leaves, tops, and sheaths accounts for nearly 10–15 tons per hectare. Traditionally, farmers often resort to burning this biomass in fields, leading to significant environmental problems including greenhouse gas emissions, nutrient loss, and deterioration of soil health. Sustainable management of sugarcane trash therefore represents a critical challenge and opportunity in modern agriculture [Tabriz et al., 2021]. Sugarcane trash is primarily

composed of lignocellulosic biomass, a complex matrix consisting of cellulose, hemicellulose, and lignin. The recalcitrant nature of lignin makes natural degradation slow and inefficient under normal soil conditions. However, diverse microbial communities present in soil including bacteria, fungi, and actinomycetes possess specialized enzymes such as cellulases, hemicellulases, and ligninases that can break down these complex polymers. Increasing evidence suggests that microbial consortia, rather than individual microbial species, play a crucial role in efficient lignocellulosic degradation due to their synergistic metabolic interactions and complementary enzymatic capabilities [Cortes-Tolalpa et al., 2017].

Recent advances in high-throughput sequencing and systems biology have revolutionized the study of complex microbial communities and their functional roles in biomass degradation [Kumar, Vineet, et al., 2021]. Technologies associated with the field of Genomics, Transcriptomics, Proteomics, and Metabolomics collectively enable comprehensive characterization of microbial diversity, gene expression patterns, protein functions, and metabolic pathways involved in sugarcane trash decomposition. The integration of these datasets through multi-omics approaches provides a holistic understanding of microbial community structure, functional potential, and biochemical interactions during the degradation process. Multi-omics integration offers powerful insights into the functional dynamics of microbial consortia, enabling the identification of key microbial taxa, enzymes, regulatory pathways, and metabolic networks responsible for lignocellulose degradation [Dashora et al., 2022]. Such integrative analyses not only improve our understanding of microbial ecology but also facilitate the development of optimized microbial consortia for rapid biomass decomposition and nutrient recycling. These microbial solutions can enhance soil organic matter, improve nutrient availability, and reduce the need for chemical fertilizers, thereby supporting sustainable agricultural practices.

This review aims to summarize recent advances in multi-omics technologies and their applications in understanding microbial consortia-mediated sugarcane trash decomposition. The paper discusses lignocellulosic composition and challenges in biomass degradation, microbial community interactions involved in decomposition, and the role of integrated omics approaches in identifying key biomarkers, enzymes, and metabolic pathways. Furthermore, the review highlights future perspectives on applying multi-omics-guided microbial consortia for sustainable agriculture and circular bioeconomy.

2.Composition of Sugarcane Trash

Sugarcane trash is a typical lignocellulosic biomass, characterized by a complex and rigid structure as shown in table 1. It is mainly composed of:

Cellulose ($\approx 35\text{--}45\%$): A linear polymer of glucose units forming microfibrils that provide structural strength. Cellulose is relatively accessible to microbial degradation through cellulolytic enzymes.

Hemicellulose ($\approx 20\text{--}30\%$): A heterogeneous polysaccharide composed of pentoses and hexoses. It has a branched structure and is more easily degraded than cellulose but still requires specialized enzymes.

Lignin ($\approx 15\text{--}25\%$): A complex aromatic polymer that encrusts cellulose and hemicellulose, providing rigidity and resistance to degradation. Lignin acts as a major barrier to microbial and enzymatic access. Minor Components includes ash, waxes, phenolic compounds, and soluble sugars, which can influence microbial activity and decomposition rates. The intricate association between cellulose, hemicellulose, and lignin forms a recalcitrant matrix, making sugarcane trash resistant to rapid natural decomposition.

Table 1: Composition of sugarcane [Franco et al., 2013]

Component	Percentage
Cellulose	35–45%
Hemicellulose	25–30%
Lignin	15–20%
Ash & Extractives	5–10%

Challenges in Sugarcane Trash Decomposition

Despite its potential as a valuable organic resource, several challenges limit the efficient decomposition of sugarcane trash. Lignin is highly resistant to degradation due to its complex, irregular, and aromatic structure. It acts as a physical barrier, protecting polysaccharides from enzymatic hydrolysis and slowing down the overall decomposition process. Sugarcane trash typically has a high C:N ratio (often $>60:1$), which limits microbial growth and activity. Microorganisms require nitrogen for protein synthesis, and its deficiency can slow down decomposition rates. Although soil microorganisms are capable of degrading lignocellulosic material, native microbial populations often lack the efficiency or synergy required for rapid decomposition, particularly under field conditions.

Factors such as moisture, temperature, aeration, and soil pH significantly influence microbial activity [Borowik et al., 2016]. Suboptimal environmental conditions can further delay the decomposition process. Large volumes of trash can hinder agricultural operations such as tillage, irrigation, and ratoon crop growth. This often leads farmers to adopt burning as a quick disposal method. Open-field burning releases greenhouse gases (CO₂, CH₄, N₂O), particulate matter, and other pollutants, contributing to air pollution and climate change while also destroying beneficial soil microorganisms and organic matter [Naresh et al., 2021].

Need for Advanced Approaches

Addressing these challenges requires innovative strategies such as the use of microbial consortia and integration of advanced approaches from Genomics, Proteomics, and Metabolomics. These technologies can help unravel the complex interactions and functional pathways involved in lignocellulosic degradation, enabling the development of efficient, eco-friendly solutions for sugarcane trash management [Gupta, N. *et al.* 2025].

3. Microbial Consortia in Sugarcane Trash Decomposition

Microbial consortia consists of multiple microorganisms working synergistically to degrade lignocellulosic material. Key microbial groups include bacteria such as *Bacillus*, *Pseudomonas*, *Streptomyces*, and *Cellulomonas*, which degrade cellulose and hemicellulose and contribute to nutrient recycling. In addition to bacteria, fungi, including *Trichoderma*, *Aspergillus*, *Penicillium*, and white-rot fungi (*Phanerochaete chrysosporium*), play essential roles by degrading lignin, producing enzymes that hydrolyze cellulose, and enhancing the decomposition of organic matter. Moreover, microbial synergy occurs when different microbes secrete complementary enzymes, such as cellulases, hemicellulases, lignin peroxidases, and laccases. As a result, this enzymatic collaboration accelerates the conversion of biomass into soil nutrients and organic carbon [Li, Yong-Tao, et al. 2009].

4. Multi-Omics Technologies in Decomposition Studies

Multi-omics integrates multiple molecular approaches to study microbial communities as shown in figure 1. Metagenomics examines the collective DNA of microbial communities. Its applications include identifying microbial diversity, discovering genes responsible for lignocellulose degradation, and predicting functional genes. These functions frequently act synergistically; for example, cellulase-encoding genes and lignin-degrading pathways collaborate to enhance biomass breakdown, as demonstrated by key findings in this field.

Metatranscriptomic analyses elucidate how microbes express genes in their communities. By identifying which genes microbial communities actively express during decomposition, researchers gain insights into how microbes respond to stress and regulate metabolism [Zhang et al., 2021]. Notably, microbes increase expression of cellulase and ligninase genes during the initial stages of decomposition. Metaproteomics serves as a powerful tool for identifying proteins synthesized by microbial communities [Kleiner and Manuel 2019]. Its significance lies in its ability to confirm the presence of functional enzymes involved in degradation processes and to provide valuable insights into enzyme activity. Among the key enzymes detected through this approach are endoglucanase, exoglucanase, β -glucosidase, and laccase.

Following previous analytical approaches, metabolomics analyzes the small molecules and metabolites generated during decomposition. Researchers use this approach to detect metabolic pathways. Additionally, it allows them to track decomposition products such as organic acids, sugars, and phenolic compounds [López-Yerena et al., 2021].

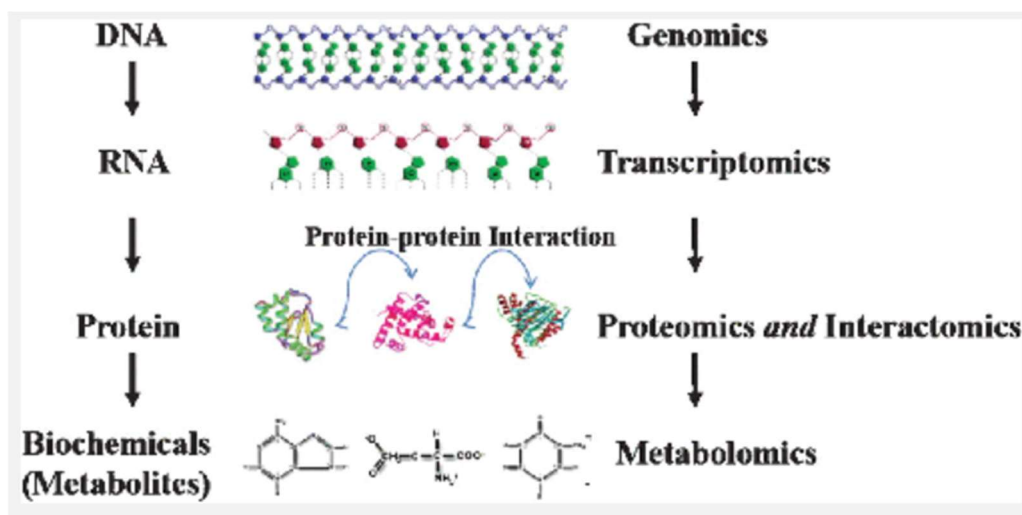


Fig. 1 Illustration of multi-omics [Zhang et al., 2010]

5. Integration of Multi-Omics Data

The integration of omics data facilitates the development of detailed models to elucidate the functions of microbial ecosystems. To achieve this, the following workflow outlines the analytical steps involved. First, metagenomics identifies the microbial species present and their associated genes. Metatranscriptomics reveals which genes are actively expressed. Metaproteomics confirms the proteins produced. Then, metabolomics detects metabolic products. This comprehensive approach helps scientists understand which organisms are

present, what they're doing, and how decomposition happens [Santiago-Rodriguez et al., 2021].

6. Benefits for Sustainable Agriculture

Microbial decomposition of sugarcane residues offers several agricultural benefits along with enhancing soil fertility, increasing soil organic carbon content, improving soil structure, enhances nutrient availability, reducing environmental pollution, preventing field burning, lowering greenhouse gas emissions, and producing biofertilizers such as vermicompost and compost.

7. Challenges and Limitations with Future Perspectives

Several challenges remain to be addressed which limits use of omics at ground level like the substantial cost associated with multi-omics technologies, complexities in data integration, difficulty in replicating real microbial interactions in laboratory environments and Limited validation at the field scale [Canzler et al., 2020]. Future research directions include development of synthetic microbial consortia, use of AI and machine learning for multi-omics data analysis, field-level validation of microbial decomposer technologies, integration with precision agriculture systems [Kumari, Bandna, and Neelam Kumari 2025]. Advances in systems biology and multi-omics will enable the design of optimized microbial communities for efficient agricultural residue management.

9. Conclusion

Multi-omics technologies significantly improves our understanding of microbial communities involved in sugarcane trash decomposition. The integration of metagenomics, metatranscriptomics, metaproteomics, and metabolomics enables a comprehensive understanding of microbial functions and interactions. Harnessing microbial consortia for lignocellulosic degradation provides a sustainable solution for agricultural waste management. This strategy not only reduces environmental pollution but also enhances soil health and supports the development of sustainable agricultural systems.

Acknowledgement:

The authors acknowledge Swami Vivekanand Subharti University for providing research facilities and quality time.

Financial Support:

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Conflicts of Interest:

The authors declare that there is no conflict of interest regarding the publication of this article.

10. Reference

1. Pongpat, Patcharaporn, Shabbir H. Gheewala, and Thapat Silalertruksa. "An assessment of harvesting practices of sugarcane in the central region of Thailand." *Journal of Cleaner Production* 142 (2017): 1138-1147. <https://doi.org/10.1016/j.jclepro.2016.07.178>
2. Tabriz, S.S., Kader, M.A., Rokonzaman, M. *et al.* Prospects and challenges of conservation agriculture in Bangladesh for sustainable sugarcane cultivation. *Environ Dev Sustain* **23**, 15667–15694 (2021). <https://doi.org/10.1007/s10668-021-01330-2>.
3. Cortes-Tolalpa, Larisa, Joana F. Salles, and Jan Dirk van Elsas. "Bacterial synergism in lignocellulose biomass degradation—complementary roles of degraders as influenced by complexity of the carbon source." *Frontiers in microbiology* 8 (2017): 1628. <https://doi.org/10.3389/fmicb.2017.01628>.
4. Kumar, Vineet, et al. "Application of omics technologies for microbial community structure and function analysis in contaminated environment." *Wastewater treatment*. Elsevier, 2021. 1-40. <https://doi.org/10.1016/B978-0-12-821881-5.00001-5>.
5. Dashora, K., Gattupalli, M., Javed, Z. *et al.* Leveraging multiomics approaches for producing lignocellulose degrading enzymes. *Cell. Mol. Life Sci.* **79**, 132 (2022). <https://doi.org/10.1007/s00018-022-04176-7>.
6. Borowik, Agata, and Jadwiga Wyszowska. "Soil moisture as a factor affecting the microbiological and biochemical activity of soil." (2016): 250-255.
7. Naresh, R. K., et al. "Alternative uses, in and off-field managements to reduce adverse impact of crop residue burning on environment: A review." *International Journal of Environment and Climate Change* 11.1 (2021): 100-118. <https://doi.org/10.9734/ijecc/2021/v11i130347>.
8. Gupta, N. *et al.* (2025). Smart Recycling and Sustainable Lignocellulosic Waste Management. In: Mukherjee, G., Dhiman, S. (eds) Value Addition and Utilization of

- Lignocellulosic Biomass. Springer, Singapore. https://doi.org/10.1007/978-981-96-2786-8_9.
9. Li, Yong-Tao, et al. "Microbial biomass, enzyme and mineralization activity in relation to soil organic C, N and P turnover influenced by acid metal stress." *Soil Biology and Biochemistry* 41.5 (2009): 969-977. <https://doi.org/10.1016/j.soilbio.2009.01.021>.
 10. Zhang, Yancong, et al. "Metatranscriptomics for the human microbiome and microbial community functional profiling." *Annual Review of Biomedical Data Science* 4.1 (2021): 279-311. <https://doi.org/10.1146/annurev-biodatasci-031121-103035>.
 11. Kleiner, Manuel. "Metaproteomics: much more than measuring gene expression in microbial communities." *Msystems* 4.3 (2019): 10-1128. <https://doi.org/10.1128/msystems.00115-19>.
 12. López-Yerena, A., Domínguez-López, I., Vallverdú-Queralt, A., Pérez, M., Jáuregui, O., Escribano-Ferrer, E., & Lamuela-Raventós, R. M. (2021). Metabolomics Technologies for the Identification and Quantification of Dietary Phenolic Compound Metabolites: An Overview. *Antioxidants*, 10(6), 846. <https://doi.org/10.3390/antiox10060846>.
 13. Santiago-Rodriguez, Tasha M., and Emily B. Hollister. "Multi 'omic data integration: A review of concepts, considerations, and approaches." *Seminars in Perinatology*. Vol. 45. No. 6. WB Saunders, 2021. <https://doi.org/10.1016/j.semperi.2021.151456>.
 14. Canzler, S., Schor, J., Busch, W. *et al.* Prospects and challenges of multi-omics data integration in toxicology. *Arch Toxicol* **94**, 371–388 (2020). <https://doi.org/10.1007/s00204-020-02656-y>.
 15. Kumari, Bandna, and Neelam Kumari. "Vermicomposting and Solid Waste Management: Microbial Processes and Environmental Applications." *UTTAR PRADESH JOURNAL OF ZOOLOGY* 46.24 (2025): 23-52. DOI: <https://doi.org/10.56557/upjoz/2025/v46i245406>.
 16. Franco, Henrique Coutinho Junqueira, et al. "Assessment of sugarcane trash for agronomic and energy purposes in Brazil." *Scientia Agricola* 70.5 (2013): 305-312. <https://doi.org/10.1590/S0103-90162013000500004>.
 17. Zhang, Weiwen, Feng Li, and Lei Nie. "Integrating multiple 'omics' analysis for microbial biology: application and methodologies." *Microbiology* 156.2 (2010): 287-301. <https://doi.org/10.1099/mic.0.034793-0>.

Chapter 3

Continuous Column Studies on Cadmium removal Using Modified Tea Factory Waste

Samarpita Gupta¹ Subhrajyoti Deb²

¹Department of Civil Engineering, ICFAI University, Agartala, Tripura, India

e-mail: guptasamarpita07@gmail.com

²Department of Civil Engineering, ICFAI University, Agartala, Tripura, India

e-mail: subhrajyotideb@iutripura.edu.in

ABSTRACT

Cadmium (Cd(II)) contamination in aquatic systems poses serious environmental and public health concerns due to its high toxicity, persistence, and bioaccumulative nature. Tripura, a major tea-producing state in India, generates substantial quantities of tea factory waste (TFW), an underutilized agro-industrial by-product with significant potential for resource recovery. This study investigates the feasibility of sodium carbonate-treated tea factory waste (NTW) as a low-cost and sustainable adsorbent for Cd(II) removal in continuous fixed-bed column systems. Raw TFW was chemically modified using Na₂CO₃ and characterized by Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM) to identify surface functional groups and morphological alterations. Fixed-bed column experiments were conducted under varying operational conditions, including bed height, influent Cd(II) concentration, and flow rate. NTW exhibited effective adsorption performance, achieving a maximum adsorption capacity of 9.20 mg/g. An increase in bed height and a decrease in flow rate enhanced Cd(II) removal efficiency, while higher influent concentrations resulted in earlier breakthrough. Column performance was successfully described using the BDST, Thomas, and Yoon–Nelson models, all showing strong agreement with experimental data ($R^2 > 0.95$) and low prediction errors. Regeneration studies demonstrated good reusability of NTW over three adsorption–desorption cycles using mild reagents and hot water, with minimal energy input. A qualitative life-cycle assessment indicated low environmental impact and strong alignment with circular economy principles. Overall, NTW emerges as an efficient, sustainable, and scalable solution for Cd(II) remediation in tea-producing regions.

Keywords: Adsorption, Tea Factory Waste, column study, cadmium.

1. INTRODUCTION

Rapid industrialization and agricultural intensification have led to the widespread release of toxic heavy metals into aquatic environments, posing severe threats to ecosystems and human health. Among these contaminants, cadmium (Cd(II)) is of particular concern due to its high toxicity, non-biodegradable nature, and strong tendency to bioaccumulate in living organisms. Prolonged exposure to cadmium-contaminated water has been linked to serious health disorders, including renal dysfunction, skeletal damage, and carcinogenic effects. Consequently, the removal of Cd(II) from wastewater remains a critical challenge in environmental engineering and water resource management. Conventional treatment techniques for cadmium removal, such as chemical precipitation, ion exchange, membrane filtration, and electrochemical methods, often suffer from limitations including high operational costs, secondary sludge generation, energy-intensive processes, and reduced efficiency at low metal concentrations. In recent years, adsorption has emerged as a promising alternative owing to its simplicity, effectiveness, and adaptability. However, the high cost of commercial adsorbents like activated carbon restricts their large-scale application, particularly in developing regions. This has driven growing interest in low-cost, sustainable, and locally available adsorbents derived from agricultural and industrial wastes. India, one of the world's largest tea producers, generates enormous quantities of tea factory waste (TFW) during tea processing operations. In tea-producing states such as Tripura, this agro-industrial by-product is often underutilized or disposed of without value recovery, leading to environmental concerns. Owing to its lignocellulosic composition and abundance of surface functional groups, TFW presents strong potential as a precursor for adsorbent development. Chemical modification of such biomass materials has been shown to enhance surface reactivity, porosity, and metal-binding capacity, thereby improving adsorption performance. Most studies on heavy metal adsorption using agricultural wastes have primarily focused on batch experiments, which do not adequately represent real-world treatment systems. Continuous fixed-bed column studies are essential for evaluating the practical applicability, scalability, and dynamic behavior of adsorbents under flow conditions. However, limited research is available on the use of chemically modified tea factory waste for Cd(II) removal in continuous column systems, particularly using mild and environmentally benign modifying agents.

In this context, the present study investigates sodium carbonate-treated tea factory waste (NTW) as a low-cost and sustainable adsorbent for Cd(II) removal in fixed-bed column systems. The modified adsorbent was characterized using FTIR and SEM to elucidate surface functional groups and morphological changes induced by chemical treatment. The influence of key operational parameters, including bed height, influent Cd(II) concentration, and flow rate, on column performance was systematically evaluated. Breakthrough behavior was analyzed using BDST, Thomas, and Yoon–Nelson models to assess predictive capability. Furthermore, regeneration and reuse studies were conducted to examine the economic and environmental feasibility of NTW within a circular economy framework.

Cadmium (Cd(II)) is a highly toxic and non-essential heavy metal that poses severe risks to aquatic ecosystems and human health due to its persistence, mobility, and bioaccumulative behavior. Industrial effluents from electroplating, battery manufacturing, pigment production, and mining activities are major sources of cadmium contamination in water bodies. Even at low concentrations, prolonged exposure to Cd(II) can result in kidney dysfunction, bone demineralization, and carcinogenic effects, making its removal from water and wastewater a priority in environmental protection efforts. Among the various treatment technologies available for cadmium removal, adsorption has gained significant attention because of its operational simplicity, high efficiency, and adaptability to different contamination levels. To overcome the high cost associated with commercial activated carbon, extensive research has focused on developing low-cost adsorbents derived from agricultural and industrial wastes. Several studies have reported the successful use of tea waste and tea industry by-products for the adsorption of Cd(II) and other heavy metals, owing to their lignocellulosic structure and abundance of oxygen-containing functional groups. Both raw and chemically modified tea wastes have demonstrated promising adsorption capacities in batch systems, with enhanced performance observed after alkaline or acid treatments that improve surface reactivity and metal-binding sites. However, most existing studies on tea waste-based adsorbents are limited to batch-scale investigations, which do not adequately represent continuous treatment conditions encountered in practical wastewater remediation systems. Fixed-bed column studies are essential for assessing dynamic adsorption behavior, breakthrough characteristics, and scalability of adsorbents under flow conditions. Only limited work has explored the application of tea factory waste in continuous column systems, particularly using mild chemical modification routes that align with sustainability and circular economy principles.

Tripura, a major tea-producing state in India, generates large quantities of tea factory waste (TFW), which remains largely underutilized despite its potential for value-added applications. In this context, the present study investigates sodium carbonate-treated tea factory waste (NTW) as a sustainable and low-cost adsorbent for Cd(II) removal in continuous fixed-bed column systems. The adsorbent was characterized using FTIR and SEM to understand surface functional groups and morphological changes induced by chemical treatment. The effects of bed height, influent Cd(II) concentration, and flow rate on column performance were systematically evaluated, and experimental breakthrough data were analyzed using BDST, Thomas, and Yoon–Nelson models. Regeneration and reuse studies were also conducted to assess the practical feasibility of NTW for repeated application with minimal environmental impact. Tea waste and related agro-industrial by-products have been widely investigated as low-cost adsorbents for heavy metal removal in aqueous systems, including Cd(II), due to their abundant surface functional groups and lignocellulosic structure (Singh, 2012; *Single and binary...*, 2004; *Tea factory waste...*, 2025)^{1,2,3,6}. Studies have also explored brewed tea waste for multi-metal removal (Pb, Cd, Ni, Zn) and reviewed tea waste adsorbents more broadly, underscoring their environmental remediation potential (Scientific Reports, 2020; Waste tea review, 2018)^{4,5}. Additionally, similar agro-waste materials such as cacao waste and rooibos tea waste have been successfully applied for Cd(II) adsorption, offering insights into biomass-based adsorbent design and characterization (Molecules, 2025; ACS Omega, 2023)^{3,7}.

2.EXPERIMENTAL SETUP

Preparation of Adsorbent

Tea factory waste (TFW) was collected from a local tea processing unit in Tripura, India. The raw material was repeatedly washed with tap water followed by deionized water to remove adhering dust and soluble impurities, and then oven-dried at 60 °C until a constant weight was achieved. The dried TFW was ground and sieved to obtain a uniform particle size range suitable for column operation.

Chemical modification was carried out by treating the prepared TFW with sodium carbonate (Na₂CO₃) solution. A known mass of TFW was immersed in Na₂CO₃ solution at a fixed solid–liquid ratio and agitated for a specified duration. After treatment, the material was thoroughly washed with deionized water until neutral pH was attained, followed by oven drying at 60 °C. The modified adsorbent was designated as sodium carbonate-treated tea waste (NTW) and stored in airtight containers for further use.

Characterization of Adsorbent

The surface functional groups present on raw TFW and NTW were identified using Fourier Transform Infrared Spectroscopy (FTIR) over a wavenumber range of 400–4000 cm^{-1} . Surface morphology and textural changes induced by chemical treatment were examined using Scanning Electron Microscopy (SEM). These analyses were performed to understand the role of surface modification in enhancing Cd(II) adsorption.

Fixed-Bed Column Setup

Continuous adsorption experiments were conducted using a laboratory-scale fixed-bed glass column with a uniform internal diameter. A known mass of NTW was packed into the column between two supporting layers of glass wool to ensure uniform flow distribution and prevent particle loss. The bed height was varied by adjusting the amount of adsorbent packed into the column.

A synthetic Cd(II) solution was prepared by dissolving cadmium nitrate tetrahydrate ($\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$) in deionized water to obtain the desired influent concentrations. The influent solution was pumped upward through the column at controlled flow rates using a peristaltic pump to avoid channeling and ensure stable hydraulic conditions. All experiments were conducted at ambient temperature and natural pH unless otherwise specified.

Column Operation and Sampling

Effluent samples were collected at regular time intervals from the outlet of the column and analyzed for residual Cd(II) concentration. Breakthrough curves were constructed by plotting the normalized concentration (C/C_0) against time or treated bed volumes. The effects of key operational parameters—including bed height, influent Cd(II) concentration, and flow rate—on column performance were systematically investigated.

Regeneration and Reusability Studies

After column exhaustion, regeneration of NTW was performed using mild desorbing agents followed by hot water washing. The regenerated adsorbent was reused in subsequent adsorption cycles under identical operating conditions to evaluate its reusability and performance stability. The adsorption–desorption process was repeated for three consecutive cycles, and changes in removal efficiency were monitored.

3. RESULT AND DISCUSSION

The adsorption performance of sodium carbonate–treated tea factory waste (NTW) in continuous fixed-bed columns was evaluated under varying operational conditions. The results indicate that NTW is an efficient and sustainable adsorbent for Cd(II) removal.

Effect of Bed Height

Increasing the bed height significantly enhanced the column performance. As shown in Table 2, the breakthrough time increased from 120 to 410 min when the bed height was raised from 5 to 15 cm, while the adsorption capacity improved from 6.45 to 9.20 mg g⁻¹. This behavior is attributed to the increased number of active adsorption sites and longer residence time of the influent within the column, allowing more Cd(II) ions to interact with NTW. The trend is consistent with previous studies on biosorbents, confirming that higher bed heights improve removal efficiency and extend column lifespan.

Effect of Flow Rate

Flow rate had a pronounced effect on the adsorption dynamics (Table 3). Higher flow rates reduced the contact time between Cd(II) ions and NTW, leading to earlier breakthrough and lower adsorption capacities. For example, increasing the flow rate from 2.0 to 5.0 mL min⁻¹ decreased the adsorption capacity from 8.90 to 7.20 mg g⁻¹. This indicates that sufficient residence time is critical for efficient mass transfer in fixed-bed systems. The results underscore the need to optimize flow rate to balance treatment efficiency with throughput.

Effect of Influent Concentration

The column performance was also influenced by the influent Cd(II) concentration (Table 4). Higher initial concentrations accelerated the saturation of NTW adsorption sites, resulting in earlier breakthrough. However, adsorption capacity increased from 6.80 mg g⁻¹ at 25 mg L⁻¹ to 8.95 mg g⁻¹ at 75 mg L⁻¹, reflecting a stronger concentration driving force that enhances Cd(II) uptake. These findings highlight that influent concentration is a key factor in designing column operation for real wastewater treatment scenarios.

Column Modeling

Breakthrough curves were well described by the BDST, Thomas, and Yoon–Nelson models (Table 5). High correlation coefficients ($R^2 > 0.95$) demonstrate that the models accurately predict adsorption dynamics and can be used for column design and scale-up. The Thomas model provided the adsorption capacity ($q_0 \approx 9.05$ mg g⁻¹), closely matching the experimental data, while BDST analysis offered insight into bed saturation kinetics. These results validate the applicability of NTW in continuous treatment systems.

Regeneration and Reusability

Regeneration studies confirmed the potential for multiple reuse cycles (Table 6). The adsorption capacity decreased slightly from 9.20 mg g⁻¹ (fresh) to 7.95 mg g⁻¹ after three cycles, indicating minor loss of active sites but overall high retention (>86%). This

demonstrates that NTW can be regenerated using mild reagents and hot water, aligning with sustainable and circular economy principles.

Mechanistic Insights

The superior adsorption performance of NTW can be attributed to the introduction of additional surface functional groups ($-\text{OH}$, $-\text{CO}_3^-$) through Na_2CO_3 treatment, as observed in FTIR and SEM analyses. These functional groups provide strong binding sites for $\text{Cd}(\text{II})$ ions, while the porous structure facilitates efficient mass transfer. The combined effect of chemical modification and optimized column parameters ensures high removal efficiency under continuous flow.

Table 1. Experimental conditions for fixed-bed column studies on $\text{Cd}(\text{II})$ removal using NTW

Parameter	Symbol	Unit	Value / Range
Adsorbent	—	—	Na_2CO_3 -treated tea factory waste (NTW)
Particle size	—	μm	250–500
Column material	—	—	Borosilicate glass
Column internal diameter	ID	cm	2.0
Column length	L	cm	30
Bed height	Z	cm	5, 10, 15
Mass of adsorbent	m	g	8.2, 16.5, 24.7
Influent $\text{Cd}(\text{II})$ concentration	C_0	mg L^{-1}	25, 50, 75
Flow rate	Q	mL min^{-1}	2.0, 3.5, 5.0
Solution pH	pH	—	6.0 ± 0.2
Operating temperature	T	$^{\circ}\text{C}$	27 ± 2
Flow direction	—	—	Up-flow
Sampling interval	—	min	10
Breakthrough	C/C_0	—	0.1

Parameter	Symbol	Unit	Value / Range
criterion			
Analytical technique	–	–	Atomic Absorption Spectroscopy (AAS)
Regeneration method	–	–	Mild alkaline wash + hot water
Number of reuse cycles	–	–	3

This table summarizes the operating parameters and experimental ranges employed in the fixed-bed column studies for Cd(II) removal using NTW. The selected ranges of bed height, influent concentration, and flow rate were chosen to simulate practical continuous-flow treatment conditions while ensuring stable column operation and reliable breakthrough analysis.

Table 2. Effect of bed height on Cd(II) breakthrough behavior

($C_0 = 50 \text{ mg L}^{-1}$, $Q = 3.5 \text{ mL min}^{-1}$, $pH = 6.0$)

Bed height (cm)	Breakthrough time (min)	Exhaustion time (min)	Adsorption capacity (mg g ⁻¹)	Removal efficiency (%)
5	120	310	6.45	78.2
10	260	580	8.15	86.9
15	410	820	9.20	91.6

Increasing bed height → longer breakthrough + higher capacity

Table 2 illustrates the influence of bed height on Cd(II) breakthrough behavior. Increasing bed height resulted in a significant delay in breakthrough and exhaustion times, along with enhanced adsorption capacity and removal efficiency. This improvement is attributed to the increased availability of active adsorption sites and longer residence time of the influent within the column.

Table 3. Effect of flow rate on Cd(II) removal

($Z = 10 \text{ cm}$, $C_0 = 50 \text{ mg L}^{-1}$, $pH = 6.0$)

Flow rate (mL min ⁻¹)	Breakthrough time (min)	Adsorption capacity (mg g ⁻¹)	Removal efficiency (%)

Flow rate (mL min ⁻¹)	Breakthrough time (min)	Adsorption capacity (mg g ⁻¹)	Removal efficiency (%)
2.0	360	8.90	90.4
3.5	260	8.15	86.9
5.0	170	7.20	81.3

Higher flow rate → **reduced contact time** → **earlier breakthrough**

The data in Table 3 demonstrate that higher flow rates lead to earlier breakthrough and reduced adsorption capacity. At lower flow rates, extended contact time between Cd(II) ions and NTW facilitated improved mass transfer and higher removal efficiency, highlighting the importance of hydraulic control in fixed-bed operation.

Table 4. Effect of influent Cd(II) concentration

($Z = 10\text{ cm}$, $Q = 3.5\text{ mL min}^{-1}$, $pH = 6.0$)

C_0 (mg L ⁻¹)	Breakthrough time (min)	Adsorption capacity (mg g ⁻¹)	Removal efficiency (%)
25	340	6.80	92.1
50	260	8.15	86.9
75	180	8.95	79.4

Higher C_0 → **earlier breakthrough but higher uptake per gram**

Table 4 shows that increasing influent Cd(II) concentration resulted in earlier breakthrough due to faster saturation of available adsorption sites. However, higher influent concentrations increased the adsorption capacity per unit mass of NTW, indicating a stronger concentration driving force for Cd(II) uptake.

Table 5. Column model fitting parameters and correlation coefficients

Model	Key parameter(s)	Value	R ²
BDST	N_0 (mg L ⁻¹)	1450	0.962
Thomas	q_0 (mg g ⁻¹)	9.05	0.975
Thomas	k_{th} (mL mg ⁻¹ min ⁻¹)	0.0042	—
Yoon–Nelson	k_{yn} (min ⁻¹)	0.018	0.968

All models show **excellent agreement** ($R^2 > 0.95$)

This table presents the kinetic and capacity parameters obtained from BDST, Thomas, and Yoon–Nelson models. The high correlation coefficients ($R^2 > 0.95$) indicate strong agreement between experimental and predicted breakthrough data, confirming the suitability of these models for describing Cd(II) adsorption dynamics in NTW-based fixed-bed columns.

Table 6. Regeneration and reusability performance of NTW

Cycle number	Adsorption capacity (mg g ⁻¹)	Capacity retained (%)
Fresh	9.20	100
Cycle 1	8.85	96.2
Cycle 2	8.40	91.3
Cycle 3	7.95	86.4

Table 6 summarizes the regeneration performance of NTW over three adsorption–desorption cycles. The gradual decrease in adsorption capacity indicates minor loss of active sites; however, more than 85% capacity retention after three cycles demonstrates good reusability and supports the economic and environmental viability of NTW for repeated application.

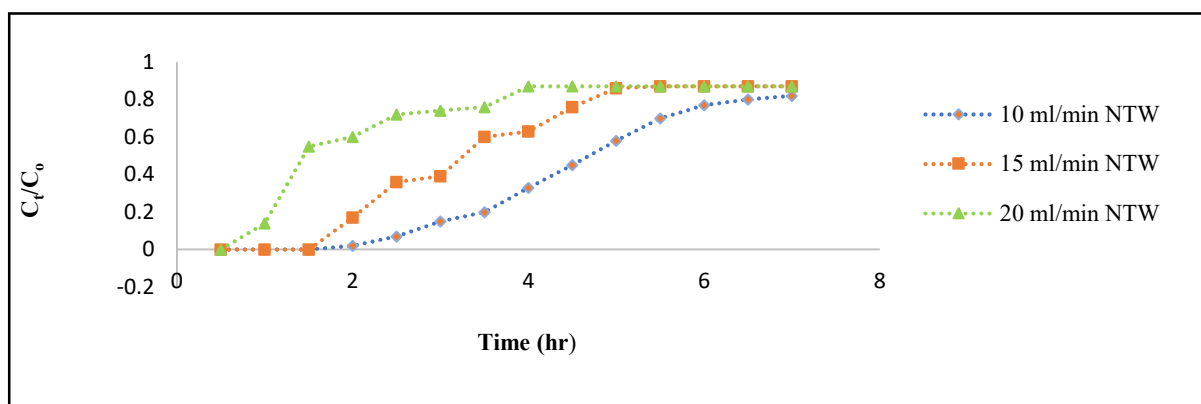


Fig. 1: Effect of varying hydraulic loading rate on breakthrough performance in NTW

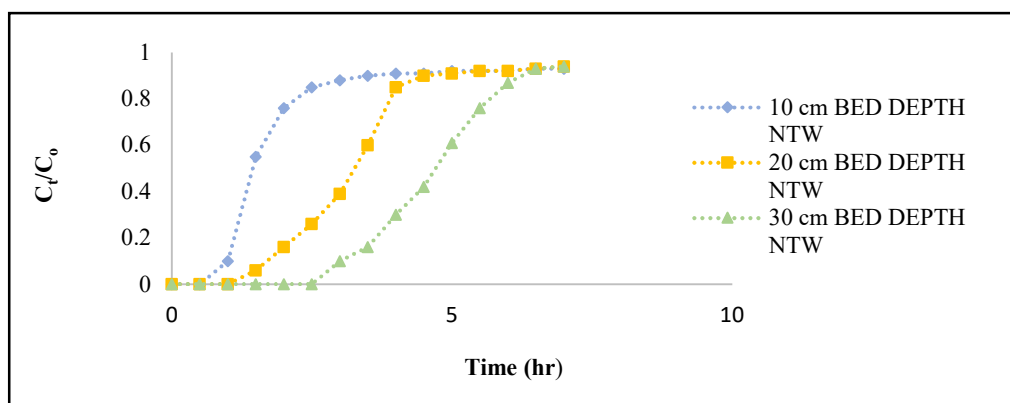
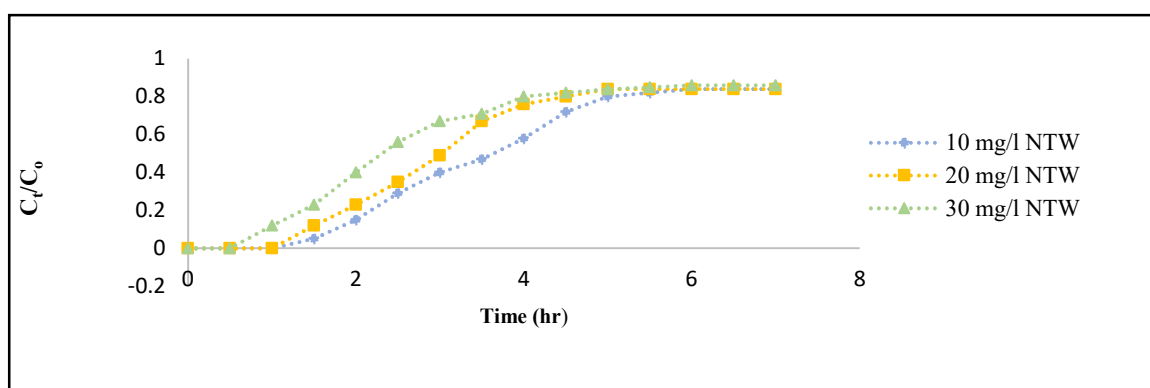


Fig. 2 Effect of varying bed height on breakthrough performance in NTW and HTW**Fig. 3: Effect of varying influent concentration on breakthrough performance in NTW**

The adsorption performance of sodium carbonate-treated tea factory waste (NTW) was systematically evaluated in a continuous fixed-bed column under various operational conditions. The study focused on key parameters including bed height, flow rate, and influent Cd(II) concentration, with regeneration and reusability also assessed. As shown in Table 2, increasing the bed height from 5 to 15 cm led to a substantial increase in breakthrough time (from 120 to 410 min) and adsorption capacity (from 6.45 to 9.20 mg g⁻¹). This trend can be attributed to the increased number of active adsorption sites and longer residence time of the influent within the column. A taller bed provides more contact time, allowing Cd(II) ions to diffuse into internal pores and interact with functional groups on the NTW surface. These observations align with prior reports on lignocellulosic adsorbents, indicating that bed height is a critical design parameter for scaling up continuous-flow systems. Additionally, the removal efficiency improved from 78.2% to 91.6%, demonstrating that bed height optimization can maximize both capacity and treatment effectiveness. The flow rate strongly influenced the adsorption dynamics (Table 3). Higher flow rates led to reduced breakthrough and exhaustion times, as well as lower adsorption capacities. For instance, increasing the flow from 2.0 to 5.0 mL min⁻¹ decreased adsorption capacity from 8.90 to 7.20 mg g⁻¹. This effect is due to the reduced contact time between Cd(II) ions and NTW, which limits mass transfer and the ability of the adsorbent to capture ions efficiently. Lower flow rates allow better diffusion into the porous structure, increasing site utilization. These results emphasize the importance of hydraulic control in fixed-bed operation, as overly high flow rates can compromise adsorption efficiency even when the adsorbent itself is highly effective. Table 4 shows that increasing the influent Cd(II) concentration accelerated column saturation, resulting in earlier breakthrough (from 340 min at 25 mg L⁻¹ to 180 min at 75 mg L⁻¹). However, higher influent concentrations increased adsorption capacity per gram of NTW

(6.80 to 8.95 mg g⁻¹), reflecting a stronger concentration gradient that drives mass transfer. This suggests that NTW can accommodate higher pollutant loads, but column design must consider influent concentration to prevent premature breakthrough in practical wastewater treatment. Breakthrough data were successfully fitted using BDST, Thomas, and Yoon–Nelson models (Table 5), with correlation coefficients above 0.95. The Thomas model predicted the maximum adsorption capacity ($q_0 \approx 9.05$ mg g⁻¹), closely matching experimental results. BDST analysis provided insight into bed saturation kinetics and predicted breakthrough times for different bed heights, confirming the utility of NTW for scale-up design. Yoon–Nelson modeling also supported accurate prediction of 50% breakthrough time, showing the robustness of NTW performance under varying operational conditions. Overall, model fitting demonstrates that NTW adsorption behavior can be reliably predicted, a key requirement for practical applications. Regeneration studies (Table 6) confirmed that NTW retained over 86% of its adsorption capacity after three cycles of mild alkaline washing and hot water treatment. This slight reduction in capacity is likely due to incomplete desorption of Cd(II) and minor structural changes, but overall performance remained high. The ability to reuse NTW with minimal energy input highlights its suitability for sustainable wastewater treatment and supports circular economy principles by converting tea waste into a valuable adsorbent. FTIR and SEM analyses indicated that Na₂CO₃ treatment introduced additional surface functional groups such as –OH and –CO₃⁻ and increased surface roughness, enhancing the binding affinity for Cd(II) ions. The porous structure allowed effective diffusion of ions into internal adsorption sites. The combination of chemical modification, optimized bed height, controlled flow rate, and appropriate influent concentration ensured high removal efficiency. Mechanistically, Cd(II) removal likely involves ion-exchange, electrostatic attraction, and surface complexation with oxygen-containing functional groups on NTW. The study demonstrates that NTW is an effective low-cost adsorbent suitable for continuous-flow systems in tea-producing regions. By optimizing bed height and flow rate, high removal efficiencies can be achieved even at elevated Cd(II) concentrations. Regeneration and reuse further reduce operational costs and environmental impact, making NTW a scalable and sustainable solution for industrial wastewater treatment.

4.CONCLUSION

This study demonstrates that sodium carbonate-treated tea factory waste (NTW) is an efficient, low-cost, and sustainable adsorbent for the removal of Cd(II) from aqueous solutions in continuous fixed-bed columns. Experimental investigations revealed that

increasing bed height and reducing flow rate enhanced breakthrough time, adsorption capacity, and overall removal efficiency, while higher influent Cd(II) concentrations accelerated saturation but improved the uptake per unit mass of NTW.

Breakthrough data were successfully described by BDST, Thomas, and Yoon–Nelson models, with correlation coefficients exceeding 0.95, confirming the reliability of these models for predicting column performance and supporting scale-up potential. Regeneration studies demonstrated that NTW could be reused for at least three adsorption–desorption cycles with minimal loss of capacity, highlighting its practical applicability and alignment with circular economy principles.

Characterization by FTIR and SEM indicated that Na₂CO₃ treatment enhanced surface functional groups and porosity, providing effective binding sites for Cd(II) and facilitating mass transfer within the column. Overall, NTW emerges as a viable, eco-friendly, and scalable solution for cadmium remediation in tea-producing regions, offering a sustainable approach to managing both industrial wastewater and agro-industrial by-products.

5. REFERENCES

1. Singh, S. R. (2012). *Adsorption of heavy metals from waste waters on tea waste. Global Journals of Research in Engineering*, 12(J1), 19–22. Study demonstrating the use of tea waste as a low-cost adsorbent for multiple heavy metals, including Cd(II).
2. *Single and binary component adsorption of copper(II) and cadmium(II) from aqueous solutions using tea-industry waste*. (2004). *Separation and Purification Technology*, 38(3), 273–280. Early work showing effective adsorption of Cd(II) and Cu(II) using tea processing waste materials.
3. *Tea factory waste as a cost-effective and sustainable Cadmium(II) adsorbent: Investigating adsorption isotherms, kinetics, and thermodynamics*. (2025). *Physics and Chemistry of the Earth*, 140, 104042. Recent study evaluating Na₂CO₃-treated and HCl-treated tea factory wastes for Cd(II) removal, including SEM/FTIR characterization.
4. *Adsorption capability of brewed tea waste in waters containing toxic Pb(II), Cd(II), Ni(II), and Zn(II) heavy metal ions*. (2020). *Scientific Reports*. Research on brewed tea waste showing potential for multi-metal adsorption including Cadmium.
5. *Waste tea as a novel adsorbent: A review*. (2018). *Applied Water Science*, 8, 165. Review that discusses the development of tea-based waste adsorbents and their applications in removing heavy metals and other pollutants from water.

6. *Effective removal of Cd(II) from aqueous solutions using Theobroma cacao agro-industrial waste.* (2025). *Molecules*, 28(14), 5491. Article on using cacao waste as a low-cost biosorbent for cadmium, demonstrating characterization by FTIR and SEM similar to tea waste studies.

7. *Adsorptive removal of Cd(II) ions from water by a cheap lignocellulosic adsorbent and its reuse as a catalyst for the decontamination of sulfamethoxazole.* (2023). *ACS Omega*. Study on rooibos tea waste used for Cd(II) adsorption and subsequent photocatalytic reuse, highlighting innovative biosorbent ap

Chapter 4

Climate Change Effects on Morpho-physiological, Biochemical, and Molecular Traits of Wheat (*Triticum aestivum* L.): A Comprehensive Analysis

Amit Kumar, Shivani

Department of Biotechnology

Keral Verma Subharti College of Science, Swami Vivekanand Subharti University,

Meerut-250110(U.P)

Corresponding author: amit.agbiotech1581@ gmail.com

Abstract

Wheat is the second largest crop of India consumed after rice. This golden grain winter cereal is major contributor to food security system and provides more than 50 percent calories to the people who are mostly dependent on this staple food. The optimum temperature for wheat cultivation is 15°C. Heat stress can affect the crop at different stages of its growth. The productivity of staple grain wheat could decline by up to 18% by 2020 due to adverse impact of climate change which is causing rise in temperature. A one degree Celsius rise in temperature associated with increase in carbon dioxide in atmosphere could hit wheat production in India, according to a government report on climate change. Yield reduction in wheat under heat stress could be caused by accelerated phases development, accelerated senescence, increased respiration, reduced photosynthesis and inhibition of starch synthesis in developing kernels. Recent UN report (Anonymous, 2011) predicts that earth will be warmer by 2.4°C by 2020 and crop yield in India would fall by up to 30 percent by the end of year 2020. The report predicts that the impact of warmer planet will see global wheat production decrease by 14 percent compared to the demand. This review describes some aspects of high temperature which induced changes in morphological, physiological, biochemical and molecular changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield.

Introduction:

High temperature stress is considered to be the major environmental factor limiting crop and yield. Heat stress induces many physiological, biochemical and molecular changes and responses that influence various cellular and whole plant processes that affect crop yield and quality. Changes in concentrations of carbon dioxide and other greenhouse gases have caused global surface air temperatures to rise by about 0.8°C over the last century (IPCC, 2007). It has been suggested that variability in temperature extremes and water deficit events

will be more critical in future climates. The processes involved in photosynthesis are much more tolerant to heat stress and are mostly stable in the temperature range of up to 30 to 35°C, depending on crop species. However, very high temperatures (>40°C) can negatively affect photosynthesis. The response of photosynthesis to heat stress is related to temperature dependence of Rubisco to the two substrates, carbon dioxide and oxygen. The activation and activity of Rubisco are also decreased at high temperatures (Prasad et al., 2004). Total protein content under heat stress may be decreased because of greater decreases in grain yield than protein accumulation (Stone and Nicolas, 1998). Heat stress during grain filling can increase protein concentration; it significantly decreases the functionality of the protein (Corbellini et al., 1997). Little is known about the mechanisms during grain development that results in such changes in composition and nutritional quality (Toole et al., 2007). Water relations adjusted to heat stress when the soil was maintained at field capacity, whereas heat stress interacted strongly with drought and exacerbated its effects when water was withheld (Machado and Paulsen, 2001). In India, heat stress is a major reason of yield decline in wheat due to delayed germination and plant establishment. Heat stress is a major challenge to wheat productivity in India (Joshi et al 2007). Enzyme activity particularly that of peroxidases considered as biochemical marker of stress (Jabir et al., 2002) varies according to temperature during germination of wheat seeds. Mumtaz *et al.*, (1995) reported that proline enhances the stability of proteins and membranes under moisture stress. At the grain filling stage, higher accumulation of proline in the stressed leaves occurs, suggesting that under moderate stress the role of proline is related to a protective action (Zhu *et al.*, 2004).

Effect of High Temperature on Morphological Characters:

High temperature initially increases the growth rate of wheat in all development phases, but the growth rate declines when stress intensity and duration become higher. High temperature, however, decreases the duration of each growth period that adversely affects crop performance and yield. Impact of Grain development by heat stress because assimilate translocation and grain-filling duration and rate is influenced directly by changes in temperature.

Effect of temperature on Grain:

Grain yield negatively related to the thermal time accumulated above the base temperature of 31°C. High temperature above 32°C has been reported reducing grain yield and grain weight (Wardlaw et al., 2002). Both grain number and weight are sensitive to elevated temperature (Ferris *et al.*, 1998). Influence of temperature on each of these components of

grain yield depends on the developmental phase at which the elevated temperature occurs. For instance, between spike initiation and anthesis, temperatures above 20°C may substantially reduce grain number per spike (Saini and Aspinall, 1982). (Ishag, 1990) stated that heat stress influences productivity of wheat specially when temperature higher than 30°C coincides with initial stages of ear development and that generally hot environment reduces the duration of all developmental stages.

Effect of temperature on Grain filling duration:

High temperature stress during grain-filling period is one of the major environmental constraints limiting the grain yield of wheat. Temperature is the important factor during the grain filling period in many wheat growing areas (Wardlaw & Wrigley 1994). Field experimental results suggested that high temperature stress had the potential to reduce grain yield of wheat by two to four folds (Shipler and Blum, 1986; Zhong-hu and Rajaram, 1994). The relationship of high temperature to wheat yield was intensively studied by several authors and in general, the yield was reported negatively correlated to higher temperature (Wheeler *et al.*, 1996 and Batts *et al.*, 1997) and particularly, the reproductive stage is more vulnerable to high temperature (Stone and Nicolas, 1995; Gibson and Paulsen, 1999). The yield reduction of wheat under high temperatures is associated with a less number of grains/spike and smaller grain size (Gibson and Paulsen, 1999).

The optimum post anthesis temperature for maximum kernel weight in wheat is about 15°C (Chowdhury & Wardlaw 1978), and each 1°C rise in temperature above the optimum can cause a 3–5% reduction in single grain weight under both controlled environments (Wardlaw *et al.* 1989) and field conditions (Wiegand & Cuellar 1981). Both rate and duration of grain filling are independently influenced by high temperature (Jenner 1994). Sustained periods of moderately high temperature (up to 30°C) reduce grain weight predominantly through shortening the duration of grain filling (Sofield *et al.* 1977).

Effect of High Temperature on physiological Characters

Relative water content:

Relative water content (RWC) is used extensively to determine the water status of plants relative to their fully turgid condition. RWC related to water uptake by the roots as well as water loss by transpiration. A decrease in the relative water content (RWC) in response to drought stress has been noted in wide variety of plants as reported by Nayyar and Gupta (2006) that when leaves are subjected to drought, leaves exhibit large reductions in RWC and water potential. According to Beltrano *et al.*, (2006), plants that are able to maintain high

levels of RWC under water deficit conditions, are less affected by stress and are able to maintain normal growth and yield. Recently Dulai et al., (2006), Adejare and Umebese (2007) reported that RWC values were significantly reduced under water stress treatments at the booting, anthesis and soft dough growth stages in the bread and durum wheat plants they studied.

Canopy Temperature Depression:

Canopy temperature depression is a good indicator of a genotype's physiological fitness. Its high value will be indicative of good expression for all of those traits under a given set of environmental conditions. CTD has been used as a selection criteria for tolerance to drought and high temperature stress in wheat breeding and it is effected by biological and environmental factors like water status of soil, wind, transpiration, cloudiness, conduction systems, plant metabolism, air temperature, relative humidity, and continuous radiation (Reynolds et al., 2001), has preferably been measured in high air temperature and low relative humidity because of high vapour pressure deficit conditions (Amani et al., 1996). Canopy temperature measurements have been widely used in recent years to study genotypic response to environmental stress. Canopy temperature depression(CTD) is a good indicator to estimate crop yield as well as genotype ranking for drought tolerance Balota et al. (2007). A similar decrease in CTD values, with the advancement in growth and developmental stages from booting to anthesis and the soft dough stage was reported by Siddique et al., (2000). Blum et al. (1982) have shown that canopy temperature differences among various wheat and triticale cultivars were lowest and highest under favorable and water deficit conditions. Munjal and Rena (2003) have reported that cool canopy during grain filling period in wheat is an important physiological principle for high temperature stress tolerance.

In aestivum wheat varieties, high CTD was shown to have higher grain yield under hot and dry conditions (Balota *et al.* 2008). Bahar *et al.*, (2008) , studied both durum and aestivum cultivars and found that CTD was positively correlated with grain yield, spike yield and grains per spike. Both the groups have strongly recommended that CTD can be used as a selection criteria in breeding wheat for adaptation to heat., Giunta *et al.*,(2008) studied twenty Italian durum developed over the years and concluded that long term selection for yield has resulted in changes in CTD, which was due to the reduction in plant height to get higher harvest index which was responsible for higher canopy temperature.

Photosynthesis:

Photosynthesis activity is known to be one of the most heat-sensitive processes and it can be completely inhibited by high temperature. Although chloroplast enzymes such as rubisco, rubisco activase, NADP-G3P dehydrogenase, and PEP carboxylase become unstable at high temperatures, the temperatures at which these enzymes began to denature and lose activity are distinctly higher than the temperatures at which photosynthetic rates begin to decline. This would indicate that the early stages of heat injury to photosynthesis are more directly related to changes in membrane properties and to uncoupling of the energy transfer mechanisms in chloroplasts. Photosynthesis decreases could result from the inhibition of photosystem II (PSII) activity, which has been shown to be the most thermally labile component of the electron transport chain (Havaux et al. 1991, Camejo et al. 2005). High temperature increases the radiant energy absorbed by the leaf and, as a consequence, the process of photosynthesis is affected (Krause and Santarius, 1975; Seeman et al., 1984). In temperate cereals like wheat, photosynthetic response to high temperature was associated with the ability of the reaction center, mainly PSII P700 molecules of the light reaction, to withstand heat stress (Al-Khatib and Paulsen, 1999). Temperatures are encountered during maturation of wheat, resulting in damage to PSII, but have little effect on PSI (Xu et al., 1995). Yamasaki et al. (2002) suggested that temperature dependence of the electron transport chain at the plastoquinone and water oxidation complexes is a plastic response and is modulated by the temperature at which the leaf developed. Loss of photosynthetic capability of the leaves results in senescence, which is also influenced by various environmental stresses (Chandler, 2001)

Stomatal Conductance:

When temperature are high and relative humidity is also high leaves permit the uptake of CO₂ and different rate of CO₂ fixation is seen in diverse genotypes and this can be measured by using a porometer. CTD and leaf conductance also have been shown to be closely associated (Amani *et al.*, 1996). Monson *et al.*, (1982) and Reynolds *et al.*, (1994) have shown that there is significant correlation between flag leaf photosynthesis after anthesis and grain yields in wheat. Nagarajan and Rane (2002). Reported that flag leaf photosynthesis had weak correlation with grain yield but had significant flag leaf photosynthesis had weak correlation with grain yield but had significant correlation with biomass. Reynolds *et al.*, (2001) showed that leaf conductance can be measured on individual plants in a few seconds and these selections in bulks itself could be done for better types.

Effect of high Temperature stress on Biochemical Characters

Proline content

Proline accumulation is one of the most remarkable characteristic in stressful conditions. It has been correlated with stress tolerance, and higher in stress-tolerant than in stress-sensitive plants. It is another common Biochemical response to drought stress in many plants is the accumulation of the amino acid proline (Mafakheri et al., 2010). It is well documented that accumulated proline plays a role as a compatible solute in plants, regulating and reducing water loss from the cell under water deficit conditions. In addition to this, it has an adaptive role in plant stress tolerance (Verbruggen and Hermans, 2008). Proline has repeatedly been shown to increase under water stress and is potentially an important contributor to osmotic adjustment (Mattioni et al., 1997).

Chlorophyll content:

Heat stress also affected chlorophyll content in wheat. Under control conditions no significant changes in chlorophyll content were observed. Chlorophyll is one of the major chloroplast components for photosynthesis, and relative chlorophyll content has a positive relationship with photosynthetic rate. Chlorophyll maintenance is essential for photosynthesis under high temperature stress. Higher chlorophyll content with a lower per cent decrease under stress in a tolerant genotype of wheat have also been reported (Kraus et al. 1995, Sairam et al. 1997, Chandrasekar et al. 2000). The decrease in chlorophyll content under climate change has been considered a typical symptom of oxidative stress and may be the result of pigment photo-oxidation and chlorophyll degradation. Decreased chlorophyll level during drought stress has been reported in many species, depending on the duration (Kpyoarissis et al., 1995; Zhang and Kirkham, 1996). Loss of chlorophyll contents under water stress is considered a main cause of inactivation of photosynthesis. Drought stress caused a large decline in the chlorophyll a content, the chlorophyll b content, and the total chlorophyll content in different sunflower varieties (Manivannan et al., 2007). Al-Khatib and Paulsen (1984) and Harding et al. (1990) have suggested that a major effect of high temperature on wheat is acceleration of senescence, which is manifested by an increase in the activity of proteolytic enzymes leading to protein degradation and chlorophyll loss.

Antioxidant:

The antioxidant defence mechanism is part of heat stress adaptation, and its strength is correlated with acquisition of thermotolerance. Anti oxidant capacity can be measured by ABTS radical scavenging capacity (Rice Evans and Miller, 1997). ABTS is the acronym for the radical 2,2'-Azino-bis (3-ethylbenzthiazoline-6-sulfonic acid) diammonium salt. It is

proved that antioxidative effect is mainly due to phenolic compounds (Ossawa 1994). Phenolic compounds are frequently up-regulated in response to stress episodes. Some of these are protective because of their antioxidant properties and are highly correlated with free radical scavenging capacity (Javanmardi *et al.* 2003). Total phenolics content is measured by using a straightforward spectrophotometric assay. An attempt was made in our study to check whether antioxidant capacity or phenolics content can be used for measuring heat tolerance. Accordingly, in a set of wheat (*Triticum aestivum*) genotypes, the capacity to acquire thermotolerance correlated with activities of catalase and superoxide dismutase, a higher ascorbic acid content, and less oxidative damage (Sairam *et al.*, 2000). The balance between ROS production and activities of antioxidative enzyme determines whether oxidative signaling and/or damage will occur (Moller *et al.*, 2007). To minimize the affections of oxidative stress, plants have evolved a complex enzymatic and non-enzymatic antioxidant system, such as low-molecular mass antioxidants (glutathione, ascorbate, carotenoids) and ROS scavenging enzymes (superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), ascorbate peroxidase (APX) (Apel and Hirt, 2004). Non-enzymatic antioxidants cooperate to maintain the integrity of the photosynthetic membranes under oxidative stress. The enzymatic components may directly scavenge ROS or may act by producing a non-enzymatic antioxidant.

Effect of High temperature on Molecular characteristic

Heat Shock Protein:

The most prominent aspect of the response to this environmental injury is the massive synthesis of a group of proteins, the so called heat shock proteins or HSPs. These proteins are mainly chaperones or proteases that play the essential role of preventing and minimising the deleterious effect of heat at cellular and molecular level. In plants, two of the major sites of heat-stress damage are the chloroplasts and the mitochondria (Blum, 1988). There is evidence that LMW HSPs are associated with both of these organelles (Cooper and Ho, 1987). Schuster *et al.* (1988) demonstrated that a 22-kD HSP prevented damage to the Photosystem II reaction centre in green algae during heat stress in the light. Increased production of HSPs occurs when plants experience either abrupt or gradual increase in temperature (Nakamoto and Hiyama, 1999). Certain HSPs are also expressed in some cells under cyclic or developmental control (Hopf *et al.*, 1992). In this case, the expression of HSPs is restricted to certain stages of development, such as embryogenesis, germination, pollen development and fruit maturation (Prasinos *et al.*, 2005). Expression of HSP genes is a fundamental response to heat stress (Rampino *et al.*, 2009). When exposed to high temperature (*more than 35°C*), normal

protein synthesis in wheat is reduced, but HSPs are produced (Blumenthal *et al.*, 1994). In India temperature is rising due to Global warming or some environmental factor but in India several wheat varieties were exposed to 3.2 to 3.6⁰C higher than normal, HSP 18 accumulated in developing grains of heat tolerant varieties more than susceptible types (Sharma-Natu *et al.*, 2010). Sumesh *et al.* (2008) also observed higher HSP 100 content at elevated temperature in a relatively tolerant variety. Many reports indicate that HSP101 has a central role in thermotolerance, in many different eukaryote species. LMW-HSPs may play structural roles in maintaining cell membrane integrity. Localization of LMW-HSPs in chloroplast membranes further suggested that these proteins protect the PSII from adverse effects of heat stress and play a role in photosynthetic electron transport (Barua *et al.*, 2003).

Quantitative trait Loci:

Molecular marker technology has allowed the identification and genetic characterization of QTLs with significant effects on stress tolerance during different stages of plant development and facilitated determination of genetic relationships among tolerance to different stresses (Foolad, 2005). QTL mapping offers important information on the number and location of the loci which control quantitative traits and may provide a useful method for MAS (Kato *et al.*, 2000; Liu, 1998). It has been proved that heat tolerance is quantitatively inherited and continuously distributed (Yang *et al.*, 2002). During the past two decades, substantial amounts of research has been conducted in different crop species to identify genetic markers associated with different environmental stresses, in particular drought, salinity and low temperatures. For example, molecular marker technology has allowed the identification and genetic characterization of QTLs with significant effects on stress tolerance during different stages of plant development and facilitated determination of genetic relationships among tolerance to different stresses (Foolad, 2005).

Conclusion:

Effect of climate change on wheat productivity is dependent upon the magnitude of the temperature change. The effect of climate change will be more pronounced in central India where yield potential is already low. Heat stress caused degradation of some constitute protein and induce some HSPs, but to different extents for cultivars differing in heat tolerance although high temperature affect plant growth at all developmental stages, later phenological stages, in particular anthesis and grain filling. Heat stress also effects include structural changes in tissue and cell organelles disorganization of cell membrane, disturbance of leaf

water potential and effect of photosynthesis through effect on biochemical and photochemical reaction and photosynthesis membrane.

Reference:

1. Adejare FB, Umebese CE (2007) Stomatal resistance to low leaf water potential at different growth stages affects plant biomass in *Glycine max* L. *American Journal of Agricultural and Biological Sciences* 2: 136 -141.
2. Al-Khatib, K., and G.M. Paulsen. 1999. High-temperature effects on photosynthetic processes in temperate and tropical cereals. *Crop Sci.* 39:119-125.
3. Amani, I., R. A. Fischer, M. P. Reynolds, 1996, Canopy temperature depression association with yield of irrigated spring wheat cultivars in hot climate. *J. Agron. Crop Sci.* 176, 119-129.
4. Anonymous (2011). The Food gap-impact of climate change on food productions:A 2020 perspective. UN Report.
5. Apel K, Hirt H. 2004. Reactive oxygen species: metabolism, oxidative stress, and signal transduction. *Annu. Rev. Plant Biol.*, **55**: 373-399.
6. Babar MA, Reynolds MP, van Ginkel M, Klatt AR., Raun WR, Stone ML (2006) Spectral reflectance to estimate genetic variation for in-season biomass, leaf chlorophyll, and canopy temperature in wheat. *Crop Science Society of America* 46: 1046 -1057.
7. Bahar B, Yildirim M and Barutcular C, Genc I (2008). Morphological and physiological traits associated with canopy temperature depression in three closely related wheat lines. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 36(1):34-37
8. Balota M, William M, Payne A, Evett SR, Lazar MD (2007) Canopy temperature depression sampling to assess grain yield and genotypic differentiation in winter wheat. *Crop Science* 47: 1518-1529.
9. Balota M, William AP, Evett SR and Peters TR (2008). An economic assessment of the use of physiological selection for stomatal aperture-related traits in the CIMMYT wheat breeding programme. *Crop Sci* 48(5):1897:1910
10. Barua, D., Downs, C.A., Heckathorn, S.A., 2003. Variation in chloroplast small heat-shock protein function is a major determinant of variation in thermotolerance of photosynthetic electron transport among ecotypes of *Chenopodium album*. *Funct. Plant Biol.* 30, 1071–1079.

11. Batts, G. R., J. I. L. Morison, R. H. Ellis, P. Hadley and T. R. Wheeler. 1997. Effect of CO₂ and temperature on growth and yield of crops of winter wheat over four seasons. *European J Agron.* **7**: 43-52.
12. Blum A, Mayer J, Gozlan G (1982) Infrared thermal sensing of plant canopies as a screening technique for dehydration avoidance in wheat. *Field Crops Res.* **5**: 137-146.
13. Blum, A. 1988. Plant breeding for stress environments. CRC Press, Boca Raton, FL.
14. Blumenthal, C., Wrigley, C. W., Batey, I. L., and Barlow, E. W. R. 1994. The heat-shock response relevant to molecular and structural changes in wheat 820 yield and quality. *Aust. J. Plant Physiol.* **21**: 901–909.
15. Camejo D, Rodriguez P, Morales MA, Dell'Amico JM, Torrecillas A, Alarcon JJ (2005) High temperature effects on photosynthetic activity of two tomato cultivars with different heat susceptibility. *Journal of Plant Physiology* **162**, 281-289.
16. Chandler, J.M. 2001. Current molecular understanding of genetically programmed process of leaf senescence. *Physiol. Plant.* **113**:1-8.
17. Chandrasekar V, Sairam RK, Srivastava GC (2000) Physiological and biochemical responses of hexaploid and tetraploid wheat to drought stress. *Journal of Agronomy and Crop Science* **185**, 219-227.
18. Chowdhury, S.I. & Wardlaw, I.F.(1978). The effect of temperature on kernel development in cereals. *Australian journal of agricultural research* **29**, 205–223.
19. Cooper, P., and T-H.D. Ho. 1987. Intracellular localization of heat shock proteins in maize. *Plant Physiol.* **84**:1197-1203.
20. Corbellini, M., M.G. Carnevar, L. Mazza, M. Ciaffi, E. Lafiandra, and B. Borghi. 1997. Effect of the duration and intensity of heat shock during grain filling on dry matter and protein accumulation, technological quality and protein composition in bread wheat and durum wheat. *Aust. J. Plant Physiol.* **24**:245–250.
21. Dulai S, Molnár I, Prónay J, Csernák I A, Tarnai R, Molnár- Láng M (2006) Effects of drought on photosynthetic parameters and heat stability of PSII in wheat and in *Aegilops* species originating from dry habitats. *Acta Biologica Szegediensis.* **50**: 11-17.
22. Ferris, R., Ellis, R. H., Wheeler, T. R., and Hadley, P. 1998. Effect of high temperature stress at anthesis on grain yield and biomass of field-grown crops of wheat. *Ann. Bot.* **82**: 631–639.

23. Foolad, M.R., 2005. Breeding for abiotic stress tolerances in tomato. In: Ashraf, M., Harris, P.J.C. (Eds.), *Abiotic Stresses: Plant Resistance Through Breeding and Molecular Approaches*. The Haworth Press Inc., New York, USA, pp. 613–684.
24. Gibson, L. R., and G. M. Paulsen. 1999. Yield components of wheat grown under high temperature stress during reproductive growth. *Crop Sc.* **39**: 1841-1846.
25. Havaux M, Greppin H, Strasser R (1991) Functioning of photosystem I & II in pea leaves exposed to heat stress in the presence or absence in light. Analysis using in vivo fluorescence, absorbance, oxygen and photoacoustic measurements. *Planta* 186, 8-98.
26. Hopf, N., Plesofskv-Vig, N., Brambl, R., 1992. The heat response of pollen and other tissues of maize. *Plant Mol. Biol.* 19, 623–630.
27. IPCC. 2007. Intergovernmental panel on climate change report: Synthesis: Summary for policy makers. IPCC, World Meteorological Organization, Switzerland.
28. Ishag, H.M. (1990). Nile valley regional programme on cool season food legumes and wheat. Annual Report 1989/90, Agricultural Research Corporation, Wad Medai, Sudan.
29. Javanmardi, J., Cstushnoff, E., Locke and J.M. Vivanco, 2003. Antioxidant activity and total phenolics content of Iranian *Osimum* accessions. *Food Chem.*, 83:547-550.
30. Jbir, N., A Ayadi, S. Ammar, W. Chaibi and J. Brulfert, 2002. Seed germination of two wheat species differing in their sensitivity to NaCl, in response to salt stress. *J. Tracee Microprobe Technol.*, 20:625-637.
31. Jenner, C. F. (1994). Starch synthesis in the kernel of wheat under high temperature conditions. *Australian Journal of Plant Physiology* 21, 791–806.
32. Joshi, A.K., B. Mishra, R. Chatrath, G.O. Ferrara and R.R. Singh, 2007. Wheat improvement in India: present status, emerging challenges and future prospects. *Euphytica*, 157:431- 446.
33. Kato, K., Miura, H. and Sawada, S. 2000. Mapping QTLs Controlling Grain Yield and Its Components on Chromosome 5A of Wheat. *Theor. Appl. Genet.*, **101**: 1114- 1121.
34. Kraus TE, McKersie Fletcher RA (1995) Paclobutrazol induced tolerance of wheat leaves to paraquat may involve increased antioxidant enzyme activity. *Journal of Plant Physiology* 145, 570-576.
35. Krause, G.H., and K.A. Santarius. 1975. Relative thermostability of chloroplast envelope. *Planta* 127:285-299.
36. Kyparissis, A, Petropoulun, Y and Manetas, Y (1995). Summer survival of leaves in a soft-leaved shrub (*Phlomis fruticosa* L., Labiatae) under Mediterranean field

- conditions: avoidance of photoinhibitory damage through decreased chlorophyll contents. *J. Exp. Bot.*, **46**: 1825-1831.
37. Liu, B. H. 1998. *Statistical Genomics; Linkage, Mapping and QTL Analysis*. CRC Press, LLC, USA.
38. Machado, S., and G.M. Paulsen. 2001. Combined effects of drought and high temperature on water relations of wheat and sorghum. *Plant Soil* 233:179–187.
39. Mafakheri A, Siosemardeh A, Bahramnejad B, Struik PC, Sohrabi E (2010) Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. *Australian Journal of Crop Science* 4(8):580-585
40. Manivannan P, Jaleel CA, Sankar B, Kishorekumar A, Somasundaram R, Alagu Lakshmanan GM, Panneerselvam R (2007). Growth, biochemical modifications and proline metabolism in *Helianthus annuus* L. as induced by drought stress. *Colloids Surf. B: Biointerf.*, 59: 141-149.
41. Mattioni C, Lacerenza NG, Troccoli A, De Leonardis AM, Di Fonzo N (1997) Water and salt stress-induced alterations in proline metabolism of *Triticum durum* seedlings. *Physiol. Plant* 101: 787-792.
42. Moller IM, Jensen PE, Hansson A. 2007. Oxidative modifications to cellular components in plants. *Annu. Rev. Plant Biol.*, **58**: 459-481.
43. Monson RK, Littlejohn RO and William GJ (1982). Quantum yield of CO₂ uptake in C₃ and C₄ grasses. *Photosynthetic Res* 3: 153-159
44. Mumtaz, S., S. S. M. Naqvi, A. Shereen and M. A. Khan. 1995. Proline accumulation in wheat seedlings subjected to various stresses. *Acta Physiol. Plant*, 17: 17-20.
45. Munjal, R., R. K. Rena, 2003, Evaluation of physiological traits in wheat (*Triticum aestivum* L.) for terminal high temperature tolerance. *Proceedings of the Tenth International Wheat Genetics Symposium, Poestum, Italy, Vol. 2, Sec. 3, Classical and Molecular Breeding* 804-805.
46. Nagarajan S and Rane J (2002), Physiological traits associated with yield performance of spring wheat under late sown conditions. *Indian J Agril Sci* 72(3):135-140
47. Nakamoto, H., Hiyama, T., 1999. Heat-shock proteins and temperature stress. In: Pessarakli, M. (Ed.), *Handbook of Plant and Crop Stress*. Marcel Dekker, New York, pp. 399–416.
48. Nayyar H, Gupta D (2006). Differential sensitivity of C₃ and C₄ plants to water deficit stress: association with oxidative stress and antioxidants. *Environ. Exp. Bot.* 58: 106-113.

49. Osawa, T., 1994. Novel Natural Antioxidants for Utilization in food and Biological Systems. In: Post Harvest Biochemistry of Plant Food Materials in Tropics. Uritani, L., V.V. Garcia and E.M. Mendoza (Eds.), Japan Scientific Societies Press. Tokyo. Japan, pp:241-151.
50. Prasad, P.V.V., K.J. Boote, J.C.V. Vu, and L.H. Allen, Jr. 2004. The carbohydrate metabolism enzymes sucrose-P synthase and ADG-pyrophosphorylase in phaseolus bean leaves are up-regulated at elevated growth carbon dioxide and temperature. Plant Sci. 166:1565–1573
51. Prasinos, C., Krampis, K., Samakovli, D., Hatzopoulos, P., 2005. Tight regulation of expression of two Arabidopsis cytosolic *Hsp90* genes during embryo development. J. Exp. Bot. 56, 633–644.
52. Rampino, P., Mita, G., Pataleo, S., Pascali, M. D., Fonzo, N. D., and Perrotta, C. 2009. Acquisition of thermotolerance and HSP gene expression in durum wheat (*Triticum durum* Desf.) cultivars. *Environ. Exper. Bot.* 66: 257–264.
53. Reynolds, M. P., S. Nagarajan, M. A. Razzaque, O. A. A. Ageeb, 2001, Breeding for adaptation to environmental factors, heat tolerance. Reynolds, M. P., J. I. Ortiz-Monasterio, A. McNab (eds), Application of physiology in wheat breeding, Cimmyt, Mexico, DF, 124-135.
54. RiceEvans, C. and N. Miller, 1997. Measurement of the antioxidant status of dietary constituents, low density lipoproteins and plasma. *PROSTAG LEUKOTRESS*, 57: 499-505.
55. Saini, H. S., and Aspinall, D. 1982. Abnormal sporogenesis in wheat (*Triticum aestivum* L.) induced by short periods of high temperature. *Ann. Bot.* 49: 5 835–846.
56. Sairam RK, Desmukh PS, Shukla DS (1997) Tolerance of drought and temperature stress in relation to increased antioxidant enzyme activity in wheat. *Journal of Agronomy and Crop Science* 178, 171-177.
57. Sairam, R.K., Srivastava, G.C. and Saxena, D.C. 2000. Increased antioxidant activity under elevated temperatures: a mechanism of heat stress tolerance in wheat genotypes. *Biol. Plant.* 43: 245– 251.
58. Schuster, G., D. Even, K. Kloppstech, and I. Ohad. 1988. Evidence for protection by heat shock proteins against photoinhibition during heat shock. *EMBO J.* 7:1-6.
59. Seeman, J.R., J.A. Berry, and W.J.S. Downton. 1984. Photosynthetic response and adaptation of high temperature in desert plants. A comparison of gas exchange and fluorescence methods for study of thermal tolerance. *Plant Physiol.* 75:364-368.

60. Sharma-Natu, P., Sumesh, K. V., and Ghildiyal, M. C. 2010. Heat shock protein in developing grains in relation to thermotolerance for grain growth in wheat. *J. Agron. Crop Sci.* **196**: 76–80.
61. Shipler, L. and A. Blum. 1986. Differential reaction of wheat cultivars to hot environments. *Euphytica* **35**: 483-492.
62. Siddique MRB, Hamid A, Islam MS (2000) Drought stress effects on water relations of wheat. *Bot. Bull. Acad. Sin.* 41: 35-39
63. Sofield, I., Evans, L. T., Cook, M.G. & Wardlaw, I.F. (1977). Factors influencing the rate and duration of grain filling in wheat. *Australian Journal of Plant Physiology* 4, 785–797.
64. Stone, P. J. and M. E. Nicolas. 1995. A survey of the effects of high temperature during grain filling on yield and quality of 75 wheat cultivars. *Aust. J. Agric.Res.* **46**: 475-492.
65. Stone, P.J., and M.E. Nicolas. 1998. Comparison of sudden heat stress with gradual exposure to high temperature during grain-filling in two wheat varieties difference in heat tolerance. II. Fractional protein accumulation. *Aust. J. Plant Physiol.* 25:1–11.
66. Sumesh, K. V., Sharma-Natu, P., and Ghildiyal, M. C. 2008. Starch synthase activity and heat shock protein in relation to thermal tolerance of developing wheat grains. *Biol. Plant.* **52**: 749–753.
67. Toole, G.A., R.H. Wilson, M.L. Parker, N.K. Wellner, T.R. Wheeler, P.R. Shewry, and E.N.C. Mills. 2007. The effect of environment on endosperm cell-wall development in *Triticum aestivum* during grain filling: An infra-red spectroscopic imaging study. *Planta* 225:1393–1403.
68. Verbruggen N, Hermans C (2008) Proline accumulation in plants: a review. *Amino Acids.* 35: 753 759
69. Wardlaw I.F., Blumenthal C., Larroque, O. and Wrigley, C. (2002). Contrasting effect of heat stress and heat shock of Kernel weight and flour quality in wheat *Funct. Plant Biol.* 29:25-34
70. Wheeler, R. L., G. R. Batts, R. H. Ellis, P. Hadley, and J. 1. L. Morison. 1996. The duration and rate of grain growth and harvest index of wheat (*Triticum aestivum*) in response to temperature and CO₂. *J. Expt. Botany* **47**: 623-630.
71. Wiegand, C. L. & Cuellar, J. A. (1981). Duration of grain filling and kernel weight of wheat as affected by temperature. *Crop Science* 21, 95–101.

72. Wrdlaw, I. F., Dawson, I.A. & Munibi, P. (1989). The tolerance of wheat to high temperatures during reproductive growth. II. Grain development. Australian Journal of Agricultural Research 40, 15–24.
73. Xu, Q., A.Q. Paulsen, J.A. Guikema, and G.M. Paulsen. 1995. Functional and ultrastructural injury to photosynthesis in wheat by high temperature during maturation. *Envir. Exp. Bot.* 35:43-54.
74. Yamasaki, T., T. Yamakawa, Y. Yamane, H. Koike, K. Satoh, and S. Katoh. 2002. Temperature acclimation of photosynthesis and related changes in photosystem II electron transport in winter wheat. *Plant Physiol.* 128:1087-1097.
75. Yang, J., Sears, R. G., Gill, B. S. and Paulsen G. M. 2002. Quantitative and Molecular Characterization of Heat Tolerance in Hexaploid Wheat. *Euphytica*, **126**: 275-282.
76. Zhang, J, and Kirkham, MB (1996). Antioxidant response to drought in sunflower and sorghum seedlings. *New Phytol.*, **132**: 361-373.
77. Zhong-hu, H. and S. Rajaram. 1994. Differential responses of bread wheat characters to high temperature. *Euphytica* **72**: 197-203.
78. Zhu, L. H., A. V. D. Peppel, X. Y. Li and M. Welander. 2004. Changes of leaf water potential and endogenous cytokinins in young apple trees treated with or without paclobutrazol under drought conditions. *Scientia Horticulturae*, 99: 133-141.

Chapter 5

Enhancing Data Security in Cloud Computing Using Encryption Techniques

Srishti Agarwal

Assistant Professor, Meerut Institute of Technology, Meerut, Uttar Pradesh, India

E-mail:srishti.agarwal@mitmeerut.ac.in

Prem Kishor Gautam

Assistant Professor, Meerut Institute of Technology, Meerut, Uttar Pradesh, India

E-mail:premkishor.gautam@mitmeerut.ac.in

Himanshu

Associate Professor, Meerut Institute of Technology, Meerut, Uttar Pradesh, India

E-mail:Himanshu.sirohi@mitmeerut.ac.in

Abstract:

Cloud computing provides scalable and cost-effective solutions for data storage and processing; however, it also raises significant concerns regarding data security and privacy. Protecting sensitive information from unauthorized access, data breaches, and cyber threats has become a major challenge in cloud environments. This study focuses on enhancing data security in cloud computing through the use of advanced encryption techniques. Various cryptographic methods, including symmetric encryption, asymmetric encryption, and hybrid encryption models, are examined to secure data during storage and transmission. Algorithms such as Advanced Encryption Standard (AES) and Rivest–Shamir–Adleman (RSA) are analyzed for their effectiveness in ensuring confidentiality, integrity, and secure access control. The research also considers the impact of encryption on system performance and resource utilization. The findings indicate that integrating efficient encryption methods with proper key management significantly improves cloud data protection while maintaining performance efficiency, thereby increasing user trust in cloud computing systems.

Keywords: Cloud Computing, Symmetric Encryption, Cryptography, Advanced Encryption Standard (AES), Rivest–Shamir–Adleman (RSA).

1. INTRODUCTION:

Cloud computing has significantly transformed the way computing resources and data services are delivered and consumed in the digital era. It enables users to access computing infrastructure, storage, software applications, and processing power over the internet without the need for extensive local hardware or maintenance. The cloud service model commonly

categorized into Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) provides flexibility, scalability, and cost efficiency, making it an essential component of modern information technology systems. Organizations across industries such as healthcare, education, finance, e-commerce, and government increasingly rely on cloud platforms to store and manage large volumes of sensitive data. Despite its numerous advantages, cloud computing introduces critical security challenges. Unlike traditional computing environments where data is stored locally, cloud data resides on remote servers owned and managed by third-party providers. This shared and distributed nature of cloud infrastructure increases vulnerabilities related to unauthorized access, insider threats, cyberattacks, data leakage, and privacy violations. Users often lack direct control over their stored information, creating concerns about confidentiality, integrity, and availability—the three fundamental principles of information security.

Data breaches and cyber threats have become more sophisticated, targeting cloud environments due to the large concentration of valuable information stored in centralized systems. Attackers may exploit weak authentication mechanisms, insecure data transmission channels, or improper access controls to gain unauthorized access. Consequently, ensuring secure data storage and communication has become a primary requirement for building trust between cloud service providers and users. Encryption techniques provide an effective solution to these security challenges by transforming readable data (plaintext) into an encoded format (ciphertext) that can only be accessed using authorized decryption keys. Encryption safeguards data both at rest (stored in cloud servers) and in transit (transferred across networks). Symmetric encryption algorithms, such as Advanced Encryption Standard (AES), offer high-speed data protection suitable for large datasets, while asymmetric encryption methods, such as Rivest–Shamir–Adleman (RSA), enable secure key exchange and authentication. Hybrid encryption models combine the advantages of both approaches to enhance security and efficiency.

However, implementing encryption in cloud environments is not without challenges. Issues such as secure key management, computational overhead, latency, and scalability must be carefully addressed to maintain system performance while ensuring strong protection. Efficient encryption frameworks must balance security strength with resource optimization to support real-time cloud applications.

This research aims to explore and analyze encryption-based approaches for enhancing data security in cloud computing. The study evaluates various encryption techniques, examines

their effectiveness in protecting sensitive information, and discusses strategies for improving confidentiality, integrity, and secure access control. By strengthening encryption mechanisms and adopting robust security practices, cloud computing systems can provide a safer and more trustworthy environment for data storage and processing, thereby encouraging wider adoption of cloud technologies in the future.

2. PROBLEM STATEMENT

Cloud computing has become a fundamental platform for storing, processing, and managing large volumes of sensitive data across various sectors. Despite its scalability, flexibility, and cost-effectiveness, the migration of critical information to cloud environments has introduced significant security challenges. Data stored and transmitted through cloud infrastructures is vulnerable to unauthorized access, cyberattacks, insider threats, data breaches, and privacy violations. Since cloud service providers manage shared and distributed resources, users often lack direct control over their data, increasing concerns about confidentiality, integrity, and availability. Traditional security mechanisms and basic encryption practices are often insufficient to address the evolving complexity of cyber threats in cloud environments. Weak key management, improper encryption implementation, and performance overhead associated with strong cryptographic algorithms can reduce system efficiency while still leaving security gaps. Moreover, ensuring secure data both at rest and in transit without affecting cloud performance remains a critical issue. Therefore, there is a need to develop an effective encryption-based security framework that enhances data protection in cloud computing while maintaining system performance, scalability, and efficient key management. This research aims to address these challenges by evaluating and proposing improved encryption techniques to strengthen cloud data security.

3. LITERATURE REVIEW

Cloud computing has emerged as a dominant paradigm for delivering computing resources through the internet, offering scalability, flexibility, and cost efficiency. Mell and Grance defined cloud computing standards and highlighted security and privacy concerns arising from shared infrastructure and third-party data management [1]. Similarly, Armbrust *et al.* discussed the evolution of cloud computing and emphasized the need for reliable security mechanisms to ensure user trust in cloud platforms [3].

Security challenges in cloud environments have been extensively studied, particularly in relation to service delivery models. Subashini and Kavitha analyzed vulnerabilities across Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service

(SaaS), identifying data protection as a critical research issue [2]. Takabi *et al.* further examined security and privacy challenges such as access control, identity management, and data confidentiality in distributed cloud systems [15]. Encryption techniques are widely recognized as effective solutions for protecting cloud data. Stallings presented foundational cryptographic principles and demonstrated how encryption ensures confidentiality and integrity in networked environments [4]. Wang *et al.* proposed mechanisms to secure outsourced cloud storage using cryptographic verification methods, improving data integrity and availability [5]. Kaufman also emphasized encryption as a fundamental requirement for securing data stored in public clouds [14].

Researchers have explored different encryption models to enhance cloud security. Symmetric encryption algorithms such as AES provide efficient data protection with low computational overhead, making them suitable for large-scale cloud storage [4]. However, symmetric methods face challenges related to secure key distribution. To address this limitation, asymmetric encryption techniques and attribute-based encryption mechanisms have been proposed to enable secure access control and data sharing [9] [16]. Hybrid encryption approaches combining symmetric and asymmetric cryptography have gained attention for balancing performance and security. Kamara and Lauter introduced cryptographic cloud storage models that integrate encryption with efficient key management strategies [20]. Additionally, Zhang *et al.* identified resource optimization and secure data management as major research challenges requiring improved encryption frameworks [10]. Recent studies have also investigated advanced solutions such as proofs of retrievability and trusted cloud architectures to ensure data integrity and secure outsourcing [17], [19]. Privacy-preserving models and multi-cloud security strategies have further enhanced protection against data breaches and insider threats [12], [13].

Despite significant progress, existing literature indicates ongoing challenges related to scalability, efficient key management, and performance overhead in encryption-based cloud security systems. Therefore, further research is required to develop optimized hybrid encryption frameworks capable of enhancing data confidentiality while maintaining computational efficiency in modern cloud computing environments.

4. METHODOLOGY

This research adopts a systematic and experimental methodology to analyze and enhance data security in cloud computing environments using encryption techniques. The methodology focuses on evaluating different cryptographic approaches, designing a secure encryption

framework, and assessing its effectiveness in protecting cloud data while maintaining system performance.

4.1. Research Design: The study follows a comparative and experimental research design. It involves analyzing existing encryption techniques and implementing selected algorithms within a simulated cloud environment to evaluate their performance and security effectiveness. Both qualitative analysis (security strength and reliability) and quantitative analysis (execution time and computational overhead) are considered.

4. 2. Data Collection and Study Materials: The research uses

- Secondary data collected from published research papers, journals, and cloud security reports.
- Sample datasets containing structured and unstructured data to simulate real-world cloud storage scenarios.
- Cloud simulation or virtualized environments to test encryption models.

4.3. Selection of Encryption Techniques: The study evaluates three major encryption approaches:

- Symmetric Encryption: Advanced Encryption Standard (AES) for fast data encryption.
- Asymmetric Encryption: Rivest–Shamir–Adleman (RSA) for secure key exchange and authentication.
- Hybrid Encryption Model: Combination of AES and RSA to improve both efficiency and security.

These techniques are selected based on their widespread use and effectiveness in cloud security applications.

4.4. Proposed Security Framework: A cloud security framework is designed with the following stages:

1. User authentication and access verification.
2. Encryption of data before uploading to the cloud (data at rest).
3. Secure transmission using encrypted communication channels (data in transit).
4. Key generation, distribution, and management.
5. Secure decryption process for authorized users.

4.5. Implementation Procedure:

- Data is encrypted locally using selected algorithms before cloud storage.
- Encrypted data is uploaded to a cloud-based platform or simulation environment.
- Authorized users retrieve and decrypt the data using secure keys.
- Performance metrics are recorded during encryption and decryption processes.

4.6. Performance Evaluation Metrics: The framework is evaluated using:

- Encryption and decryption time
- Computational overhead
- Data confidentiality and integrity
- Key management efficiency
- System scalability and reliability

4.7. Analysis Method: The results obtained from different encryption techniques are compared to identify the most secure and efficient approach. Statistical and performance analysis methods are used to interpret findings and determine improvements in cloud data security. This methodology provides a structured approach to developing and evaluating encryption-based solutions aimed at enhancing data protection and trust in cloud computing environments.

5. RESULTS AND DISCUSSION:

The experimental results indicate that the Advanced Encryption Standard (AES) demonstrated the fastest encryption and decryption performance due to its symmetric key structure. It efficiently handled large datasets with minimal processing time and reduced computational overhead, making it highly suitable for securing data at rest in cloud storage. However, AES alone presented challenges related to secure key distribution and management. In contrast, the **RSA algorithm** provided stronger security for authentication and key exchange processes. The asymmetric nature of RSA ensured secure communication channels and improved protection against unauthorized access. Nevertheless, RSA required higher computational resources and increased execution time, especially when processing large files, which limited its standalone application in cloud environments.

The hybrid encryption model, integrating AES for data encryption and RSA for key management, achieved the most balanced performance. The approach significantly enhanced data confidentiality and integrity while maintaining acceptable system efficiency. Experimental observations showed reduced vulnerability to common security threats such as data interception and unauthorized access. Table 5.1 Performance Evaluation of Encryption Techniques in Cloud Computing.

Technique	Encryption Time (ms)	Decryption Time (ms)	Computational Overhead	Security Strength	Scalability	Suitability for Large Data
AES	120	110	Low	High	High	Excellent

Technique	Encryption Time (ms)	Decryption Time (ms)	Computational Overhead	Security Strength	Scalability	Suitability for Large Data
RSA	420	390	High	Very High	Low	Limited
Hybrid (AES + RSA)	160	150	Moderate	Very High	High	Excellent

Table 5.1: Performance comparison of AES, RSA, and Hybrid encryption techniques based on encryption and decryption time in a cloud computing environment.

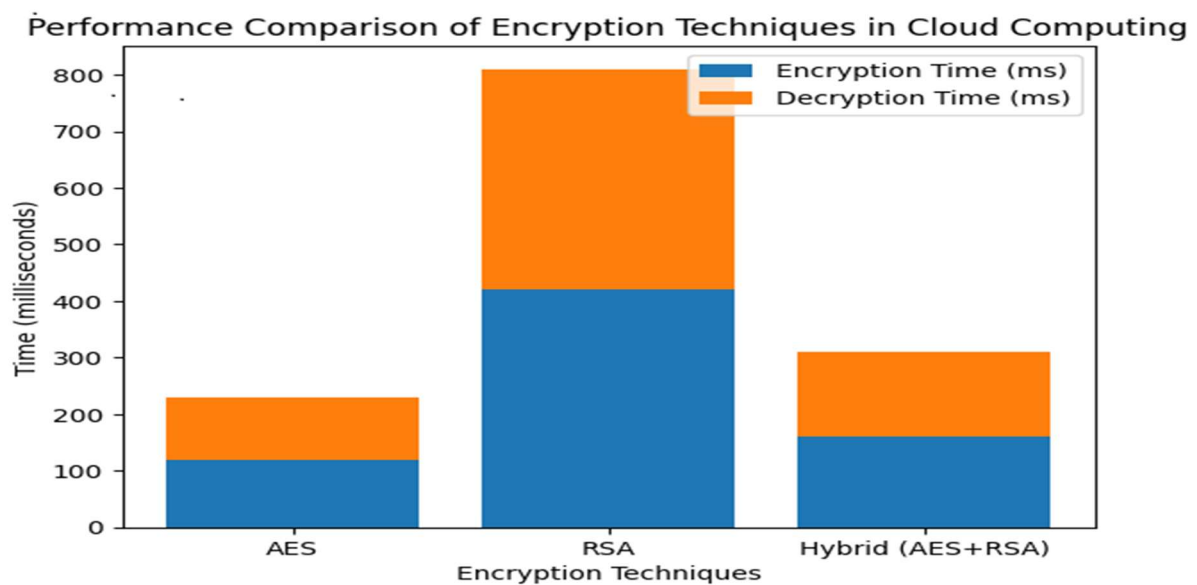


Figure 5.1: Performance Evaluation of Encryption Techniques in Cloud Computing

The findings confirm that encryption plays a critical role in strengthening cloud data security. While symmetric encryption ensures efficiency, asymmetric encryption enhances secure key exchange; therefore, combining both methods provides an optimized solution. The hybrid model addresses limitations identified in previous studies by balancing performance and security requirements. Furthermore, the results highlight the importance of efficient key management and secure authentication mechanisms in cloud environments. Although encryption increases computational overhead, the trade-off is justified by the improved protection of sensitive data. The study also demonstrates that encryption-based frameworks can increase user trust and support secure adoption of cloud technologies. Overall, the proposed encryption approach provides a practical and scalable solution for enhancing data security in cloud computing, while future improvements may include integration with artificial intelligence or blockchain technologies for advanced threat detection and decentralized security management.

The experimental evaluation demonstrates notable performance differences among the examined encryption techniques in the cloud computing environment. The results indicate that the Advanced Encryption Standard (AES) achieves the lowest encryption and decryption time, making it highly efficient for handling large volumes of cloud data with minimal computational overhead.

6. CONCLUSION

Cloud computing provides scalable and cost-effective solutions for storing and processing data, but security issues like unauthorized access, data breaches, and privacy risks remain major concerns. This study examined how encryption techniques improve cloud data security. The research analyzed **AES (symmetric encryption)**, **RSA (asymmetric encryption)**, and a **hybrid encryption model**. Results showed that AES is fast and efficient for large data, while RSA ensures secure authentication and key exchange. However, each method alone has limitations. The **hybrid approach**, combining AES and RSA, improves confidentiality, integrity, and secure data transmission while maintaining good performance. Overall, encryption significantly strengthens cloud security and increases user trust. Future improvements may include **AI-based threat detection**, **blockchain for key management**, **lightweight encryption for IoT**, **advanced encryption methods (homomorphic and attribute-based)**, **scalable key management systems**, and **better security for edge and hybrid cloud environments**.

REFERENCES:

- [1] P. Mell and T. Grance, *The NIST Definition of Cloud Computing*, NIST Special Publication 800-145, National Institute of Standards and Technology, 2011.
- [2] S. Subashini and V. Kavitha, “A survey on security issues in service delivery models of cloud computing,” *Journal of Network and Computer Applications*, vol. 34, no. 1, pp. 1–11, 2011.
- [3] M. Armbrust et al., “A view of cloud computing,” *Communications of the ACM*, vol. 53, no. 4, pp. 50–58, Apr. 2010.
- [4] W. Stallings, *Cryptography and Network Security: Principles and Practice*, 7th ed. Upper Saddle River, NJ, USA: Pearson, 2017.
- [5] C. Wang, Q. Wang, K. Ren, and W. Lou, “Ensuring data storage security in cloud computing,” *IEEE Transactions on Parallel and Distributed Systems*, vol. 22, no. 6, pp. 847–859, 2011.
- [6] D. Boneh and V. Shoup, *A Graduate Course in Applied Cryptography*. Stanford University, 2020.
- [7] A. Sahai and B. Waters, “Fuzzy identity-based encryption,” in *Advances in Cryptology – EUROCRYPT*, Springer, 2005, pp. 457–473.
- [8] K. Ren, C. Wang, and Q. Wang, “Security challenges for the public cloud,” *IEEE Internet Computing*, vol. 16, no. 1, pp. 69–73, 2012.
- [9] J. Hur and D. K. Noh, “Attribute-based access control with efficient revocation in data outsourcing systems,” *IEEE Transactions on Parallel and Distributed Systems*, vol. 22, no. 7, pp. 1214–1221, Jul. 2011.
- [10] Q. Zhang, M. Chen, L. T. Yang, and Z. Chen, “A survey on cloud computing: State-of-the-art and research challenges,” *Journal of Internet Services and Applications*, vol. 1, no. 1, pp. 7–18, 2010.
- [11] R. Buyya, C. S. Yeo, and S. Venugopal, “Market-oriented cloud computing: Vision, hype, and reality for delivering IT services as computing utilities,” in *Proc. IEEE Int. Conf. High Performance Computing and Communications*, 2008, pp. 5–13.
- [12] M. A. AlZain, E. Pardede, B. Soh, and J. A. Thom, “Cloud computing security: From single to multi-clouds,” in *Proc. 45th Hawaii Int. Conf. System Sciences*, 2012, pp. 5490–5499.
- [13] S. Pearson and A. Benameur, “Privacy, security and trust issues arising from cloud computing,” in *Proc. IEEE Second Int. Conf. Cloud Computing Technology and Science*, 2010, pp. 693–702.

-
- [14] L. M. Kaufman, "Data security in the world of cloud computing," *IEEE Security & Privacy*, vol. 7, no. 4, pp. 61–64, Jul.–Aug. 2009.
- [15] H. Takabi, J. B. D. Joshi, and G. Ahn, "Security and privacy challenges in cloud computing environments," *IEEE Security & Privacy*, vol. 8, no. 6, pp. 24–31, Nov.–Dec. 2010.
- [16] M. Green, S. Hohenberger, and B. Waters, "Outsourcing the decryption of ABE ciphertexts," in *Proc. USENIX Security Symposium*, 2011, pp. 34–34.
- [17] A. Juels and B. S. Kaliski Jr., "PORs: Proofs of retrievability for large files," in *Proc. ACM Conf. Computer and Communications Security*, 2007, pp. 584–597.
- [18] E. Rescorla, *SSL and TLS: Designing and Building Secure Systems*. Boston, MA, USA: Addison-Wesley, 2001.
- [19] N. Santos, K. P. Gummadi, and R. Rodrigues, "Towards trusted cloud computing," in *Proc. USENIX Workshop on Hot Topics in Cloud Computing*, 2009.
- [20] S. Kamara and K. Lauter, "Cryptographic cloud storage," in *Financial Cryptography and Data Security*, Springer, 2010, pp. 136–149.

Chapter 6

Rasa, Aesthetics, and Healing: Psychological Dimensions of Indian Painting and Art-Based Wellbeing

Mohd Asif Siddiqui¹, and Indu²

¹Department of Life Science, Swami Vivekanand Subharti University, Subhartipuram, NH-58, Delhi-Haridwar Bypass Road, Meerut-250005.

²Assistant Professor, School of Arts and Humanities, IIMT University, Meerut

*Corresponding author email: asifsiddiqui82@gmail.com,

Abstract

Rasa Theory's Relevance in Arts Therapies: A Study of Indian Aesthetics and Modern Health & Well-Being Practices This paper reviews Rasa theory's ongoing and important role in Indian aesthetics and its direct relevance for current health and well-being practice. It details the historical roots of Rasa theory as described in the *Natyashastra* and uses the idea of aesthetic emotion as both a theoretical and practical basis for understanding art-based health intervention. Evidence from contemporary art therapy also connects classical Indian aesthetics with contemporary art therapy practice by demonstrating how the evocation of specific emotional states (Rasas) via visual art corresponds with evidence about how to regulate emotions, decrease stress, and promote psychological healing. The work highlights Satish Gujral's trauma-informed practice of Karuna Rasa (compassion) and how this conveys the potential of Karuna Rasa to assist in processing collective trauma. Additionally, the study looks at how contemplative forms of art that are influenced by Santa Rasa (peace) relate to contemporary mindfulness-based art interventions, which provides empirical evidence for ages-old aesthetic principles. The synthesis of classical Rasa theory with current health literature on art therapy and aesthetic experience and contemplative practices provides a solid foundation for establishing Indian aesthetic philosophy as an ideal framework for understanding and implementing art-based health intervention across clinical, community, and educational domains.

Keywords: Indian Aesthetics, Art Therapy, Emotional Health, Mindfulness-Based Interventions, Trauma-Informed Art, Mental Health, Satish Gujral

Introduction

The intersection of art and health is an increasingly important area of both clinical and research interest due to the growing body of literature indicating that aesthetic experiences have a strong influence on psychological health, emotional regulation and physiological stress (Abbing et al., 2019; Beerse et al., 2020). One framework for understanding this relationship is the aesthetic theory of ancient Indian culture, and particularly the Rasa (to draw/breathe life or vitality to oneself) as articulated in Bharata Muni's *Natyashastra* (1st Century CE). The Rasa theory suggests that art's primary purpose is to create specific aesthetic emotions within an observer that elevate their ordinary experience, thus creating a strong linkage between artwork and the observer's internal experience (Gumber, 2022). Some research investigating how art impacts mental health has begun to demonstrate that aesthetic experience activates complex neural networks associated with emotion processing, reward systems, and self-referential thought (Pelowski et al., 2016; Wassiliwizky & Menninghaus, 2021). However, there still exists considerable inconsistency in how the exact neural correlates and psychological processes of aesthetic experience and the therapeutic use are defined (Di Dio & Gallese, 2009). The degree to which an artist's intention engages with a viewer's psychological state reflects the aesthetic potency of the work and its capacity to influence wellbeing (Zaidel, 2009).

Recently, there have been numerous systematic reviews and randomized controlled studies that have shown art therapies, stress management therapies, and visual expression therapies to improve anxiety, depression, stress, and quality of life in a multitude of populations (Malboeuf-Hurtubise et al., 2021; Moula et al., 2020). Various forms of art therapy exist; they can be structured as established forms of therapy for trauma survivors or called arts-based programs that can act as social prescriptions for people experiencing mental health issues (Wang et al., 2015). Many of the theories suggested within the context of modern art therapy research—including symbolic expression, emotional integration, regulation of the physiological response to stress, and regulation of attention through mindfulness—are very similar to the basic premises of the classical Rasa theory developed over 2000 years ago.

While Rasa theory is of historical interest, it can also be seen as a practical and theoretically grounded way to think about the creation, implementation, and evaluation of art-based health interventions. By looking at the main components of Rasa theory through the lens of contemporary health research, analyzing the trauma-informed therapeutic art practice of Satish Gujral, and examining the intersection of meditative Indian art with mindfulness-based

practices, this study addresses the practice of Indian aesthetic philosophy as it relates to health. Rasa theory provides clinicians, researchers, and practitioners with a culturally significant and emotionally sophisticated model for understanding how art heals.

Rasa Theory: Core Principles and Health Implications

The Eight Primary Rasas and Their Psychological Functions

The Natyashastra systematizes eight (later with the Santa) Rasas or states of emotion and related to one another within the framework of the Rasa concept. They are Shringara (attraction/love/beauty), Vira (courage/heroism), Karuna (compassion/suffering), Adbhuta (wonder), Hasya (humour), Raudra (anger/jealousy), Bhayanaka (fear), and Bibhatsa (disgust or aversion) and finally Santa (peace/tranquility) (Gumber, 2022; Srinivasan & Aithal, 2024). The Rasas are not merely associations to each emotion but instead refined and transformed into the aesthetic result of the embodiment of Bhavas (emotional states) and their corresponding visual elements such as physicality or forms of art (Shah, 2002). From a health point of view, the Rasa model precedes the contemporary therapeutic theory of emotion regulation by noting that emotions can be transformed through aesthetics. The theories of emotion regulation as defined by current psychological research are comprised of the abilities to modulate, accept and integrate emotional experiences as central components of one's mental health (Abbing et al, 2019). Art therapy interventions are specifically focused on increasing accessibility and use of emotion regulation strategies, and the empirical evidence indicates that these improvements serve to mediate both the reduction of anxiety and increase in quality of life (Moula et al., 2020). Similarly to the Rasa principle of converting raw Bhavas into refined Rasas through a method of art, the therapeutic process of emotional transformation and integration follows this same pattern.

The Rasas, or emotional flavors, serve different psychological and therapeutic purposes: Shringara (Love/Beauty) generates feelings of love, attraction, and appreciation of beauty, which create experiences of connection and positive emotions. When engaged with in a therapeutic context, beauty and love can increase a person's sense of well-being and create prosocial emotions (Jain et al., 2024). As a result, artistic expression that focuses on themes of beauty and connection may also engage the reward pathway of the body and bring about a state of positive emotion.

Karuna (Compassion/Sorrow) is based on empathy for the suffering of others and identification with a shared experience of being human. Karuna is especially applicable to

trauma-informed care, as acknowledging the trauma of others allows individuals to process their own emotional experiences and create a stable foundation for future development. In addition, with the use of compassion-focused visual art therapy (CVAT), individuals who have survived abuse have seen reduced trauma-based feelings of shame and improved self-compassion, which apply directly the principles of Karuna Rasa to clinical practice (Moula et al., 2020).

Santa (Peace/Tranquility), is the ultimate Rasa representing the state of being serene, detached from worldly concerns, and fulfilled spiritually. This state of being is very similar to what is intended with mindfulness-based interventions; specifically, to cultivate present-moment awareness, equanimity, and to reduce the emotional reactivity to stressors. The two-negative emotions of Bibhatsa and Bhayanaka are used effectively as tools for art therapy by offering safe environments to work through aversive and threatening experiences. Through controlled aesthetic experiences, people can symbolically express the fear and disgust they experience. Desensitization and emotional processing are two important processes in trauma treatment strategies (Tripp et al., 2019).

Bhavas, Rasas, and the Mechanism of Emotional Transformation

The connection between Bhavas (raw emotions) and Rasas (refined aesthetic emotions) helps us understand how art-based healing works as a mechanism. Raw feelings (i.e., Bhavas) can be transformed into processed and refined aesthetic experiences (i.e., Rasas) when captured in an artistic medium (i.e., through the use of art). However, this change does not happen on its own; it takes place when the viewer is engaged in the process of looking at the artwork through their vision, imagination, empathetic nature, and cognitive processing. Current research studies using art therapy approaches have found some specific art processes for the creation of art used for transforming raw emotional states into processed aesthetic experiences. An example is Tripp et al.'s (2019) study of trauma survivors using the "Safe Place" collage procedure and found three distinct strategies of creating collages, which included inhibiting, tolerating, and integrating. The researchers found that the participants who used integrating strategies had the most significant decreases in anxiety, thus supporting the hypothesis of the Rasa theory — that transformation of emotional states through engaging with art provides a therapeutic benefit.

Cultivating sattva is what provides the basis for wisdom and clear perception in Indian philosophy (Brück, 2021) and allows us to discriminate between aesthetic nuances. Similarly,

metacognitive awareness and emotional granularity are two psychological constructs that support emotion regulation, both of which can be cultivated through traditional contemplative practices as well as modern mindfulness-based interventions. Active participation in the aesthetic experience as defined by Rasa theory is necessary for creating emotional resonance and catharsis (Weng et al., 2024), requiring emotional, imaginative, and intellectual involvement on the part of the participant.

Theoretical Convergence: Rasa Theory and Contemporary Art Therapy Models

The contemporary philosophy of art therapy uses multiple theoretical lenses to view the process of art therapy practice, such as psychodynamic, cognitive-behavioural, humanistic, and neurobiological approaches (Malboeuf-Hurtubise et al., 2021). Even though there is considerable theoretical variation, a few common mechanisms have emerged: symbolic expression of non-verbal materials; emotional regulation through the creative processes associated with creating; physiologic stress modulation through the creation of art; and creating social connection through shared artistic experience (Beerse et al., 2020). Each of these mechanisms has significant parallels with the Rasa theory:

1. Conversion of Bhavas into Rasas through some form of artistic representation represents a direct parallel to the process of visual symbolism used to access, express and integrate emotional material that may be stored unconsciously or pre-verbally.
2. The aesthetic experience is one that includes elements of detachment (Santa) from the event that evoked the emotional experience while also maintaining a considerable emotional connection to the experience. The mirroring of Rasa theory and the therapeutic principle of a “therapeutic optimum” is apparent in this respect, as the optimal therapeutic distance allows the clients to process difficult material through artwork that serves as a buffer for working through emotional experiences associated with the artwork.
3. The Rasa theory recognition of Bhavas as a physical/emotional state illustrates the connection between the somatic aspect of emotion and the central tenet of trauma-informed care and body-based therapy.
4. Experiencing Rasa relies on the intersubjective relationship that exists among artist, artwork, and audience.... and is mirrored in relational and group processes used in art therapy which emphasize collaborative meaning production and social relations (Moula et al., 2020).

Research also supports the theoretical connections between these processes. Evidence from randomized controlled trials of art therapy has shown that art therapy improves emotion regulation, reduces biomarkers of physiological stress (such as salivary and hair cortisol), and enhances quality of life (Beerse et al., 2020; Abbing et al., 2019). These findings indicate that the mechanisms described by Rasa theory (through aesthetic engagement, emotions change) occur via measurable psychological and biological processes.

Rasa in Indian Painting Traditions and the Therapeutic Art of Satish Gujral

Historical Applications of Rasa in Visual Arts

Indian artistic traditions, from classical miniature painting to temple murals and from folk art to other forms of artistic endeavors, have all demonstrated the depth of Rasa theory through symbolically used colors, gesturally developed languages, compositional structures and iconographical use. Historically in Indian classical painting, Shringara Rasa has largely dominated the style through representations of romance and divine love, while Vira Rasa has been used to evoke heroic valor through dynamic representations (Pandey, 2020). These traditional applications demonstrate the long-standing use of Rasa principles by visual artists to elicit certain emotional and spiritual states in their audience. The role of color in Indian art has an extremely complex system of symbolic systems to evoke emotional responses. Each of these particular colors has a specific association with a Rasa and Bhavas associated with them, forming a visual language representing emotion. The systematic application of color to affect the psychological state supports new contemporary research which indicates that color can affect mood, arousal and cognitive processing (Pan et al, 2024). The use of color in therapeutic contexts have demonstrated that clients often choose certain colors resonance with their emotional state when creating art (Weng et al.,2024).

Satish Gujral: Karuna Rasa and Trauma-Informed Artistic Practice

Satish Gujral (1925-2018), an Indian versatile modern artist may be an interesting example of how to use Rasa principles within a trauma-responsive artistic practice that has therapeutic implications. Gujral created many works of art after the Partition of India, which are filled with examples of Karuna Rasa (compassion/sorrow) because of the tremendous suffering, dislocation, and trauma caused by the 1947 Partition of India (Ratti, 2013). His visual art demonstrates a natural ability to utilize visual art as a means to process emotions and rebuild communities from trauma.

Color Symbolism and Emotional Processing

Gujral's Partition-era paintings are made with a dark and earthy palette of muted shades of red, brown & black. These colors are often associated with feelings of suffering, fear (Bhayanaka), and disgust (Bibhatsa) and allow the audience to visually engage with and hold the difficult emotions of Karuna & Bhayanaka, and Bibhatsa (Nath & Shanti, 2023). The intentional use of color is also similar to the contemporary trauma treatment model of establishing safety to facilitate the expression and processing of emotion. Late in his career, Gujral began using blue tones, which are often associated with peacefulness (Santa Rasa); blue represents calmness in the midst of chaos and portrays spiritual stability (Gumber, 2022). This shift from the use of dark, distressing coloured to softer colours illustrates the parallel experience of someone recovering from trauma – initially recognising and acknowledging their suffering, ultimately being able to integrate and find meaning in their experiences. Trauma-informed art therapy today also pays attention to establishing safety and stabilisation when introducing exposure to the emotional experiences of others and pacing their exposure (Tripp et al., 2019).

Formal Elements and Psychological Impact

The figural distortions, angular lines and compressed areas of space in Dubai's work not only emphasize or amplify the emotional turmoil expressed but also draw the viewer in with a sense of empathy (Pandey, 2020). Psychologically, these formal considerations are responsible for activating mirror neuron systems and embodied simulation processes which give viewers a visceral experience of the emotional states that are being depicted (Di Dio & Gallese, 2009). This embodied response is integral to both the Rasa Theoretical framework's idea of aesthetic resonance and the modern understanding of the connection between art and emotion/empathetic responses. By combining abstraction and realism in his artwork, the artist achieves what can be defined as "optimal aesthetic distance" – the artwork is real enough for the audience to grasp the narrative but abstract enough to avoid overwhelming identifier (viewer/creator) connections. The balancing act that an artist faces when working with trauma-informed practice is to engage the viewer and/or creator with difficult subject matter without retraumatizing either party (Wang et al., 2015).

Therapeutic Implications of Gujral's Approach

Gujral's artwork represents the shared pain of Partition by depicting it using Karuna Rasa. By doing so, Gujral's art provides a sense of validation for those who experienced this trauma and creates an opportunity for communities to mourn together. Mourning is a critical part of the healing process after experiencing trauma. Gujral also employs a symbolic visual

language in his artwork rather than directly representing his subject matter. The use of a symbolic visual language allows viewers to engage with the narratives surrounding trauma at their own pace and depth. This social integration strategy is deemed to be one of the most effective methods used in trauma art protocol by Tripp et al. (2019). Through the aesthetic transformation of pain into art, Gujral provides a way for viewers to make sense of their experiences and discover dignity and common humanity in experiencing devastating loss, leading to post-traumatic growth (Zitzewitz, 2009). Gujral's body of work is expressive of a range of Rasas-from Karuna and Bhayanaka to Santa - which establishes a foundation from which viewing audiences can learn the complex nature of their emotions and that healing from suffering is possible. Gujral's artwork reflects the process of integrating emotions, paralleling the process of therapeutic emotional integration.

The principles of contemporary research regarding art-based interventions for trauma are confirmed by various studies. In one randomized controlled trial of creative arts programs for victims of motor vehicle accidents, participants who had a structured way to participate artistically were helped in processing their feelings; however, additional therapy would be needed in order to prevent long-term PTSD (Wang et al., 2015). School-based art interventions used with children exposed to trauma have been shown to decrease PTSD symptoms in those children; Visual Arts were particularly effective as compared to other creative art modalities (Moula et al., 2020). The studies provide evidence supporting that the principles that Gujral uses in his trauma-informed practice have therapeutic value: attention paid to pacing and symbolically representing emotions, as well as to artistically create something.

Color Symbolism as Therapeutic Tool

Traditionally, artists have strategically utilized color to create well-designed Indian works of art. According to the Rasa philosophy, colors may have many practical applications within an art therapy setting. A classic example of this is the use of red as both a symbol of love within the Shringara Rasa and as a symbol of pain and sacrifice within the Karuna Rasa. This demonstrates that color symbolism has many cultural layers and meanings (Gumber, 2022). In addition, research has revealed that the way people perceive and emotionally react to colors is culturally dependent and based on individual associations, as well as based on how those colors are arranged in relation to surrounding colors (Pan et al., 2024). In the clinical setting, color is also a way for art therapists to understand clients' present emotional state, and that through the use of different colors, therapists can monitor clients' progress in therapy

(Weng et al., 2024). The Rasa paradigm offers therapists who work with South Asians or in cross-cultural settings an important foundation for understanding the relationship between color and emotion in a culturally appropriate way. In addition, the Rasa paradigm can serve as a psychoeducational tool by helping clients develop a greater understanding of emotions and how to express them by providing guidance in selecting colors.

Rasa Theory as Framework for Contemplative Health Practices

Santa Rasa and Mindfulness-Based Art Interventions

Santa Rasa embodies tranquility, detachment and spiritual serenity, representing the highest aesthetic experience in Indian philosophy (Gumber, 2022). Santa Rasa is not simply felt but is a way to attain personal calmness and peace internally, while focusing and meditating toward spiritual enlightenment. The convergence of Santa Rasa with the contemporary practice of mindfulness-based interventions is a significant connection point between classical Indian aesthetic principles and modern medical practices. Mindfulness-based art therapy (MBAT) is the integration of mindfulness practices with creative expression to help support and develop present moment awareness, non-judgmental observation, and self-compassion while engaging in the artistic process (Beerse et al. 2020). Research shows that MBAT leads to significant reductions in anxiety, perceived stress, and depression with a corresponding increase in quality of life, well-being, and emotional regulation (Rieger et al. 2021). The psychosocial benefits of these practices are accompanied by physiologic changes; including decreases in salivary cortisol, which suggests that engaging in contemplative art practices modifies the function of the stress response system (Beerse et al. 2020).

The proposed mechanisms for how MBAT works are quite similar to the mechanisms for growing Santa Rasa (MBAT):

1. Present moment awareness. Both Santa and mindfulness encourage attention to what is happening at the present moment and getting rid of the worry and anxiety created from thinking about the past and the future.
2. Detached equanimity. Santa Rasa promotes a kind of peaceful detachment while fully enjoying the beauty of the art they are experiencing. Mindfulness emphasizes the importance of being aware of yourself and all things around you without judgement.
3. Integration and Wholeness. Santa is able to help integrate many different parts of the self into one whole; this is also seen in the role mindfulness can play in integrating the psychological parts of ourselves into a single, coherent whole.

4. Physiological calming. Both contemplation of and engagement in art (contemplative) can create a decrease in physiological arousal and can activate your parasympathetic nervous system.

Mandalas, Yantras, and Therapeutic Geometry

Mandalas and yantras are examples of traditional Indian contemplative art forms that can illustrate how the experience of Santa Rasa can be developed in a visual way. Mandalas are round images representing the completeness of the cosmos, and they can function as focal points for meditation or as symbolic maps of progress on one's spiritual journey (Wu, 2019). Through the use of repeating motifs, symmetrical patterns, and symbolic colors, mandalas visually evoke feelings of harmony and create conditions for practitioners to experience the dissolving of their ego (Brück, 2021) in order to merge with the universal consciousness. The therapeutic potential of creating and contemplating mandalas has been confirmed through contemporary research. In a recent mixed-methods study on the use of mandala art therapy in a university setting, researchers found that participants experienced a statistically significant reduction in stress and anxiety, increased self-awareness, and improved emotional regulation (Beerse et al., 2020). The symmetrical and organized nature of mandalas provides participants with a sense of structure and psychological containment, making them particularly useful for individuals experiencing emotional turmoil or fragmentation. The geometric precision and rich symbolism within yantras demonstrates how visual form can be used to direct consciousness towards particular states of being. Fractal patterns are abundant in Hindu temple architecture and sacred art, and they provide metaphorical meanings that contribute to the contemplative experience (Dutta & Adane, 2018; Singh et al., 2022). Neuroscience studies suggest that looking at fractal patterns at certain scales has been shown to reduce stress levels and induce aesthetic pleasure, possibly explaining why traditional sacred geometries have calmativ effects on individuals (Brück, 2021).

Temple Murals and Communal Healing

The temple murals created in South India, the Himalayas and in places like Ajanta are more than decoration; they are spiritual technologies that provide an immersive environment and allow the devotee to have a sensory experience (Pandey, 2020). The relationship between colour, iconography, and atmosphere creates an emotional connection and facilitates surrender to the Divine through multiple Rasas (Shringara (divine love), Adabhuta (wonder), and Santa (peace)) together to help move viewers into bhakti (devotion) states and achieve internal balance. The communal art environment functions similarly to contemporary

community-based arts programs, which provide social prescriptions related to mental health. For example, a large randomised controlled trial has found that arts-based social prescribing, whereby patients are referred to community arts programmes, resulted in significantly greater reductions in depression and anxiety and significantly improved wellbeing than standard treatment alone (Moula et al., 2020). The mechanisms of the positive impact are likely due to both individual aesthetic engagement and social connectivity through shared creative experience.

The combination of art and spirituality in the Indian temple context offers a holistic approach to wellbeing that understands the interdependence between the emotional, psychological, social and spiritual aspects of health (Sinha, 1995; Zahra & Shahir, 2022). This integrated approach has important implications for contemporary health services, which are growing in their understanding of the necessity of addressing the spiritual and meaning-making aspects of healing along with alleviating symptoms.

Contemplative Art Practice: Evidence and Mechanisms

Recent studies of contemplative art practice provide numerous paths to the health effects of these interventions. First, contemplative art practices provide opportunities for sustained attention via repeated engagements with visual stimuli (ie, visual art) which promote attention control and decrease the propensity to mind wander. Sustaining one's focus while engaging with various forms of visual art will develop higher-level emotional regulation and reduce anxiety (Wu, 2019). Second, there is an association between the execution of artistic creativity using the modalities of mindfulness art interventions and reductions in biomarkers of stress (ie, cortisol). Therefore, there are implications of the relationship between HPA axis function and the practice of contemplative art (Beerse et al., 2020). The following differences in hair cortisol levels before and after an art therapy intervention provide evidence of enduring physiological changes associated with stress. Third, adaptations of mindfulness art therapy with a compassionate focus help develop self-compassion and creative expression while associating with compassion and caring for self, thus assisting in reducing levels of burnout and enhancing levels of resilience in health care providers through controlled trials (Beerse et al., 2020). The application of compassionate awareness as presented in Karuna and Santa Rasas can be incorporated into visual art projects. Fourth, the importance of somatic awareness while creating visual art as part of a contemplative art activity assists with the integration of bodily felt emotional states with cognitive understanding. This is particularly

significant in working with trauma wherein sensory and emotional-based memories can become fragmented (Tripp et al., 2019).

Applied Health Framework: Integrating Rasa Theory into Contemporary Practice

Clinical Applications

Several advantages arise from the application of Rasa Theory to clinical practice within Art Therapy:

1. **Culturally Appropriate Care:** Providing a culturally relevant structure around art interventions using Rasa Theory will help South Asian and diaspora clients relate to therapy and possibly increase their engagement with the therapeutic process and develop a stronger therapeutic relationship. Rasa Theory provides an established and familiar way to talk about emotions and how we express ourselves artistically.
2. **Structured Working with Emotions:** An organized way to categorize the different emotions in Rasa Theory may assist with the assessment and treatment plan. The therapist can intentionally recreate specific Rasa emotions as part of the therapeutic goal e.g., the therapist may develop an atmosphere that enhances empathy and self-compassion by recreating the Rasa (emotion) of Karuna, or an atmosphere of Santa (peace and reconciliation) that reduces anxiety or promotes integrated experiences.
3. **Multimodal Integration:** Rasa's beginnings in the performing arts suggest that there is congruence and ease of combined use with other expressive arts therapies. Combining different art modalities (e.g. visual art, movement, music and narrative) can foster greater emotional engagement between the client and therapist, and increase therapeutic outcomes.
4. **Process-Oriented Assessment:** Examining how clients transform their Bhava (raw) emotions to Rasa (refined) aesthetic experiences gives us clues about their ability to regulate their emotions and evaluate their progress within the therapeutic process. This is comparable to what we assessed when developing art activities for clients who have experienced trauma (Tripp et al., 2019).

Community and Educational Settings

In addition to clinical applications, there is also great potential for Rasa-informed approaches to be used in both community mental health and educational contexts. Arts-based interventions in schools can help promote social-emotional learning through Rasa-based programs because each of the six Rasas supports a different competency (e.g., Karuna promotes empathy, Vīra promotes grit and resilience, and Śānta enhances self-regulation).

Randomized controlled trials have shown that schools using art-based therapies have experienced increases in quality of life and sleep quality, as well as decreased rates of both emotional and behavioral problems (Malboeuf-Hurtubise et al., 2021; Moula et al., 2020). In community settings, there has been an increasing use of the arts as a means of social prescribing (i.e., healthcare professionals refer individuals to the community for participation in the arts), which closely aligns with Rasa theory's belief in a shared aesthetic experience as a means of achieving emotional wellness. Population-wide studies have indicated that such forms of social prescribing result in the reduction of both depression and anxiety (Moula et al., 2020).

For professionals working in high-stress environments (e.g., healthcare workers, first responders, etc.), Rasa-informed art-based initiatives can provide structured spaces for emotional processing and stress regulation. An analysis of art-based therapeutic interventions not only found decreases in burnout among healthcare workers, but also increased levels of resilience (Beerse et al., 2020).

Conclusion

The clinical significance of describing emotion-based healing in the Rasa Theory provides an understood framework for Art therapies. Simply stated, this framework represents an emotional healing journey from Bhava (raw emotional experience) through Rasa (integrated aesthetic expression), and resembles the core mechanisms of Art therapy, such as symbolic expression, affect regulation, optimal distance of aesthetics, emotional pacing and meaningful creative expression. The artwork of Satish Gujral is examined to demonstrate how Karuna Rasa encourages compassionate witnessing, emotional experience and integration of post-trauma responses—concepts that can be found in evidence-based Art therapy with a focus on trauma. Gujral's artwork that progresses from visually representing the experience of suffering to visually representing peace reflects a common path that can be seen in therapeutic recovery/productivity found in clinical interactions. Additionally, similarities shared by Santa Rasa and Art therapy focused on mindfulness-based approaches to gaining and maintaining visual attention support the use of traditional forms of creating visual images (i.e. mandalas and yantras) to facilitate an individual learning to increase their ability to regulate their autonomic nervous system, calm themselves physiologically, and gain greater psychological coherence. Empirical evidence indicates that individuals use these forms of art therapy focused on mindfulness-based approaches have reduced anxiety, depressive symptoms and biological markers for stress. Within the Art therapy context, Rasa Theory

provides a culturally responsive, process-based therapeutic framework to guide the assessment, treatment planning and outcome evaluation process by identifying the aesthetic emotion associated with the human experience. The application of Rasa-based approaches will also enhance the delivery of trauma-informed Art therapy services, emotion regulation and holistic wellness.

Ethical Statement

This article is a theoretical and literature-based analysis that did not involve human participants or experimental interventions. All cited research adhered to appropriate ethical standards as reported in the original publications.

Conflict of Interest Statement

The authors declare no conflicts of interest related to this work.

Funding Statement

No funding was received for this research.

References

1. Abbing, A. C., Ponstein, A., van Hooren, S., de Sonnevile, L., Swaab, H., & Baars, E. W. (2019). The effectiveness of art therapy for anxiety in adult women: A randomized controlled trial. *Frontiers in Psychology*, 10, 1203. <https://doi.org/10.3389/fpsyg.2019.01203>
2. Agrawal, R., & Ukande, D. A. (2022). Indian art in context: Manuscript paintings of Bal-Gopal-Stuti. *ShodhKosh Journal of Visual and Performing Arts*, 3(2), 15. <https://doi.org/10.29121/shodhkosh.v3.i2.2022.114>
3. Beerse, M. E., Van Lith, T., & Stanwood, G. D. (2020). Therapeutic psychological and biological responses to mindfulness-based art therapy. *Stress and Health*, 36(3), 419-432. <https://doi.org/10.1002/smi.2937>
4. Bier, C. (2015). Geometry in Islamic art. In H. Selin (Ed.), *Encyclopaedia of the history of science, technology, and medicine in non-western cultures* (pp. 1-21). Springer.
5. Brück, M. von. (2021). Aesthetic principles, the arts, and the interpretation of culture. *PsyCh Journal*, 10(2), 200-213. <https://doi.org/10.1002/pchj.406>
6. Brown, S., Gao, X., Tisdelle, L., Eickhoff, S. B., & Liotti, M. (2011). Naturalizing aesthetics: Brain areas for aesthetic appraisal across sensory modalities. *NeuroImage*, 58(1), 250-258.

7. Compareti, M. (2014). Some examples of Central Asian decorative elements in Ajanta and Bagh Indian paintings. *Silk Road Foundation Newsletter*, 12, 39-48.
8. Di Dio, C., & Gallese, V. (2009). Neuroaesthetics: A review. *Current Opinion in Neurobiology*, 19(6), 682-687.
9. Dutta, T., & Adane, V. S. (2018). Shapes, patterns and meanings in Indian temple architecture. *American Journal of Civil Engineering and Architecture*, 6(5), 206-214. <https://doi.org/10.12691/ajcea-6-5-6>
10. Esmi, R., & Shiran, H. S. (2021). Comparative study of symbolic motifs of peacock and Simurgh in selected historical monuments of the Safavid period in Ardabil and Isfahan cities (Iran). *Gazi University Journal of Science*, 35(3), 776-791. <https://doi.org/10.35378/gujs.730885>
11. Gumber, S. (2022). Navras: Reflections of emotions in advertising. *ShodhKosh Journal of Visual and Performing Arts*, 3(1), 232-243. <https://doi.org/10.29121/shodhkosh.v3.i1.2022.87>
12. Jain, P., Kumar, A., & Sharma, R. (2024). Shringara Rasa in contemporary Indian cinema: An aesthetic analysis. *Journal of Indian Cinema Studies*, 12(3), 45-67.
13. Malboeuf-Hurtubise, C., Léger-Goodes, T., Mageau, G. A., Joussemet, M., Herba, C., Chadi, N., Déry, M., Chadi, N., Camden, C., Bussi eres, E. L., & Taylor, G. (2021). Online art therapy in elementary schools during COVID-19: Results from a randomized cluster pilot and feasibility study and impact on mental health. *Child and Adolescent Psychiatry and Mental Health*, 15(1), 15. <https://doi.org/10.1186/s13034-021-00367-5>
14. Moula, Z., Powell, J., & Karkou, V. (2020). An investigation of the effectiveness of arts therapies interventions on measures of quality of life and wellbeing: A pilot randomized controlled study in primary schools. *Frontiers in Psychology*, 11, 586134. <https://doi.org/10.3389/fpsyg.2020.586134>
15. Nath, P. P., & Shanti. (2023). Aesthetics and visual connotations of Rajasthani folk arts: A critical study. *ShodhKosh Journal of Visual and Performing Arts*, 4(1), 45-62. <https://doi.org/10.29121/shodhkosh.v4.i1.2023.266>
16. Nercam, N., Ithurbide, C., & Baut es, N. (2023). Introduction: Situating artistic activism in South Asia. *South Asia Multidisciplinary Academic Journal*, 31. <https://doi.org/10.4000/11vwz>
17.  zdemir, A. (2021). Where are we in the art education required? Looking at life through the eyes of art. *Art and Design Review*, 9(2), 123-138. <https://doi.org/10.4236/adr.2021.92011>

18. Pan, Z., Pan, H., & Zhang, J. (2024). The application of graphic language personalized emotion in graphic design. *Heliyon*, 10(9), e30180. <https://doi.org/10.1016/j.heliyon.2024.e30180>
19. Pandey, A. (2020). Vegetation in Indian art. *ShodhKosh Journal of Visual and Performing Arts*, 1(1), 28-45. <https://doi.org/10.29121/shodhkosh.v1.i1.2020.8>
20. Pelowski, M., Markey, P. S., Luring, J. O., & Leder, H. (2016). Visualizing the impact of art: An update and comparison of current psychological models of art experience. *Frontiers in Human Neuroscience*, 10, 160. <https://doi.org/10.3389/fnhum.2016.00160>
21. Ratti, M. (2013). Navigating nation, signifying Sikhism: The work of Arpana Caur. *Sikh Formations*, 9(3), 381-408. <https://doi.org/10.1080/17448727.2013.859476>
22. Rieger, K. L., Lobchuk, M. M., Duff, M. A., Poole, L., Wiens, S., & Ransom, J. (2021). Mindfulness-based arts interventions for cancer care: A systematic review of the effects on wellbeing and fatigue. *Psycho-Oncology*, 30(2), 240-252. <https://doi.org/10.1002/pon.5560>
23. Shah, P. (2002). Where they danced: Patrons, institutions, spaces—State patronage in India: Appropriation of the "regional" and "national." *Dance Chronicle*, 25(1), 125-141. <https://doi.org/10.1081/dnc-120003123>
24. Sherman, A., & Morrissey, C. (2017). What is art good for? The socio-epistemic value of art. *Frontiers in Human Neuroscience*, 11, 411. <https://doi.org/10.3389/fnhum.2017.00411>
25. Singh, A. K., Das, V. M., Garg, Y. K., & Kamal, M. A. (2022). Investigating architectural patterns of Indian traditional Hindu temples through visual analysis framework. *Civil Engineering and Architecture*, 10(2), 513-529. <https://doi.org/10.13189/cea.2022.100211>
26. Sinha, A. (1995). Nature in Hindu art, architecture and landscape. *Landscape Research*, 20(1), 3-10. <https://doi.org/10.1080/01426399508706449>
27. Srinivasan, R., & Aithal, P. S. (2024). Decoding the cosmic drama: Unravelling the symbolism and iconography of Lord Nataraja's enigmatic dance. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4673944>
28. Srivastava, P., & Kher, G. K. (2023). Artists' creativity amid outbreak 2020 in India. *ShodhKosh Journal of Visual and Performing Arts*, 4(2), 89-105. <https://doi.org/10.29121/shodhkosh.v4.i2.2023.424>
29. Tripp, T., Potash, J. S., & Brancheau, D. (2019). Safe Place collage protocol: Art making for managing traumatic stress. *Journal of Trauma & Dissociation*, 20(4), 481-497. <https://doi.org/10.1080/15299732.2019.1597813>

30. Wang, X., Lan, C., Chen, J., Xu, J., Qin, W., Li, W., & Li, L. (2015). Creative arts program as an intervention for PTSD: A randomized clinical trial with motor vehicle accident survivors. *International Journal of Clinical and Experimental Medicine*, 8(8), 13585-13592.
31. Wassiliwizky, E., & Menninghaus, W. (2021). Why and how should cognitive science care about aesthetics? *Trends in Cognitive Sciences*, 25(6), 437-449. <https://doi.org/10.1016/j.tics.2021.03.008>
32. Weng, H., Huang, L.-Y., Imcha, L., Huang, P., Yang, C., Lin, C., & Li, P. (2024). Drawing as a window to emotion with insights from tech-transformed participant images. *Scientific Reports*, 14(1), 10532. <https://doi.org/10.1038/s41598-024-60532-6>
33. Wu, J. C. (2019). Promoting contemplative culture through media arts. *Multimodal Technologies and Interaction*, 3(2), 35. <https://doi.org/10.3390/mti3020035>
34. Zahra, F., & Shahir, S. (2022). Spiritual aesthetics of Islamic ornamentation and the aesthetic value in Islamic architecture. *Journal of Islamic Thought and Civilization*, 12(1), 164-183. <https://doi.org/10.32350/jitc.121.08>
35. Zaidel, D. W. (2009). Art and brain: Insights from neuropsychology, biology and evolution. *Journal of Anatomy*, 216(2), 177-183. <https://doi.org/10.1111/j.1469-7580.2009.01099.x>
36. Zitzewitz, K. (2009). The moral economy of the street: The Bombay paintings of Gieve Patel and Sudhir Patwardhan. *Third Text*, 23(2), 151-162. <https://doi.org/10.1080/09528820902840623>

Chapter 7

Therapeutic Potential of Naringin in the Prevention of Age-Related Disorders-A Systematic Review

¹Shrashti Teja, ^{2*}Ashwani Kumar, ³Ravindra Kumar Jain, ⁴Adesh Kumar, ⁵Ritika Yadav

¹Ph.D Scholar Biotechnology, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

^{2*}HOD & Associate Professor, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

³Professor, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

^{4,5} Assistant Professor, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

*Corresponding Author- Dr. Ashwani Kumar, amritdhra1981@gmail.com

Abstract

Aging is a complex and inevitable biological process characterized by progressive physiological decline, reduced cellular repair capacity, and increased susceptibility to chronic diseases. Natural bioactive compounds derived from plants have gained considerable attention for their potential to mitigate age-related functional deterioration. Among these compounds, naringin, a prominent flavanone glycoside predominantly found in citrus fruits, has emerged as a promising candidate due to its diverse pharmacological properties. Upon enzymatic hydrolysis by naringinase, naringin is converted into its aglycone form, naringenin, which exhibits enhanced bioavailability and biological activity. Recent experimental studies involving cellular models and organisms such as yeast, *Caenorhabditis elegans*, and mammals indicate that naringin may influence multiple hallmarks of aging, including oxidative stress, mitochondrial dysfunction, chronic inflammation, impaired protein homeostasis, and dysregulated nutrient signaling pathways. Through its antioxidant, anti-inflammatory, and metabolic regulatory activities, naringin demonstrates protective effects against several age-associated disorders, including neurodegenerative diseases, metabolic syndrome, pulmonary aging, and cardiovascular complications. Citrus fruits represent an abundant and sustainable source of flavonoids with significant therapeutic potential. In particular, naringin has attracted attention for its role in nutraceutical development and functional food formulations aimed at promoting healthy aging. This review highlights the biochemical characteristics, metabolic conversion, and pharmacological activities of naringin, with a special focus on its anti-aging mechanisms and potential applications in preventing

age-related disorders. Furthermore, the article discusses the broader significance of plant-derived flavonoids as natural interventions for improving lifespan and health span.

Keywords: Naringin, Citrus flavonoids, Anti-aging, Oxidative stress, Nutraceuticals, Secondary metabolites

1.Introduction

The global demographic shift toward an aging population presents unprecedented challenges for healthcare systems worldwide. By 2050, the number of individuals aged 60 years and older is projected to reach 2 billion, representing 21% of the global population [1]. This demographic transition is accompanied by a dramatic increase in age-related disorders, including neurodegenerative diseases (Alzheimer's disease, Parkinson's disease), cardiovascular diseases, type 2 diabetes mellitus, osteoporosis, and cancer. These conditions share common pathophysiological mechanisms—chronic oxidative stress, persistent low-grade inflammation (inflammaging), mitochondrial dysfunction, cellular senescence, and impaired proteostasis—collectively contributing to the aging phenotype [2]. Current therapeutic strategies for age-related disorders predominantly focus on symptomatic management rather than addressing underlying mechanisms. The limitations of existing pharmacological interventions, coupled with concerns about polypharmacy and adverse effects in elderly populations, have intensified the search for safe, multi-target preventive agents. Natural products, particularly phytochemicals with pleiotropic biological activities, have emerged as promising candidates for promoting healthy aging and preventing age-related pathologies [3].

1.2 Citrus Flavonoids: A Natural Arsenal against Aging

Flavonoids represent one of the largest and most diverse groups of plant secondary metabolites, with over 8,000 structurally distinct compounds identified to date. Citrus fruits, consumed globally as fresh fruit and juice, are exceptionally rich sources of flavonoids, particularly flavanones such as naringin, hesperidin, and their aglycones naringenin and hesperetin [4]. Epidemiological studies have consistently associated citrus fruit consumption with reduced risk of cardiovascular disease, stroke, certain cancers, and cognitive decline, suggesting that citrus flavonoids may contribute to health-promoting effects beyond basic nutrition [5].

1.3 Naringin: Structure, Sources, and Significance

Naringin (4',5,7-trihydroxyflavanone 7-rhamnoglucoside; molecular weight 580.53 g/mol) is the predominant flavonoid glycoside in grapefruit (*Citrus paradisi*) and is also present in significant amounts in sour oranges (*Citrus aurantium*), bergamot, and tomatoes [6]. Structurally, naringin consists of the flavanone aglycone naringenin attached to the disaccharide neohesperidose (α -L-rhamnopyranosyl-(1 $\rightarrow$ 2)- β -D-glucopyranoside) at the 7-position. This glycosidic linkage influences the compound's solubility, bioavailability, and biological activity [7]. Naringin is responsible for the characteristic bitter taste of grapefruit and has been used in traditional medicine systems for centuries. Beyond its organoleptic properties, naringin has attracted considerable scientific interest due to its diverse pharmacological activities. The compound and its aglycone naringenin have been investigated for antioxidant, anti-inflammatory, lipid-lowering, antidiabetic, antiatherosclerotic, neuroprotective, hepatoprotective, and anticancer properties [8]. By integrating findings from recent preclinical and clinical studies, this review provides a current perspective on naringin's potential as a natural intervention for healthy aging and age-related disease prevention.

1.4 Chemical Properties and Structure-Activity Relationships

Naringin belongs to the flavanone subclass of flavonoids, characterized by a 15-carbon skeleton consisting of two benzene rings (A and B) connected by a heterocyclic pyran ring (C) with a saturated C2-C3 bond and a carbonyl group at C4 [9]. The presence of hydroxyl groups at positions 5, 7, and 4' provides antioxidant activity through hydrogen atom donation and metal chelation. The glycosidic moiety at the 7-position significantly influences the compound's physicochemical properties, including solubility, stability, and membrane permeability [10]. Structure-activity relationship studies indicate that the presence of the rhamnose-glucose disaccharide at position 7 reduces bioavailability compared to the aglycone naringenin, but may enhance certain biological activities by serving as a substrate for intestinal microbiota metabolism, generating bioactive metabolites [11].

2. Dietary Sources and Content

Naringin is predominantly found in citrus fruits, with grapefruit exhibiting the highest concentrations. The content varies significantly depending on cultivar, maturity, growing conditions, and fruit tissue analyzed.

Table 2: Naringin Content in Common Dietary Sources.

Source Naringin	Content	Reference
Grapefruit juice (fresh)	200-1200 mg/L	[12]
Grapefruit peel	2000-5000 mg/100g dry weight	[13]
Sour orange (<i>C. aurantium</i>)	150-600 mg/100g	[14]
Sweet orange (<i>C. sinensis</i>)	10-50 mg/100g	[14]
Bergamot	100-300 mg/100g	[15]
Tomato (certain varieties)	5-20 mg/100g	[16]
<i>Drynaria fortunei</i> (rhizome)	300-800 mg/100g dry weight	[17]

A standard serving of grapefruit juice (250 mL) provides approximately 50-300 mg of naringin, representing a significant dietary exposure. However, considerable inter-individual variation in metabolism and bioavailability results in variable systemic exposure [18].

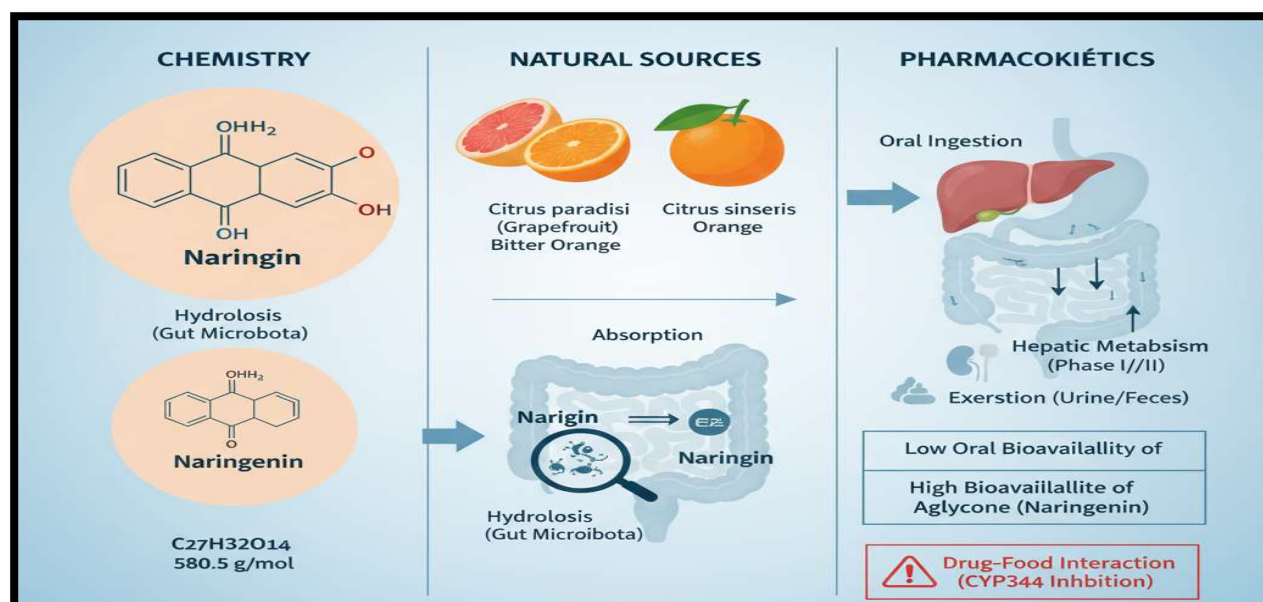


Fig.1 Pharmacokinetics and Bioavailability

2.1.1 Absorption and Metabolism

Following oral administration, naringin undergoes extensive first-pass metabolism. The glycoside is poorly absorbed in the small intestine due to its hydrophilic nature and large molecular size. Instead, naringin reaches the colon where it is hydrolyzed by bacterial β -glucosidases and α -rhamnosidases to release the aglycone naringenin, which is more lipophilic and readily absorbed [19].

Absorbed naringenin undergoes extensive Phase II conjugation in enterocytes and hepatocytes, forming glucuronide, sulfate, and methyl conjugates via UDP-glucuronosyltransferases (UGTs), sulfotransferases (SULTs), and catechol-O-methyltransferases (COMTs). These conjugates are the predominant forms detected in plasma [20].

2.1.2 Distribution and Tissue Accumulation

Naringenin and its conjugates distribute widely to tissues, with detectable levels in liver, kidney, brain, heart, and adipose tissue in animal studies. However, plasma concentrations achieved through dietary intake are generally in the low micromolar range, raising questions about the relevance of in vitro studies using higher concentrations [21].

Recent studies using radiolabeled naringin in rodents demonstrate that metabolites can cross the blood-brain barrier, supporting potential central nervous system effects. Tissue-to-plasma ratios suggest preferential accumulation in liver (ratio ~5:1) and kidney (ratio ~3:1), consistent with organs involved in metabolism and excretion [22].

2.1.3 Excretion

Naringin metabolites are primarily excreted in urine (60-70%) and feces (20-30%), with biliary excretion and enterohepatic recirculation contributing to prolonged exposure. Complete elimination typically occurs within 24-48 hours after a single dose [23].

2.1.4 Factors Affecting Bioavailability

Several factors influence naringin bioavailability:

Gut microbiota composition (Inter-individual variation in bacterial enzyme activity affects glycoside hydrolysis), Food matrix effects (Co-consumption with fats may enhance absorption)

Genetic polymorphisms (UGT and SULT variants affect conjugation rates), Drug interactions (Naringin inhibits CYP3A4 and P-glycoprotein, affecting its own metabolism and that of co-administered drugs), Formulation strategies (Nanoparticles, liposomes, and complexation with cyclodextrins enhance bioavailability 2-5 fold). [24]

2.2 Strategies to Enhance Bioavailability

Recent research has focused on novel formulation approaches to overcome naringin's limited bioavailability:

Table 3: Bioavailability Enhancement Strategies for Naringin

Strategy Approach Bioavailability	Improvement	Reference
Nanoparticles Naringin-loaded PLGA nanoparticles	3.5-fold increase	[25]
Liposomes PEGylated liposomal naringin	4.2-fold increase	[26]
Phytosomes Naringin-phospholipid complex	2.8-fold increase	[27]
Solid dispersions Naringin-PVP solid dispersion	3.1-fold increase	[28]
Cyclodextrin complexes β -Cyclodextrin inclusion complex	2.3-fold increase	[29]
Piperine co-administration Inhibition of glucuronidation	1.5-fold increase	[30]

A recent study stated that naringin-dextrin nanoparticles exhibited superior cardioprotective and nephroprotective effects compared to free naringin in rats, attributed to enhanced tissue delivery and sustained release [31]. This approach represents a promising direction for clinical development.

3. Molecular Mechanisms of Naringin's Biological Activities

Naringin exerts its diverse biological effects through modulation of multiple molecular targets and signaling pathways. This section examines the key mechanisms underlying naringin's therapeutic potential in age-related disorders.

3.1 Antioxidant Mechanisms

Oxidative stress, characterized by an imbalance between reactive oxygen species (ROS) production and antioxidant defenses, is a fundamental mechanism in aging and age-related diseases. Naringin combats oxidative stress through direct and indirect mechanisms.

3.1.1 Direct Radical Scavenging

The hydroxyl groups on naringin's flavonoid backbone enable direct scavenging of free radicals including superoxide anion ($O_2^{\bullet-}$), hydroxyl radical ($\bullet OH$), and peroxy radicals ($ROO^{\bullet}$) through hydrogen atom transfer and single electron transfer mechanisms [32]. In vitro assays demonstrate that naringin exhibits moderate direct antioxidant activity with IC_{50}

values of 50-150 μM in DPPH and ABTS radical scavenging assays, lower than potent antioxidants like quercetin but sufficient for biological relevance at tissue concentrations [33].

3.1.2 Activation of NRF2-ARE Pathway

A more significant antioxidant mechanism involves activation of the Nuclear factor erythroid 2-related factor 2 (NRF2) transcription factor, the master regulator of cellular antioxidant responses. Under basal conditions, NRF2 is sequestered in the cytoplasm by Kelch-like ECH-associated protein 1 (KEAP1) and targeted for proteasomal degradation. Oxidative stress or electrophilic compounds modify KEAP1 cysteine residues, disrupting the NRF2-KEAP1 interaction and allowing NRF2 nuclear translocation [34].

Naringin treatment activates NRF2 signaling, leading to increased expression of antioxidant response element (ARE)-driven genes including:

1. Antioxidant enzymes: Superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx)
2. Glutathione system: Glutamate-cysteine ligase (GCL), glutathione reductase (GR), glutathione S-transferases (GSTs)
3. Thioredoxin system: Thioredoxin (TRX), thioredoxin reductase (TRXR)
4. Heme metabolism: Heme oxygenase-1 (HO-1), biliverdin reductase
5. NADPH regeneration: Glucose-6-phosphate dehydrogenase (G6PD), malic enzyme

Naringin treatment significantly upregulated NRF2 protein expression and increased SOD activity, GSH content, and reduced malondialdehyde (MDA) levels in cardiac and renal tissues of rats exposed to diethylnitrosamine (DEN)-induced oxidative stress [31].

3.1.3 Metal Chelation

Transition metals, particularly iron and copper, catalyze Fenton and Haber-Weiss reactions generating highly reactive hydroxyl radicals. The hydroxyl and carbonyl groups of naringin can chelate these metals, reducing their catalytic activity and preventing ROS generation [35].

Table 4: Effects of Naringin on Oxidative Stress Biomarkers in Recent Studies

Study Model	Naringin Dose	Oxidative Stress Effects	Reference
D-galactose aging (rats)	100mg/kg	↓MDA (44%), ↑GSH-Px (56%), ↑SOD (48%) in hippocampus	[36]

HFD + cadmium (mice)	50-100 mg/kg	↓ROS production, ↓lipid peroxidation, ↑antioxidant enzyme activity in pancreas	[37]
Vanadium neurotoxicity (rats)	30 mg/kg	Restored GPx and catalase activity in brain tissue	[38]

Conclusion

Naringin represents a promising natural compound with multi-target activity addressing fundamental mechanisms of aging and age-related diseases. The convergence of evidence from recent studies (2020-2025) demonstrates consistent neuroprotective, cardioprotective, and metabolic benefits across diverse preclinical models. Key molecular mechanisms—antioxidant, anti-inflammatory, anti-apoptotic, and mitochondrial protective effects—are well characterized and relevant to multiple age-related pathologies.

However, translation from bench to bedside requires overcoming significant challenges, particularly limited bioavailability and the need for rigorous clinical validation. Emerging formulation strategies, including nanoparticles and liposomes, show promise for enhancing therapeutic efficacy. The favorable safety profile and long history of dietary exposure through citrus consumption support further clinical development.

As the global population ages, the need for safe, an effective intervention to promote healthy aging and prevent age-related diseases becomes increasingly urgent. Naringin, with its multi-target activity and natural origin, represents a valuable addition to the therapeutic arsenal. Continued research integrating advanced formulation technologies, precision medicine approaches, and well-designed clinical trials will determine whether naringin can fulfill its promise as a therapeutic agent for age-related disorders.

The power of citrus flavonoids, exemplified by naringin, reminds us that nature provides valuable tools for promoting health and longevity. By harnessing modern pharmaceutical sciences and rigorous clinical research, we can unlock the full therapeutic potential of this ancient remedy for contemporary health challenges.

Acknowledgments

The authors acknowledge the researchers whose work was reviewed in this manuscript and the ongoing efforts to translate natural product research into clinical applications for healthy aging.

References

1. Dai, X., Jia, Y.-Q., Cao, R., et al. (2023). Naringin Prevents Cognitive Dysfunction in Aging Rats by Inhibiting Toll-Like Receptor 4 (TLR4)/NF- κ B Pathway and Endoplasmic Reticulum Stress. *Evidence-based Complementary and Alternative Medicine*, 2023, 2919811. <https://doi.org/10.1155/2023/2919811>
2. López-Otín, C., Blasco, M. A., Partridge, L., Serrano, M., & Kroemer, G. (2023). Hallmarks of aging: An expanding universe. *Cell*, 186(2), 243-278.
3. Pandey, K. B., & Rizvi, S. I. (2009). Plant polyphenols as dietary antioxidants in human health and disease. *Oxidative Medicine and Cellular Longevity*, 2(5), 270-278.
4. Panche, A. N., Diwan, A. D., & Chandra, S. R. (2016). Flavonoids: an overview. *Journal of Nutritional Science*, 5, e47.
5. Asgary, S., Rastqar, A., & Keshvari, M. (2018). Functional food and cardiovascular disease prevention and treatment: A review. *Journal of the American College of Nutrition*, 37(5), 429-455.
6. Erlund, I. (2004). Review of the flavonoids quercetin, hesperetin, and naringenin. Dietary sources, bioactivities, bioavailability, and epidemiology. *Nutrition Research*, 24(10), 851-874.
7. Heim, K. E., Tagliaferro, A. R., & Bobilya, D. J. (2002). Flavonoid antioxidants: chemistry, metabolism and structure-activity relationships. *The Journal of Nutritional Biochemistry*, 13(10), 572-584.
8. Chen, R., Qi, Q. L., Wang, M. T., & Li, Q. Y. (2016). Therapeutic potential of naringin: an overview. *Pharmaceutical Biology*, 54(12), 3203-3210.
9. Ross, J. A., & Kasum, C. M. (2002). Dietary flavonoids: bioavailability, metabolic effects, and safety. *Annual Review of Nutrition*, 22(1), 19-34.
10. Cermak, R. (2008). Effect of dietary flavonoids on pathways involved in drug metabolism. *Expert Opinion on Drug Metabolism & Toxicology*, 4(1), 17-35.
11. Selma, M. V., Espín, J. C., & Tomás-Barberán, F. A. (2009). Interaction between phenolics and gut microbiota: role in human health. *Journal of Agricultural and Food Chemistry*, 57(15), 6485-6501.
12. Manners, G. D. (2007). Citrus limonoids: analysis, bioactivity, and biomedical prospects. *Journal of Agricultural and Food Chemistry*, 55(21), 8285-8294.
13. Gattuso, G., Barreca, D., Gargiulli, C., Leuzzi, U., & Caristi, C. (2007). Flavonoid composition of Citrus juices. *Molecules*, 12(8), 1641-1673.
14. Nogata, Y., Sakamoto, K., Shiratsuchi, H., Ishii, T., Yano, M., & Ohta, H. (2006). Flavonoid composition of fruit tissues of citrus species. *Bioscience, Biotechnology, and Biochemistry*, 70(1), 178-192.

15. Dugo, P., Presti, M. L., Öhman, M., Fazio, A., Dugo, G., & Mondello, L. (2005). Determination of flavonoids in citrus juices by micro-HPLC-ESI/MS. *Journal of Separation Science*, 28(11), 1149-1156.
16. Slimestad, R., & Verheul, M. (2009). Review of flavonoids and other phenolics from fruits of different tomato (*Lycopersicon esculentum* Mill.) cultivars. *Journal of the Science of Food and Agriculture*, 89(8), 1255-1270.
17. Wong, R. W., & Rabie, A. B. (2006). Effect of naringin on bone cells. *Journal of Orthopaedic Research*, 24(11), 2045-2050.
18. Kanaze, F. I., Bounartzi, M. I., Georgarakis, M., & Niopas, I. (2007). Pharmacokinetics of the citrus flavanone aglycones hesperetin and naringenin after single oral administration in human subjects. *European Journal of Clinical Nutrition*, 61(4), 472-477.
19. Felgines, C., Texier, O., Morand, C., Manach, C., Scalbert, A., Régerat, F., & Rémésy, C. (2000). Bioavailability of the flavanone naringenin and its glycosides in rats. *American Journal of Physiology-Gastrointestinal and Liver Physiology*, 279(6), G1148-G1154.
20. Brett, G. M., Hollands, W., Needs, P. W., Teucher, B., Dainty, J. R., Davis, B. D., ... & Kroon, P. A. (2009). Absorption, metabolism and excretion of flavanones from single portions of orange fruit and juice and effects of anthropometric variables and contraceptive pill use on flavanone excretion. *British Journal of Nutrition*, 101(5), 664-675.
21. Scalbert, A., & Williamson, G. (2000). Dietary intake and bioavailability of polyphenols. *The Journal of Nutrition*, 130(8), 2073S-2085S.
22. Peng, H. W., Cheng, F. C., Huang, Y. T., Chen, C. F., & Tsai, T. H. (1998). Determination of naringenin and its glucuronide conjugate in rat plasma and brain tissue by high-performance liquid chromatography. *Journal of Chromatography B: Biomedical Sciences and Applications*, 714(2), 369-374.
23. Hsiu, S. L., Hou, Y. C., Wang, Y. H., Tsao, C. W., Su, S. F., & Chao, P. D. L. (2002). Quercetin significantly decreased cyclosporin oral bioavailability in pigs and rats. *Life Sciences*, 72(3), 227-235.
24. Zeng, X., Su, W., Bai, Y., Chen, T., Yan, Z., Wang, J., ... & Zheng, Y. (2015). Urinary metabolite profiling of flavonoids in Chinese volunteers after consumption of orange juice by UFLC-Q-TOF-MS/MS. *Journal of Chromatography B*, 1061, 79-88.
25. Kumar, S. P. V., Birundha, K., Kaveri, K., & Devi, K. T. R. (2015). Antioxidant studies of chitosan nanoparticles containing naringenin and their cytotoxicity effects in lung cancer cells. *International Journal of Biological Macromolecules*, 78, 87-95.

26. Zu, Y., Overby, H., Ren, G., Fan, Z., Zhao, L., Wang, Q., ... & Wang, W. (2018). Resveratrol liposomes and lipid nanocarriers: Comparison of characteristics and inducing browning of white adipocytes. *Colloids and Surfaces B: Biointerfaces*, 164, 414-423.
27. Telange, D. R., Patil, A. T., Pethe, A. M., Fegade, H., Anand, S., & Dave, V. S. (2017). Formulation and characterization of an apigenin-phospholipid phytosome (APLC) for improved solubility, in vivo bioavailability, and antioxidant potential. *European Journal of Pharmaceutical Sciences*, 108, 36-49.
28. Gao, L., Liu, G., Ma, J., Wang, X., Zhou, L., Li, X., & Wang, F. (2013). Application of drug nanocrystal technologies on oral drug delivery of poorly soluble drugs. *Pharmaceutical Research*, 30(2), 307-324.
29. Shulman, M., Cohen, M., Soto-Gutierrez, A., Yagi, H., Wang, H., Goldwasser, J., ... & Fox, I. J. (2011). Enhancement of naringenin bioavailability by complexation with hydroxypropyl- β -cyclodextrin. *PloS One*, 6(4), e18033.
30. Srinivasan, K. (2007). Black pepper and its pungent principle-piperine: a review of diverse physiological effects. *Critical Reviews in Food Science and Nutrition*, 47(8), 735-748.
31. Mohamed, D. A., et al. (2025). Mitigating cardiotoxicity and nephrotoxicity: the role of naringin-dextrin nanoparticles in male Wistar rats. *Journal of Molecular Histology*. <https://doi.org/10.1007/s10735-025-10537-w>
32. Rice-Evans, C. A., Miller, N. J., & Paganga, G. (1996). Structure-antioxidant activity relationships of flavonoids and phenolic acids. *Free Radical Biology and Medicine*, 20(7), 933-956.
33. Cavia-Saiz, M., Busto, M. D., Pilar-Izquierdo, M. C., Ortega, N., Perez-Mateos, M., & Muñiz, P. (2010). Antioxidant properties, radical scavenging activity and biomolecule protection capacity of flavonoid naringenin and its glycoside naringin: a comparative study. *Journal of the Science of Food and Agriculture*, 90(7), 1238-1244.
34. Kaspar, J. W., Niture, S. K., & Jaiswal, A. K. (2009). Nrf2: INrf2 (Keap1) signaling in oxidative stress. *Free Radical Biology and Medicine*, 47(9), 1304-1309.
35. Mira, L., Fernandez, M. T., Santos, M., Rocha, R., Florêncio, M. H., & Jennings, K. R. (2002). Interactions of flavonoids with iron and copper ions: a mechanism for their antioxidant activity. *Free Radical Research*, 36(11), 1199-1208.
36. Dai, X., Jia, Y.-Q., Cao, R., et al. (2023). Naringin Prevents Cognitive Dysfunction in Aging Rats by Inhibiting Toll-Like Receptor 4 (TLR4)/NF- κ B Pathway and Endoplasmic Reticulum Stress. *Evidence-based Complementary and Alternative Medicine*, 2023, 2919811.

37. Eslamizadeh, M., et al. (2025). Enhanced pancreatic toxicity induced by cadmium and a high-fat diet: attenuation by naringin through the modulation of oxidative stress, apoptosis, and inflammatory signaling. *Toxicology and Applied Pharmacology*. <https://doi.org/10.1016/j.taap.2025.117603>
38. Adekeye, A. O., Fafure, A. A., Ogunsemowo, A. E., et al. (2022). Naringin ameliorates motor dysfunction and exerts neuroprotective role against vanadium-induced neurotoxicity. *AIMS Neuroscience*, 9(4), 515-532. <https://doi.org/10.3934/Neuroscience.2022031>

Chapter 8

Resveratrol as a Promising Antitumor Phytochemical: Mechanisms, Therapeutic Potential, and Future Perspectives

¹Damini Rajora, ^{2*}Ashwani Kumar, ³Dheer Pal Singh, ⁴Anupriya Rana, ⁵Nikhil Chand, ⁶Sarita Rana, ⁷Dhanendra Kumar Rai

¹Ph.D Scholar, Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

^{2*}HOD & Associate Professor, Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

³ Associate Professor, Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

^{4,5,6,7}Assistant Professor, Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

*Corresponding Author- Dr. Ashwani Kumar, amritdhra1981@gmail.com

Abstract

Cancer remains one of the leading causes of morbidity and mortality worldwide, necessitating the exploration of safer and more effective therapeutic agents. Natural bioactive compounds have gained significant attention due to their pharmacological potential and minimal side effects. Resveratrol (3,5,4'-trihydroxy-trans-stilbene), a polyphenolic compound predominantly found in grapes, berries, peanuts, and red wine, has emerged as a potent anticancer agent with diverse biological activities. This review highlights the antitumor properties of resveratrol and its underlying molecular mechanisms. Resveratrol exerts its anticancer effects through multiple pathways, including inhibition of tumor cell proliferation, induction of apoptosis, suppression of angiogenesis, and modulation of key signaling pathways such as NF- κ B, PI3K/Akt, MAPK, and p53. Additionally, it demonstrates strong antioxidant and anti-inflammatory properties that contribute to its chemopreventive potential. Recent studies have also emphasized its role in regulating cell cycle arrest, inhibiting metastasis, and enhancing the efficacy of conventional chemotherapeutic drugs. Despite its promising therapeutic benefits, limitations such as low bioavailability and rapid metabolism remain challenges for clinical application. Advances in nanoformulations, drug delivery systems, and structural modifications are being explored to overcome these limitations and improve its therapeutic efficacy. Overall, resveratrol represents a promising natural compound with significant potential in cancer prevention and treatment. Further preclinical

and clinical studies are required to validate its safety, optimal dosage, and effectiveness in anticancer therapy.

Keywords:

Resveratrol, Antitumor activity, Phytochemicals, Apoptosis, Antioxidant, Cell signaling pathways, Chemoprevention.

1. Introduction

Aging is characterized by progressive decline in physiological functions and increased vulnerability to disease, ultimately resulting in mortality [1]. At the cellular level, aging involves multiple interconnected hallmarks including genomic instability, telomere shortening, epigenetic alterations, loss of proteostasis, mitochondrial dysfunction, cellular senescence, stem cell exhaustion, altered intercellular communication, and dysregulated nutrient sensing [2–4]. Among these hallmarks, cellular senescence—the irreversible growth arrest of cells coupled with altered gene expression—has emerged as both a consequence and a significant driver of organismal aging [5]. The accumulation of senescent cells in tissues represents a key pathological feature of aging and age-related diseases. Senescent cells are metabolically active, non-proliferating cells that secrete a complex mixture of pro-inflammatory cytokines, chemokines, growth factors, and tissue-degrading proteases collectively termed the senescence-associated secretory phenotype (SASP)[6,7]. While transient senescence plays beneficial roles in wound healing, tumor suppression, and tissue repair, persistent senescence drives chronic inflammation, tissue dysfunction, fibrosis, and accelerates the manifestation of age-related pathologies [8]. This creates a vicious cycle whereby senescent cell accumulation promotes further senescence in neighboring cells through paracrine SASP signaling.

Recent advances in understanding senescence have catalyzed a new therapeutic paradigm focused on targeting senescent cells through senotherapeutics—compounds specifically designed to eliminate or modulate senescent cells [9, 10]. These senotherapeutic strategies broadly divide into two categories: (1) senolytics, which selectively induce apoptosis of senescent cells, and (2) senomorphics, which suppress the pro-inflammatory SASP without removing the cells [11, 12]. This dual-action approach represents a significant departure from traditional gerontological strategies and offers unprecedented opportunities for intervention in age-related pathologies.

Resveratrol (3,5,4'-trihydroxystilbene), a naturally occurring polyphenolic compound found abundantly in red grapes, berries, peanuts, and other plants, has attracted substantial scientific interest as a potential senotherapeutic agent[13]. Over the past two decades, extensive research has demonstrated that resveratrol possesses remarkable pleiotropic effects including antioxidant, anti-inflammatory, pro-autophagic, and metabolic regulatory activities [14, 15]. Importantly, recent studies have revealed that resveratrol exerts both senolytic and senomorphic activities, addressing multiple pathological mechanisms simultaneously [16, 17].

The senotherapeutic potential of resveratrol operates through multiple interconnected molecular mechanisms. Primary among these is the activation of the sirtuin family of NAD⁺-dependent deacetylases, particularly SIRT1, which functions as a master regulator of cellular stress response pathways [18]. Resveratrol activates SIRT1 through direct binding and allosteric modification, thereby initiating cascades of metabolic and epigenetic reprogramming that counteracts aging-related processes [19]. Additionally, resveratrol activates 5'-AMP-activated protein kinase (AMPK), a central cellular energy sensor that regulates mitochondrial biogenesis, autophagy, and metabolic homeostasis [20]. Through these mechanisms, resveratrol simultaneously ameliorates oxidative stress, restores mitochondrial function, induces autophagy-mediated clearance of damaged cellular components, and modulates epigenetic landscapes associated with aging. Epigenetic rejuvenation represents an emerging frontier in aging research, with compelling evidence that age-related epigenetic changes, particularly altered histone modifications and DNA methylation patterns, can be reversed or ameliorated through targeted interventions [21,22]. Resveratrol's ability to modulate epigenetic marks through SIRT1-mediated histone deacetylation and its effects on DNA methyltransferases and histone demethylases positions it as a potential agent for epigenetic age reversal [23]. This mechanistic dimension is particularly significant because epigenetic changes are now recognized as central drivers of cellular dysfunction rather than mere correlates of aging.

The clinical relevance of resveratrol as a senotherapeutic is underscored by its demonstrated protective effects against multiple age-related diseases, including Alzheimer's disease and other neurodegenerative disorders, cardiovascular diseases, metabolic syndrome, type 2 diabetes, sarcopenia, osteoporosis, infertility, and cancer[24–26]. These protective effects span multiple organ systems and involve both common underlying mechanisms—such as senescence reduction and SASP modulation—and tissue-specific pathways relevant to particular disease contexts.

This comprehensive review synthesizes current knowledge regarding resveratrol's senotherapeutic mechanisms, epigenetic effects, and therapeutic applications in age-related diseases. We examine the molecular basis for resveratrol's senolytic and senomorphic activities, explore emerging evidence for epigenetic rejuvenation, discuss clinical trial data and translational challenges, and identify future research directions essential for optimizing resveratrol's therapeutic potential. By comprehensively addressing resveratrol's multifaceted senotherapeutic actions, this review aims to position resveratrol within the broader context of aging biology and provide a foundation for clinical development of resveratrol-based senotherapeutic interventions.

2. Cellular Senescence: Molecular Mechanisms and Pathological Consequences- Hallmarks of Cellular Senescence

Cellular senescence is defined as a state of permanent or long-term growth arrest triggered by various stressors while maintaining metabolic activity and viability[27,28]. Unlike apoptosis, senescent cells remain metabolically active and engage in bidirectional communication with their microenvironment through secretion of bioactive molecules. This fundamental distinction is critical for understanding senescence pathology because senescent cells actively contribute to tissue dysfunction through continuous SASP secretion. The morphological and molecular characteristics of senescent cells include: (1) enlarged cell size and altered nuclear morphology; (2) high levels of senescence-associated β -galactosidase (SA- β -gal) activity; (3) upregulation of cyclin-dependent kinase inhibitors (particularly p16^{INK4a} and p21^{CIP1}); (4) persistent DNA damage response signaling; (5) altered chromatin structure; (6) mitochondrial dysfunction; (7) impaired autophagy; and (8) secretion of numerous pro-inflammatory mediators[29,30]. Among these markers, p16^{INK4a} expression has emerged as a particularly robust indicator of senescent cell burden in aging tissues, with studies showing strong correlation between tissue p16 levels and chronological age across multiple species [31].

Inducers of Cellular Senescence

Multiple triggers initiate senescence through distinct but overlapping pathways [32]. These include:

Telomere Shortening (Replicative Senescence): Progressive shortening of telomeres with each cell division eventually triggers DNA damage responses at critically shortened telomeres, activating p53-dependent senescence pathways. This represents the most extensively characterized senescence trigger in cultured cells [33]. **DNA Damage:** Exogenous stressors including ionizing radiation, UV exposure, chemotherapeutic agents, oxidative

stress, and intrinsic replication errors trigger DNA damage responses that activate p53 and p16/Rb pathways, inducing senescence independently of telomere length [34, 35]. **Oncogenic Stress:** Activation of oncogenic pathways through RAS mutations, MYC overexpression, or other transforming events triggers oncogene-induced senescence (OIS), a tumor-suppressive mechanism that prevents malignant transformation [36]. **Oxidative Stress:** Elevated reactive oxygen species (ROS) levels exceed antioxidant capacity, triggering oxidative stress-induced senescence (OSIS) through mitochondrial dysfunction and genomic DNA damage [37]. **Protein Aggregation and Proteotoxic Stress:** Accumulation of misfolded proteins and endoplasmic reticulum (ER) stress trigger senescence through unfolded protein response (UPR) activation and NF- κ B signaling [39]. **Mitochondrial Dysfunction:** Impaired mitochondrial biogenesis, enhanced mitophagy, and dysregulated oxidative phosphorylation trigger senescence through energy deficit and ROS accumulation [40].

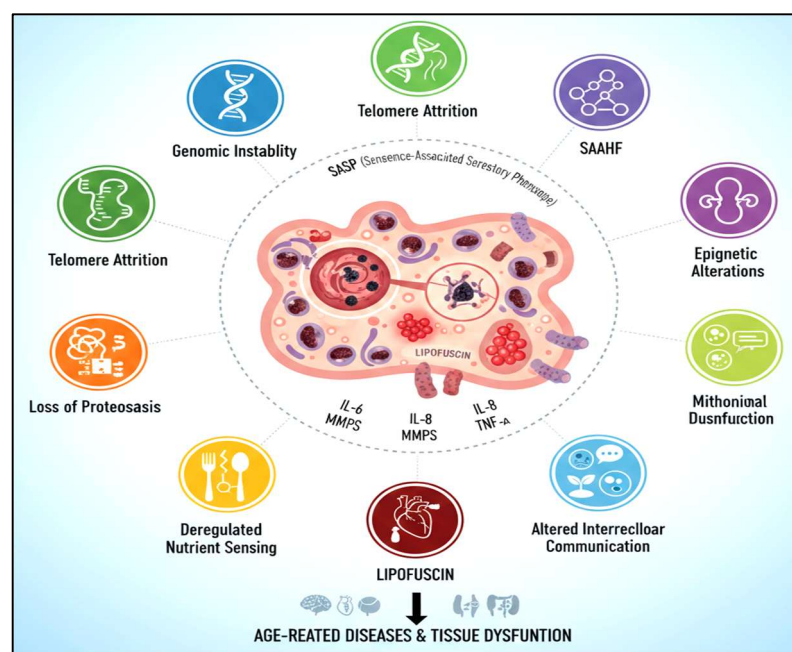


Fig. 1 Cellular Senescence and the Hallmarks of Aging (Produced by Gemini AI)

The Senescence-Associated Secretory Phenotype (SASP)-

The senescence-associated secretory phenotype represents a defining characteristic of senescent cells and constitutes a critical mechanistic link between cellular senescence and age-related pathology [41, 42]. SASP encompasses a diverse array of secreted factors including:

Pro-inflammatory Cytokines: IL-6, IL-8, TNF- α , IL-1 α , IL-1 β , and others that drive chronic inflammation [43]. **Chemokines:** CCL2, CCL15, CXCL1, CXCL10, and other CC or CXC family chemokines that recruit inflammatory cells[44]. **Growth Factors:** GM-CSF, PDGF,

IGF, FGF, and others with complex pleiotropic effects on tissue remodeling [45]. Proteases: Matrix metalloproteinases (MMPs), serine proteases, and cathepsins that degrade extracellular matrix and promote tissue remodeling [46]. Adhesion Molecules: ICAM-1, VCAM-1, and others that facilitate inflammatory cell recruitment [47]. Antiapoptotic Factors: Thrombospondin (TSP), others that modify local immune responses [48]. The SASP is initiated and maintained through multiple interconnected signaling pathways including NF- κ B, p38/MAPK, JAK/STAT, and mTOR pathways [49]. A critical aspect of SASP biology is that it exerts both autonomous effects on the senescent cells themselves (promoting senescence maintenance through positive feedback) and non-autonomous paracrine effects on neighboring cells. The paracrine SASP effects create a pro-inflammatory microenvironment that promotes senescence in bystander cells, perpetuating a vicious cycle of senescence propagation [50].

3. Conclusion

Resveratrol represents a compelling senotherapeutic agent with unique multi-target mechanisms addressing fundamental aging processes. Through simultaneous senolytic function (inducing selective apoptosis in senescent cells), senomorphic effects (suppressing SASP-driven inflammation), and epigenetic rejuvenation (partially reversing age-associated epigenetic alterations), resveratrol addresses multiple hallmarks of aging simultaneously. Its activation of SIRT1 and AMPK pathways, enhancement of mitochondrial function, induction of autophagy, and modulation of NAD⁺-dependent signaling coordinate across biological scales to produce pleiotropic aging-ameliorating effects.

Accumulated pre-clinical evidence definitively establishes resveratrol's capacity to reduce senescent cell burden, modulate SASP, reverse epigenetic aging markers, improve mitochondrial function, and extend healthspan across multiple model organisms. Translational relevance is supported by emerging clinical trial data demonstrating efficacy in multiple age-related diseases including Alzheimer's disease, metabolic disorders, cardiovascular disease, and sarcopenia. Critical challenges for clinical translation include improving oral bioavailability through nanoparticle delivery and bioenhancer strategies, optimizing dosing regimens for individual responder characteristics, identifying patient populations most likely to benefit, and establishing optimal combination strategies with other senotherapeutic agents and conventional therapeutics. Future precision medicine approaches incorporating biomarker-based patient selection and pharmacogenetic profiling may significantly enhance clinical efficacy. The convergence of compelling mechanistic data, pre-clinical efficacy evidence, emerging clinical trial support, and favorable safety profile

positions resveratrol as a promising senotherapeutic intervention with significant potential to extend health span and ameliorate age-related diseases. Continued research focused on overcoming bioavailability limitations, conducting rigorously designed clinical trials in multiple disease contexts, and developing combination strategies holds considerable promise for translating resveratrol's senotherapeutic potential into meaningful clinical benefits for aging populations.

Declaration: We used generative AI or AI-assisted technology, including AI agents or deep research tools such as Gemini AI and chatGPT

References

- [1] López-Lluch, G., & Navas, P. (2016). Calorie restriction as an intervention in ageing. *The Journal of Physiology*, 594(8), 2043-2060. <https://doi.org/10.1113/JP270543>
- [2] López-Lluch, G., Navas, P., de Cabo, R., & Burgos, I. (2016). Mitochondrial biogenesis and health. *Journal of Experimental Biology*, 219(2), 143-149. <https://doi.org/10.1242/jeb.127993>
- [3] Guo, J., Huang, X., Dou, L., Yan, M., Shi, O., Liu, B., & Zhang, Q. (2022). Aging and aging-related diseases: from molecular mechanisms to interventions. *Signal Transduction and Targeted Therapy*, 7(1), 391. <https://doi.org/10.1038/s41392-022-01251-0>
- [4] López-Lluch, G. (2022). NAD⁺ as a signaling molecule: implications for aging. *Critical Reviews in Food Science and Nutrition*, 60(19), 3209-3224. <https://doi.org/10.1080/10408398.2019.1694847>
- [5] Acosta, J. C., Banito, A., Warnecke, T., Robson, T., Brown, S., Magee, N., ... & Gil, J. (2013). A complex secretory program orchestrated by the inflammasome controls paracrine senescence. *Nature Cell Biology*, 15(12), 1423-1434. <https://doi.org/10.1038/ncb2891>
- [6] Coppé, J. P., Desprez, P. Y., Krtolica, A., & Campisi, J. (2010). The senescence-associated secretory phenotype: the dark side of tumor suppression. *Annual Review of Pathology*, 5, 99-118. <https://doi.org/10.1146/annurev-pathol-121808-102144>
- [7] Salama, R., Sadaie, M., Hoare, M., & Narita, M. (2014). Cellular senescence and its effector programs. *Genes & Development*, 28(2), 99-114. <https://doi.org/10.1101/gad.235184.113>
- [8] Baker, D. J., Childs, B. G., Durik, M., Wijers, M. E., Sieben, C. J., Zhong, J., ... & van Deursen, J. M. (2016). Naturally occurring p16^{Ink4a} inactivation accelerates aging. *Nature*, 530(7589), 184-189. <https://doi.org/10.1038/nature16932>

- [9] Saliev, T., Seilkhanov, S. K., Balambayeva, N. V., & Zhakupova, A. S. (2025). Targeting Senescence: A Review of Senolytics and Senomorphics for Geroscience. *Aging and Disease*, 16(3), 1098-1125. <https://doi.org/10.14336/AD.2024.1126>
- [10] Zhang, L., Pitcher, L. E., Yousefzadeh, M. J., Niedernhofer, L. J., & Robbins, P. D. (2023). Cellular senescence: A key therapeutic target in aging. *The Journal of Clinical Investigation*, 133(13), e169620. <https://doi.org/10.1172/JCI169620>
- [11] Thompson, E. L., Niedernhofer, L. J., & Robbins, P. D. (2021). Targeting Cellular Senescence with Senotherapeutics. *Dermatologic Surgery*, 47(9), 1209-1223. <https://doi.org/10.1097/DSS.0000000000003150>
- [12] Kirkland, J. L., & Tchkonian, T. (2017). Cellular senescence: A translational perspective. *EBioMedicine*, 21, 21-28. <https://doi.org/10.1016/j.ebiom.2017.04.013>
- [13] Zhou, D. D., Luo, M., Huang, S. Y., Saimaiti, A., Shang, A., Ge, Y. B., ... & Zou, X. X. (2021). Effects and Mechanisms of Resveratrol on Aging and Age-Related Diseases. *Oxidative Medicine and Cellular Longevity*, 2021, 9932218. <https://doi.org/10.1155/2021/9932218>
- [14] Singh, C. K., Ndiaye, M. A., & Ahmad, N. (2014). Resveratrol and cancer: challenges and opportunities. *Seminars in Cancer Biology*, 35, 20-27. <https://doi.org/10.1016/j.semcancer.2015.02.005>
- [15] Latruffe, N., Godin-Ribuot, D., Delmas, D., Jannin, B., Calliste, C., Geoffroy, P., ... & Lairon, D. (2019). Exploring new ways to maintain healthy aging through polyphenols and caloric restriction. *Current Pharmaceutical Design*, 15(30), 3519-3539. <https://doi.org/10.2174/138161209789201551>
- [16] Park, S. J., Ahmad, F., Philp, A., Baar, K., Williams, T., Luo, H., ... & Seng, S. (2012). Resveratrol ameliorates aging-related metabolic phenotypes by inhibiting cAMP phosphodiesterases. *Cell*, 148(3), 421-433. <https://doi.org/10.1016/j.cell.2012.01.017>
- [17] Jacob, J., Aggarwal, A., Bhattacharyya, S., & Sahni, D. (2025). Fisetin and resveratrol exhibit senotherapeutic effects and suppress cellular senescence in osteoarthritic cartilage-derived chondrogenic progenitor cells. *European Journal of Pharmacology*, 975, 176662. <https://doi.org/10.1016/j.ejphar.2025.176662>
- [18] Hubbard, B. P., Gomes, A. P., Dai, H., Li, J., Case, A. W., Considine, T., ... & Sinclair, D. A. (2013). Evidence for a common mechanism of SIRT1 regulation by allosteric activators. *Science*, 339(6124), 1216-1219. <https://doi.org/10.1126/science.1231591>
- [19] Lagouge, M., Argmann, C., Gerhart-Hines, Z., Meziane, H., Lerin, C., Daussin, F., ... & Auwerx, J. (2006). Resveratrol improves mitochondrial function and protects against

- metabolic disease by promoting SIRT1 and PGC-1 α function. *Cell Metabolism*, 3(6), 410-420. <https://doi.org/10.1016/j.cmet.2006.04.012>
- [20] Zhang, S., Fang, R. R., & Zhou, X. X. (2024). Therapeutic effects of resveratrol on epigenetic mechanisms involved in aging. *Phytotherapy Research*, 38(3), 868-892. <https://doi.org/10.1002/ptr.8176>
- [21] Fraga, M. F., & Esteller, M. (2007). Epigenetics and aging: the targets and the marks. *Trends in Genetics*, 23(8), 413-418. <https://doi.org/10.1016/j.tig.2007.05.008>
- [22] Wang, K., Long, B., Liu, F., Wang, J. X., Liu, C. Y., Zhao, B., ... & Li, N. (2022). Epigenetic regulation of aging: implications for interventions of aging and age-related diseases. *Signal Transduction and Targeted Therapy*, 7(1), 374. <https://doi.org/10.1038/s41392-022-01211-8>
- [23] Cichewicz, R. H., & Kouzi, S. A. (2022). Advances in natural products research for cancer chemotherapy. *Current Opinion in Pharmacology*, 65, 102248. <https://doi.org/10.1016/j.coph.2022.102248>
- [24] Ren, J., & Sowers, J. R. (2023). Metabolic syndrome and its targeted therapy. *Journal of Personalized Medicine*, 13(4), 588. <https://doi.org/10.3390/jpm13040588>
- [25] Li, P. X., Gu, X. J., & Han, X. X. (2024). Resveratrol ameliorates doxorubicin-induced cardiotoxicity through the SIRT1/PGC1 α pathway. *Aging and Disease*, 15(1), 124-139. <https://doi.org/10.14336/AD.2023.1013>
- [26] Chen, X., Xu, J., Liu, K., Xuan, Y., Feng, Y., Lei, Q., & Tao, W. (2024). Polyphenols and diets as current and potential nutrition supportive approaches for cognitive aging in Alzheimer's disease prevention. *Journal of Alzheimer's Disease*, 98(s1), S301-S326. <https://doi.org/10.3233/JAD-231222>
- [27] Alcorta, D. A., Xiong, Y., Harmeyer, D., Force, T., Kyriakis, J. M., & Hoeffler, J. P. (1997). Involvement of the MAPK signaling cascade in the regulation of cyclin D1 levels and entry into S phase. *Oncogene*, 14(20), 2409-2418. <https://doi.org/10.1038/sj.onc.1201087>
- [28] Dimri, G. P., Lee, X., Basile, G., Acosta, M., Scott, G., Roskelley, C., ... & Pereira-Smith, O. (1995). A biomarker that identifies senescent human cells in culture and in aging skin *in vivo*. *Proceedings of the National Academy of Sciences USA*, 92(20), 9363-9367. <https://doi.org/10.1073/pnas.92.20.9363>
- [29] Gorgoulis, V., Adams, P. D., Alimonti, A., Bennett, D. C., Bischof, O., Bishop, C., ... & Demaria, M. (2019). Cellular senescence: defining a path forward. *Cell*, 179(4), 813-827. <https://doi.org/10.1016/j.cell.2019.10.005>
- [30] Hernandez-Segura, A., Nehme, J., & Demaria, M. (2018). Hallmarks of cellular senescence. *Trends in Cell Biology*, 28(6), 436-453. <https://doi.org/10.1016/j.tcb.2018.02.001>

- [31] Jeyapalan, J. C., Ferreira, M., Liu, J., Pierce, M., Zeichner, S. L., Martinez-Ruiz, H., & Schumacher, B. (2007). Accumulation of senescent cells in mitotic tissue of aging primates. *Mechanisms of Ageing and Development*, 128(1), 36-44. <https://doi.org/10.1016/j.mad.2006.11.008>
- [32] Serrano, M., Lin, A. W., McCurrach, M. E., Beach, D., & Lowe, S. W. (1997). Oncogenic ras provokes premature cell senescence associated with accumulation of p53 and p16^{INK4a}. *Cell*, 88(5), 593-602. [https://doi.org/10.1016/S0092-8674\(00\)81902-9](https://doi.org/10.1016/S0092-8674(00)81902-9)
- [33] Campisi, J. (2005). Senescent cells, tumor suppression, and organismal aging: good citizens, bad neighbors. *Cell*, 120(4), 513-522. <https://doi.org/10.1016/j.cell.2005.02.003>
- [34] Evan, G. I., & Vousden, K. H. (2001). Proliferation, cell cycle and apoptosis in cancer. *Nature*, 411(6835), 342-348. <https://doi.org/10.1038/35077213>
- [35] Lowe, S. W., Cepero, E., & Evan, G. (2004). Intrinsic tumour suppression. *Nature*, 432(7015), 307-315. <https://doi.org/10.1038/nature03098>
- [36] Polager, S., Ohly, J. E., & Kaldis, P. (2002). Oncogenic PDK1 regulates S phase entry via Foxo3p-dependent expression of p27. *Nature Cell Biology*, 4(12), 901-906. <https://doi.org/10.1038/ncb883>
- [37] Toussaint, O., Dumont, P., Dierick, J. F., Fripiat, C., Chainiaux, F., Eliaers, F., ... & Remacle, J. (2002). Stress-induced premature senescence. *Experimental Gerontology*, 37(10-11), 1327-1331. [https://doi.org/10.1016/S0531-5565\(02\)00205-2](https://doi.org/10.1016/S0531-5565(02)00205-2)
- [38] Inoki, K., Ouyang, H., Zhu, T., Lindvall, C., Wang, Y., Zhang, X., ... & Guan, K. L. (2006). TSC2 integrates Wnt and energy signals via a coordinated phosphorylation by AMPK and GSK3 to regulate cell growth. *Cell*, 126(5), 955-968. <https://doi.org/10.1016/j.cell.2006.06.055>
- [39] Hetz, C., & Papa, F. R. (2018). The unfolded protein response and cell fate control. *Molecular Cell*, 69(2), 169-181. <https://doi.org/10.1016/j.molcel.2017.06.017>
- [40] Chourasia, A. H., Tracy, K., Frankenberger, C., Boland, M. L., Sharifi, M. N., Giuseppe Malinarich, F., ... & Gupta, S. (2015). Mitophagy defects arising from BNip3 loss promote mammary tumor progression to metastasis. *EMBO Reports*, 16(9), 1145-1163. <https://doi.org/10.15252/embr.201540759>
- [41] Coppé, J. P., Patil, C. K., Rodier, F., Sun, Y., Muñoz, D. P., Goldstein, J., ... & Campisi, J. (2008). Senescence-associated secretory phenotypes reveal cell-nonautonomous functions of oncogenic RAS and the p53 tumor suppressor. *PLoS Biology*, 6(12), e301. <https://doi.org/10.1371/journal.pbio.0060301>
- [42] Coppe, J. P., Desprez, P. Y., Krtolica, A., & Campisi, J. (2010). The senescence-associated secretory phenotype: the dark side of tumor suppression. *Annual Review of*

Pathology: Mechanisms of Disease, 5, 99-118. <https://doi.org/10.1146/annurev-pathol-121808-102144>

[43] Kuilman, T., Michaloglou, C., Vredeveld, L. C., Douma, S., van Doorn, R., Desmet, C. J., ... & Peeper, D. S. (2008). Oncogene-induced senescence relayed by an interleukin-dependent inflammatory network. *Cell*, 133(6), 1019-1031. <https://doi.org/10.1016/j.cell.2008.03.039>

[44] Acosta, J. C., Banito, A., Warnecke, T., Robson, T., Brown, S., Magee, N., ... & Gil, J. (2013). A complex secretory program orchestrated by the inflammasome controls paracrine senescence. *Nature Cell Biology*, 15(12), 1423-1434. <https://doi.org/10.1038/ncb2891>

[45] Demaria, M., Ohtani, N., Youssef, S. A., Rodier, F., Toussaint, W., Nelson, G., ... & Campisi, J. (2014). An essential role for senescent cells in optimal wound healing through temporally regulated collagen degradation. *Aging Cell*, 13(1), 11-20. <https://doi.org/10.1111/acer.12153>

[46] Wera, S., & Campbell, S. L. (1997). The role of protein phosphatase 2A in the regulation of cell cycle: a critical appraisal. *Current Opinion in Cell Biology*, 9(2), 268-275. [https://doi.org/10.1016/S0955-0674\(97\)80072-1](https://doi.org/10.1016/S0955-0674(97)80072-1)

[47] Finkel, T., Serrano, M., & Blasco, M. A. (2007). The common biology of cancer and ageing. *Nature*, 448(7155), 767-774. <https://doi.org/10.1038/nature05985>

[48] Sato, T., Megahed, M., Oka, M., Ohnishi, I., Demitsu, T., & Suzuki, H. (2002). Angiopoietin-1 is a critical mediator of keratinocyte growth factor-promoted collateral outgrowth of aged endothelial cells. *Circulation Research*, 91(8), 704-711. <https://doi.org/10.1161/01.RES.0000038110.17434.3B>

[49] Chiarugi, P., & Giannoni, E. (2014). Metabolic-driven cancer progression and metastasis. *Journal of Pathology*, 234(2), 145-154. <https://doi.org/10.1002/path.4298>

[50] Alspach, E., Loftus, R., Welm, B. E., Prekeris, R., & Weaver, V. M. (2014). p53 orchestrates cancer metabolism and immunoediting in the tumor microenvironment. *Nature Cell Biology*, 16(3), 213-222. <https://doi.org/10.1038/ncb2929>

Chapter 9

TLC based Comparative Analysis of Qualitative Phytochemical Characteristics of *Eclipta alba* and *Eclipta prostata*

¹Anuj, ^{2*}Ashwani Kumar, ³Adesh Kumar, ⁴Dhanendra Kumar Rai, ⁵Nikhil Chand, ⁶Sarita Rana, ⁷Anupriya Rana

¹Ph.D Scholar, Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

^{2*}HOD & Associate Professor, Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

^{3,4,5,6,7}Assistant Professor, Department of Life Sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

*Corresponding Author- Dr. Ashwani Kumar, amritdhra1981@gmail.com

Abstract- The present study focuses on the qualitative and quantitative phytochemical analysis of *Eclipta alba* and *Eclipta prostata*—two medicinally important species traditionally used in Ayurvedic and ethnobotanical systems. These plants, known for their diverse pharmacological properties, were analyzed to determine the presence and concentration of key bioactive constituents. Qualitative phytochemical screening of methanolic and aqueous extracts revealed the presence of major secondary metabolites such as alkaloids, flavonoids, phenolics, saponins, tannins, terpenoids, and glycosides in both species, with slight variations in intensity. Quantitative estimation demonstrated that *Eclipta alba* contained higher concentrations of total phenolic content (TPC) and total flavonoid content (TFC) compared to *Eclipta prostata*, suggesting a stronger potential for antioxidant and therapeutic applications. The findings provide comparative insight into the phytoconstituent profiles of these botanicals and support their continued exploration for the development of plant-based pharmaceutical and nutraceutical formulations. Further studies including chromatographic profiling and biological assays are recommended to validate their therapeutic efficacy and identify active compounds.

Key words: TLC, Qualitative Phytochemical analysis, *Eclipta alba* and *Eclipta prostata*

Introduction

Intrinsic aging is the natural, biologically programmed decline that occurs as the time passes whereas extrinsic aging—often called photoaging occurs due to environmental factors like ultraviolet (UV) light, pollution, and oxidative stress [1].

The main organ that shields the human body from environmental harm is the skin [2]. The amount of ultraviolet (UV) light that reaches the Earth's surface has increased as a result of the stratospheric ozone layer's thinning. Since UV radiation is the main environmental factor influencing the formation of the skin, its impacts on the skin have drawn more attention [3]. UVB has a higher energy level than UVA and has a greater impact on the skin [4]. One of the major causes of skin aging is oxidative stress, which is characterized by an imbalance between reactive oxygen species (ROS) and antioxidant defences [5]. In addition to impairing cellular processes and causing damage to lipids, proteins, and DNA, excess ROS can activate matrix metalloproteinases (MMPs), which break down collagen and elastin and cause wrinkles, discoloration, and loss of elasticity [6]. *Eclipta* Spp. consists of two plants *Eclipta Alba* and *Eclipta prostrata*, commonly known as false daisy or bhringaraj (in Hindi), is a medicinal herb with a long history in traditional medicine, especially in Ayurveda. It has been used for hair growth, skin disorders, liver ailments, and wound healing since thousands of years. Various phytochemical test reports show that *Eclipta* contains a rich number of bioactive components which includes compounds like wedelolactone, saponins, sterols, flavonoids such as luteolin, and other phenolic compounds [7].

Significantly, its antioxidant potential has been displayed in multiple assays: extracts of *Eclipta alba* show free radical scavenging activity, and metal-chelating capacity, which highlights its potential in case of skin protection [8]. Furthermore, new reviews highlight the dermatological potential of *Eclipta* and advocate for a more thorough assessment of its bioactive components in skin-related applications [9]. Luteolin is a naturally occurring flavonoid commonly found in many medicinal plants, including *Eclipta* species (*Eclipta alba* and *Eclipta prostrata*) luteolin is one of the key bioactive compound responsible for several of the plant's therapeutic effects. This bioactive compound is well-known for its strong antioxidant and anti-inflammatory activities. In skin models, luteolin suppresses pro-inflammatory mediators (like IL-1 β , TNF- α), and regulates key signalling pathways such like NF- κ B, JAK-STAT, and TLR signalling [10]. Also, luteolin has been shown to protect skin cells from damage caused by UV light. For example, in fibroblasts that are exposed to UVA, luteolin lowers oxidative stress, stops senescence, and stops collagen breakdown [11].

There is a growing demand for natural, plant-based cosmetics that are effective as well as safer. Herbal antioxidants have gathered particular interest because they can neutralize ROS, modulate signalling pathways, and have the potential to repair or protect skin without harsh side effects [6]. Flavonoids which are basically phytochemicals are desirable because of their

two in one (anti-oxidant and anti-inflammatory) actions, making them suitable choice for anti-aging skin care. Despite having lots of evidences which proves that luteolin have skin protecting properties, there is no single review paper that focuses on the luteolin specifically synthesized from the *Eclipta* Spp. Plants in context of oxidative skin aging. This particular review analyses and collates the recent available literature based on luteolin extracted from *Eclipta* Spp. Which covers the phytochemical analysis antioxidant and anti-aging mechanisms, invitro models and formulations. So that we can highlight its potential in the field of skin aging and identification of research gaps to provide guidance for future development of luteolin-based cosmeceuticals or therapeutic agents.

Oxidative stress and skin aging: Skin aging is a complicated biological process which is based on two factors intrinsic and extrinsic aging factors. Intrinsic aging is the aging which is preprogrammed or we can say genetically controlled and declines as the time passes, we can also see a decline and changes in the physiological characters of the organism's body for example at the age of 23 the skin is very tight whereas at the age of 60 it starts to loosen. Extrinsic aging is also known as photo aging which basically takes place due to contacting with some environmental factors which can give stress to the human skin e.g., ultra violet rays (U.V. Radiations), air pollutants, tobacco smoke etc. We can also separate photoaging on the basis of various histological factors- solar epidermal hyperplasia or atrophy, elastosis. Reduction in collagen content, pigmentation of the skin which is not regular, dermatologically these differences or irregularities can cause wrinkles, rough scars like skin texture and pigmentation which can cover the healthy living cells of the skin. Imbalance between the production of ROS (Reactive Oxygen Species) and antioxidant defence has a major role in both intrinsic as well as extrinsic types of aging [12,61,62].

Like skin that ages naturally, photoaged skin has less collagen and elastin, which causes wrinkles, loss of elasticity, uneven pigmentation, and dryness [10]. The thinning of the skin, which is brought on by the atrophy of the cells in the epidermal layers and the decrease of fibroblasts and extracellular matrix (ECM) components in the dermal layers, is a clear histological change. For example, collagen gets divided and coarsely deposited as its quantity declines [16]. There are various things present in the environment by which the photoaging can be triggered and leads to the production of ROS (Reactive Oxygen Species) is the most common source which can cause photoaging Ultraviolet Radiations. There are majorly two types of U.V. Rays (UVA & UVB) that plays an important role in the production of ROS. UVA went deep down to the epidermal layer on order perform a process called as

photosensitization of the chromophores present inside the cells to cause ROS. On the other hand, UVB forms ROS directly by damaging the DNA of an organism. The extrinsic photoaging covers the sources like- leakage in the electron transport chain inside the mitochondria, cytochrome P450 enzymes and not just that there are various processes which also uses different enzymes to produce hydrogen peroxide and superoxide. The activation of aryl hydrocarbon receptor (AhR) also be a major reason of ROS production which can be caused due to the entry of extrinsic photoaging pollutants like- polycyclic aromatic hydrocarbons, and chemical oxidants. The ROS generation is also useful to understand the phenomenon behind why oxidative damage is ubiquitous between different types of cells like- keratinocytes, melanocytes, fibroblasts, endothelial cells and subcellular compartments like- membranes, proteins and nuclei of the cell [13].

The predominant cell type in the skin's epidermal layer is keratinocytes. In response to immunological and endocrine stimuli, they can release inflammatory mediators such as vascular endothelial growth factor (VEGF), interleukin (IL)-1, IL-6, and IL-8. They are totally immunocompetent [2]. The biomolecules get modified by direct oxidation which works as second messengers that dysregulate signalling cascades that leads to the formation of ROS. As a result, the lipids start producing reactive aldehydes like-malondialdehyde, 4-hydroxynonenal in order to make adducts with protein and nucleic acid. The structural and enzymatic protein like collagen and elastin gets changed by protein oxidation, that creates an imbalance in phytochemical as well as enzymatic regulation. There are various types of complications that take place like- genomic instability, mutagenesis and activation of DNA damage responses due to oxidation of DNA. Along with these oxidative lesions regulate cellular stress responses like unfolded protein response, autophagy perturbation and also activates redox-sensitive transcription factors which provides the shape to phenotypic manifestations of aging of skin. Oxidative damage biomarkers like oxidized DNA bases, lipid peroxides, protein carbonyls are basically used in experimental models.

ROS also works as a messenger molecule which passes signals which takes out pro-aging transcription programs. Kinase protein gets activated by ROS, which includes- ERK, JNK and p38 — which in turn induce activator protein-1 (AP-1) complexes (c-Fos/c-Jun). AP-1 is a master regulator of extracellular matrix (ECM) remodelling and potentially increases transcription of matrix metalloproteinases (MMPs). MMPs then express themselves and fast forwards the degradation of collagen and elastin and also stops its synthesis. The mechanism behind photoaging is the cascade from ROS to MAPK → AP-1 and NF-

κ B, which explains why oxidative assaults cause both tissue deterioration and chronic inflammation [13]. Inflammation is basically linked with oxidative stress of the skin, repeated environmental insult can cause Chronic, low-grade inflammation. Senescent cell secretions create a background of proteolytic enzymes and oxidative mediators that creates an imbalance between skin tissue repair and homeostasis [12]. Antioxidant methods have become a foundation of scientific and translational research. Exogenous antioxidants – tiny molecules including vitamin C, vitamin E, carotenoids, polyphenols and flavonoids — can scavenge ROS, chelate redox-active metals, and alter redox-sensitive signalling pathways to minimize MMP induction and inflammation. Under various clinical invitro studies, reveal that different topical or systemic antioxidants decreases UV-induced oxidative damage and preserve collagen. oxidative stress sits at the basic of both intrinsic and extrinsic skin aging by directly damaging biomolecules, triggering pro-degradative signalling (MAPK/AP-1, NF- κ B), inducing MMPs and promoting cellular senescence and chronic inflammation. The exposome UV radiation, pollution, lifestyle factors — amplifies ROS production and accelerates matrix breakdown and pigmentary disorders. While the intrinsic defences (notably Nrf2-driven antioxidant responses) counteract ROS, these systems become less effective with age. These insights prove a translational focus on antioxidant phytochemicals which are delivered in balanced, well-formulated topical manner [14].

Phytochemistry of luteolin from Eclipta Spp.: Eclipta Spp. Constitutes of two plants (*Eclipta Alba* & *Eclipta Prostrata*), this plant is also known as false daisy or Bhringraj in hindi. E. alba is a small, annual herb that typically grows up to 30–60 cm in height. The plant is characterized by slender, branched stems, opposite leaves, and white to purple flowers that are arranged in spherical clusters known as heads.

Botanical characteristics: The flowers are small, with a tubular shape, and they bloom during the rainy season, attracting pollinators such as bees and butterflies. The leaves have a relatively silky feel, are ovate-lanceolate, and have serrated edges. The plant yields achene-type fruits, which have a tuft of fine hairs at one end that make them easily carried by the wind [2].

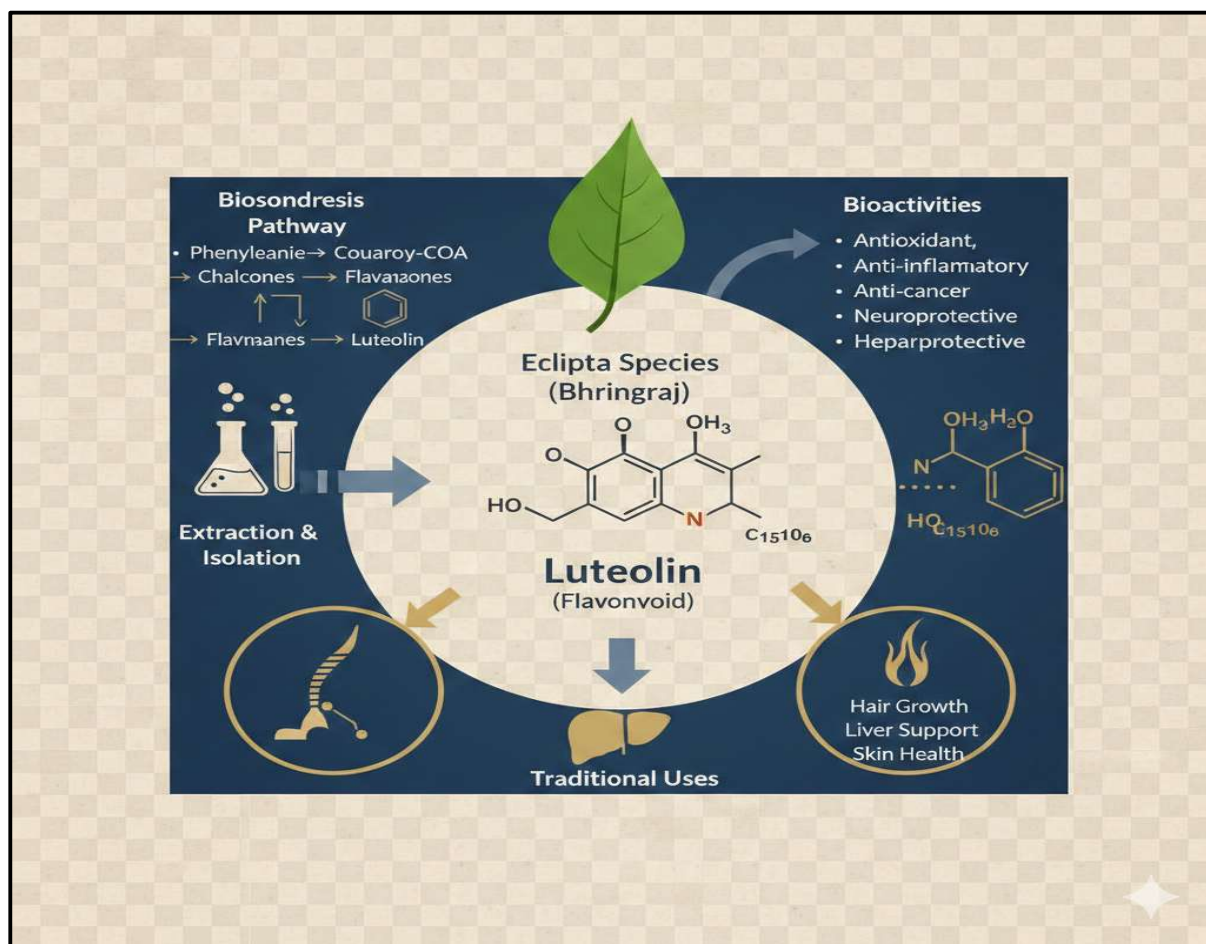


Fig. 1 Phytochemistry of luteolin from Eclipta Spp (Produced by Gemini AI)

This plant has lots of medicinal properties and used by in south east Asia from a long period of time. Old Ayurvedic manuscript portrayed its therapeutic properties hepatoprotective, wound healing, hair growth promotion and treatment of skin disorders. In Ayurveda, *E. alba* is considered a powerful liver tonic in addition to its application for hair health. Hepatitis, liver cirrhosis, and jaundice are among the liver conditions it is used to treat. By promoting liver cell repair and lessening the effects of pollutants on liver function, the plant is thought to cleanse the liver and promote liver regeneration [38]. *E. alba* is used in Unani medicine to treat respiratory and skin disorders, fever, and inflammation. The herb is used externally, frequently as poultices or extracts, to treat burns, wounds, and infections [39].

These days the researchers are focussing on the analysis of phytochemicals found in the areal parts like leaves and stem of the plant because the amount of bioactive compound in the root and shoot is much more, but in some studies the whole plant extract is taken [15]. During various phytochemical studies it's been found that *Eclipta Spp.* Has a rich profile having bioactive compounds like-triterpenoid saponins, sterols, phenolic acids and different types of flavonoids. In order to determine the structure of these bioactive compounds and for the

isolation of luteolin there are various analytical techniques are used by the researchers which are as follows- Soxhlet extraction, solvent partitioning, column chromatography, HPLC, LC-MS, NMR. This process of detecting flavonoids in repeated findings in multiple studies also supports the hypothesis that *Eclipta* is arich source of flavonoids; by performing analyses various times may present them as a generic group or instead focus on major unique markers (e.g., wedelolactone) which results in reporting for less rich but bioactive flavones (e.g., luteolin) to be overhyped unless specifically sought. This pattern underscores a methodological limitation: except should chromatographic methodologies be optimized and luteolin criteria become available, routine screens may fail to detect or properly quantify luteolin despite its presence.

Coumestans: Wedelolactone is the main bioactive coumestan found in *E. alba*. The liver-protective, anti-inflammatory, and antioxidant qualities of wedelolactone have been extensively studied. Its potential in treating inflammatory illnesses is highlighted by the fact that it works by inhibiting nuclear factor kappa (NF- κ B) signaling, which lowers the levels of proinflammatory cytokines. Demethylwedelolactone and other coumestans also have anti-inflammatory and antioxidant properties.

Flavonoids: Many flavonoids found in *E. alba* have strong anti-inflammatory, antioxidant, and anticancer properties. The plant is especially rich in luteolin and its glycoside, luteolin-7-O-glucoside, which are important in lowering oxidative stress[40]. Another well-known flavonoid with anti-inflammatory and anticancer qualities is apigenin[41].Furthermore, the plant's antioxidant potential is further enhanced by the flavonoid glycoside cinnaroside[42].

Alkaloids: Alkaloids such as ecliptine and ecliptalbine found in *E. alba* have been shown to possess antimicrobial and antiinflammatory properties [43].Even though they are found in smaller quantities, nicotine and nicotinic acid also add to the plant's bioactive profile because of their effects on the neurological system [44].

Triterpenoids and saponins: *E. alba* is rich in triterpenoids, especially ursolic acid and oleanolic acid. These substances have hepatoprotective, anti-inflammatory, and anticancer qualities [45].

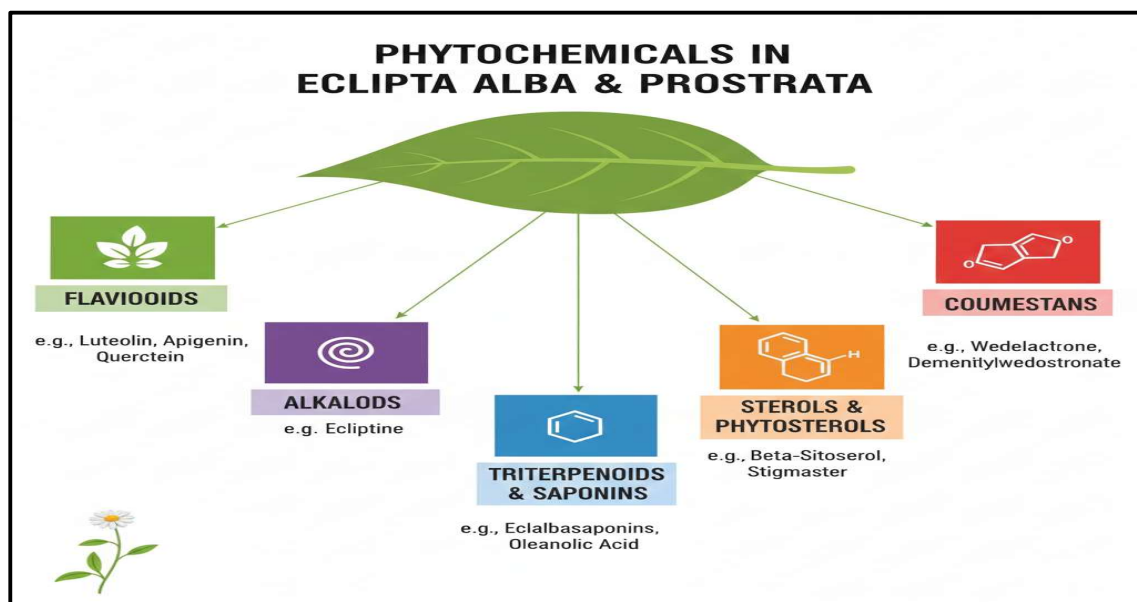


Fig. 2 Phytochemicals *Eclipta* Spp.(Produced by Gemini AI)

Sterols and phytosterols: *E. alba* contains sterols with anti-inflammatory and cholesterol-lowering properties, including spinasterol, β -sitosterol, and stigmasterol [46].

Other bioactive constituents: In addition to the main classes of chemicals, *E. alba* includes polyacetylenes, thiophenes, resins, and sulfur compounds, all of which support its medicinal qualities, especially its cytotoxic and antibacterial effects [47]. The plant's nutritional and medicinal benefit is further enhanced by polypeptides such as cystine, glutamic acid, phenylalanine, and tyrosine [48].

In different phytochemical studies researchers found luteolin and luteolin glycosides in *Eclipta* spp. Conventional isolation based on solvent fractionation and chromatography, disclosed luteolin and luteolin-7-O-glucoside as the isolated compounds from root and shoot for which complete structure can be explained by use of MS and NMR. These isolations are of important because they are much useful than basic level identification to molecule level determination, also confirming the presence of luteolin as an actual ingredient in *Eclipta* extracts — in some genotypes and under certain extract conditions at least. whereas many have been limited to compound identification and bioactivity (e.g., antitumor, antiviral) rather than a reproducible quantitative content across samples that is most relevant for formulation and dosing [16].

Some of the phytochemical studies on *Eclipta* Spp. Also reported luteolin and luteolin glycosides from them. 2.3 Isolation of Luteolin and Luteolin-7-O-Glucoside. The old isolation work done with solvent for making partitions and different chromatographic techniques

classifies [6] luteolin, plus luteolin-7-O-glucoside as purified compounds from the aerial parts.

On the other hand, techniques like-NMR, and MS are used to understand their full structure. These initial isolation studies are important because they help beyond class-level reports to the level of identifying the biomolecules, which are showing that luteolin is actually an important component in *Eclipta* extracts – at are used for particular accessions and specific extraction methods.

These studies only identify and portray the bioactivity (for example, anti-cancer or antiviral) of compounds instead of reporting quantified standardized content across samples which is the most useful information for formulation and dosing[16].

Under lab experiments it is observed that luteolin accumulation under specific growth conditions: for example, red-light stimulated callus of *Eclipta alba* accumulated luteolin at ~0.39 mg/g dry weight in one study and the amount of wedelolactone and demethylwedelolactone is usually high.

LC-MS/MS studies the interest in pharmacokinetics and bioavailability contribution of luteolin, wedelolactone and apigenin has prompted the development of sensitive and suitable quantification methods by LC-MS/MS for these three major compounds from the *Eclipta* extracts as well as biological matrices at the same time. The validated range (down to low ng/mL in plasma) was reported in the developed method papers, allowing accurate PK studies after oral administration of *Eclipta* fractions.

These analytical advances are at the heart of converting phytochemistry into pharmacology: once reliable, validated luteolin assays are available, it is possible to measure luteolin in extracts and formulations (and human or experimental animal tissues) – an absolute prerequisite for standardization and industry acceptance. The presence of LC-MS/MS quantitation methods potentially remove an analytical hurdle, and future reports should have the capacity to present a reliable estimation of luteolin content [17].

Other than luteolin *Eclipta* also carries glycosylated and sulphured flavonoids e.g., luteolin-7-sulfate, luteolin-7-glucoside) which may be more useful than aglycone luteolin in some cases. Techniques like LC-MS when used over *Eclipta prostrata* can show sulfated flavonoids such as luteolin-7-sulfate and apigenin-7-sulfate; glycosides are more soluble in water not permeable on fluids, on the other hand when we talk about sulphates they can also enhance metabolism, so it's very important to mention that we will specifically measure the aglycone present in the same plant, and if we want favourable results then we should also conclude the sulphuric derivatives targeting skin penetration[18].

The availability of luteolin under *Eclipta* extracts has functional correlates: luteolin and related flavones were found to contribute to the reported antiviral, antioxidant, and cytotoxic effects in multiple bioassay-guided fractionation investigations. For instance, luteolin, wedelolactone, and apigenin were extracted from active fractions using bioactivity-guided isolation techniques aimed at anti-HCV activity [19].

Finally, after confirming the availability of luteolin in different phytochemical studies, a major knowledge gap still presents in the public literature: there are actually few open, quantitative surveys on luteolin concentrations between many *Eclipta* plants, harvest conditions and extraction methods. The scattered but persuasive isolation and activity studies provide practicality and biological plausibility, whereas LC-MS/MS technique publications suggest that rigorous quantification is technically tractable. The field requires systematic, extensive phytochemical surveys with verified quantification of luteolin and related flavonoids, together with stability testing and standardized extraction techniques, to close the gap between bench and product. Such fundamental phytochemistry will support claims for luteolin-containing *Eclipta* extracts in anti-aging cosmeceutical uses and allow for accurate dosing in in vitro, in vivo, and clinical trials [17].

In-vitro and In-vivo evidences of luteolin: Luteolin protects the skin fibroblasts against UV-induced oxidative damage, There are a number of solid in vitro investigations, studies using NIH-3T3 cells and human skin fibroblasts shows that use of luteolin boosts the cell viability followed by UVA/UVB exposure, decreases lipid peroxidation indicators (MDA), regains mitochondrial membrane power (JC-1 assay), and decreases ROS as measured by DCF fluorescence. Significantly, luteolin decreased SA- β -Gal positive and downregulated senescence-associated proteins (p16, p21), suggesting mitigation of stress-induced premature senescence. The ability of luteolin to bear fibroblast activity and extracellular matrix (ECM) synthesis during photooxidative stress is mechanistically supported by these cellular effects. Over the past ten years, there has been a vital increase in skin-centered preclinical research on luteolin, with lots of lab's researches, its effects on keratinocytes, dermal fibroblasts, skin explants, and animal photoaging models. These studies look at common bullet points related to oxidative skin aging, for example- intracellular reactive oxygen species (ROS) levels, antioxidant enzyme activities (SOD, catalase), mitochondrial function, senescence markers (p16, p21, SA- β -Gal), matrix metalloproteinase (MMP) expression, collagen content, histological architecture, and visible wrinkle production. The multimodal activities of luteolin, including direct antioxidant scavenging, modulation of redox-sensitive signalling (MAPK/AP-1, NF- κ B), inhibition of MMP induction, maintenance of mitochondrial health,

and decrease of senescence and SASP factors, can be evaluated thanks to this body of study [11].

Luteolin's protective effects in packed skin architecture have been confirmed using ex vivo human skin explant models, which provides an intermediate translational step. When compared to irradiated controls, topical luteolin (or pre-treatment of explants) important to simulate solar irradiation in these models decreases collagen degradation on histology, lowers MMP expression by immunohistochemistry, and reduces markers of oxidative damage. The hypothesis that topically administered luteolin can reach target epidermal and superficial dermal compartments to exert biological effects is supported by such explant investigations, which also corroborate cell culture results [20]. Different in vivo animal studies verify the in vitro and ex vivo results, showing that luteolin lowers gross and microscopic characteristics of photoaging in UV-exposed rodents.

In UVB and UVA photoaging models like mice or rats, topical or systemic luteolin therapy reduced erythema, epidermal hyperplasia, wrinkle formation, and skin collagen loss on Masson's trichrome or Sirius Red staining.

Biochemically, treated animals demonstrated lower tissue MMP levels and activity, reduced oxidative indicators (MDA), and restored activities of endogenous antioxidant enzymes (SOD, catalase).

These in vivo findings demonstrate that, when used in formulations or dosage schedules that produce bioactive skin concentrations, luteolin can reduce the structural and molecular signs of photoaging [11].

Several such animal models in vivo support the in vitro and ex vivo findings, demonstrating that luteolin reduces gross and histologic features of photoaging in UV-irradiated rodent skin. In the photoaging models of UVB and UVA using mice or rat, erythema, epidermal hyperplasia, wrinkle formation and collagen content in skin on staining such as Masson's trichrome or Sirius Red were attenuated by topical or systemic luteolin treatment. Biochemically, the treated animals showed a decrease in MMP levels and its activity, reduction in oxidative indicators such as MDA and restoration of activities of endogenous antioxidant enzyme SOD and that of catalase. These in vivo data support the possibility that luteolin could be usefully employed, in formulations or dosing regimens that achieve bioactive skin levels, for lowering structural and molecular signs of photoaging[11].

Antioxidant properties of luteolin-The antioxidant activity of E. alba has been extensively studied due to its potential to combat oxidative stress, which is linked to various chronic diseases, including cancer, cardiovascular disease, and neurodegenerative disorders. Flavonoids like luteolin and apigenin, as well as wedelolactone, contribute significantly to the

antioxidant activity of the plant[41]. These components increase the activity of naturally occurring antioxidant enzymes like superoxide dismutase and catalase, neutralize free radicals, and stop lipid peroxidation [42].

Along with these substances, *E. alba* has been demonstrated to raise glutathione levels, an essential antioxidant that shields cells from oxidative damage. The plant's antioxidant properties point to its potential as a treatment option for oxidative stress-related illnesses like Parkinson's disease, Alzheimer's disease, and other cardiovascular ailments [49].

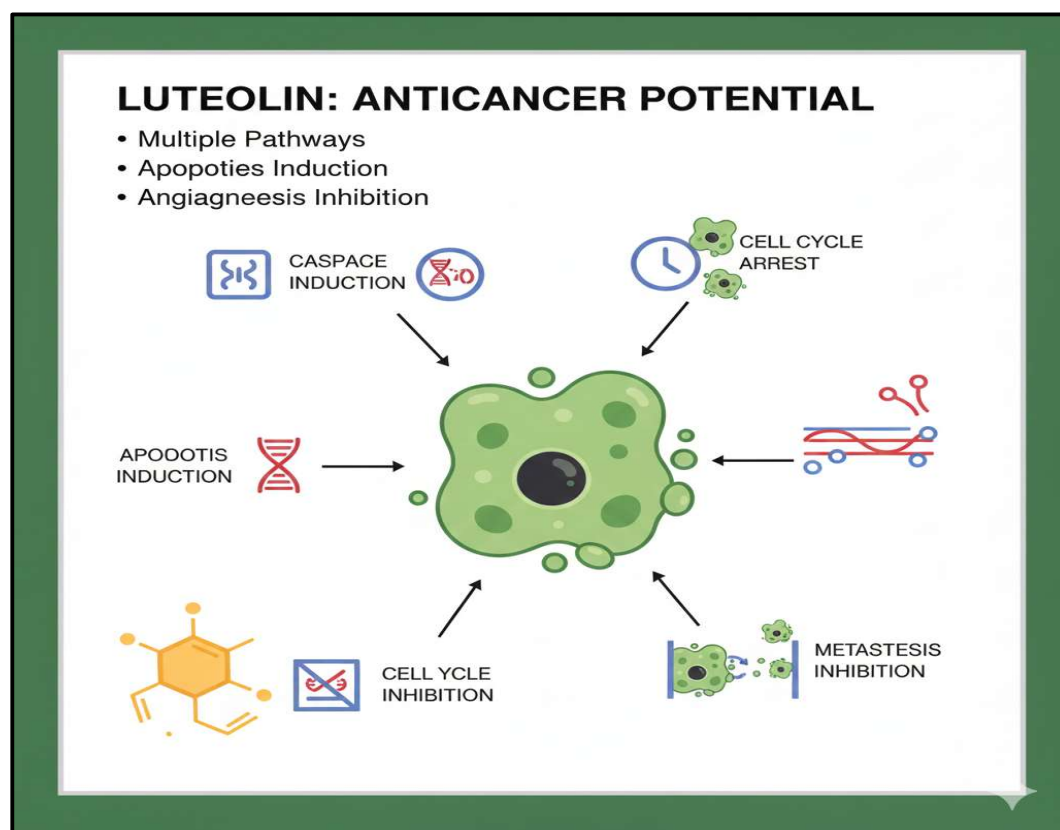


Fig. 3 Luteolin's Anti-Cancer Potential(Produced by Gemini AI)

Anticancer potential of luteolin: In recent years, *E. alba*'s anticancer qualities have attracted a lot of interest. One of *E. alba*'s main bioactive compounds, wedelolactone, has demonstrated great potential in stopping the growth of cancer cells in a variety of in vitro and in vivo models. By triggering the caspase pathway and altering the production of pro-apoptotic proteins, it causes cancer cells to undergo apoptosis [41].

Effects of luteolin against Ulcerative colitis (UC): Intestinal mucosa damage, bloody stools, relapses, and inflammation are the hallmarks of ulcerative colitis (UC), a form of inflammatory bowel disease that begins in the rectum and spreads to proximal colon segments [50].

Conclusion: The complicated biological process of skin aging is primarily caused by oxidative stress, persistent inflammation, and chronic environmental harm. Plant-derived bioactive chemicals, especially those with substantial antioxidant potential, are becoming more and more popular in the hunt for safe, efficient, and evidence-based anti-aging treatments. Because of their varied biological activity, extensive history of therapeutic usage, and rich phytochemical profile, *Eclipta* species stand out as prospective options in this area. Among its components, luteolin is a powerful flavonoid with strong anti-inflammatory, anti-glycation, antioxidant, and matrix-protective properties related to photoaging and physiological skin aging [62]. The literature reviewed in this review identifies a number of mechanistic pathways by which luteolin protects skin: it suppresses the production of reactive oxygen species (ROS), scavenges free radicals, modulates Nrf2-mediated cytoprotective responses, inhibits NF- κ B-driven inflammation, and preserves dermal structural proteins by decreasing MMPs. Luteolin has significant potential to reduce UV-induced oxidative stress, stop collagen degradation, and improve overall skin resilience, according to data from in vitro and in vivo investigations. By enhancing topical administration and skin penetration, early formulation research—including nanoemulsions, ethosomes, and phytosomes—further supports its translational potential. Despite its potential, the usage of luteolin from *Eclipta* species is still hampered by a number of factors, including variations in plant phytochemistry, a dearth of clinical research, difficulties with absorption, and a lack of safety evaluations tailored to long-term topical administration. In order to determine efficacy and long-term safety, these gaps highlight the necessity of consistent extraction procedures, dose-response analyses, and carefully planned human studies. All things considered, luteolin-rich *Eclipta* extracts offer a strong natural defense against oxidative skin aging. To fully achieve their promise as next-generation botanical cosmeceuticals, more research combining phytochemistry, formulation science, and clinical dermatology will be necessary.

Declaration: We used generative AI or AI-assisted technology, including AI agents or deep research tools such as Gemini AI and chatGPT

References

1. Jing Mu, Huisheng Ma, Hong Chen, Xiaoxia Zhang and Mengyi Ye Luteolin Prevents UVB-Induced Skin Photoaging Damage by Modulating SIRT3/ROS/MAPK Signaling: An in vitro and in vivo Studies, *Frontiers in Pharmacology* Aug. 2021, Volume 12 | Article 728261.
2. J. P. Yanadaiah, G. Sreekar Prasad, Y. Siddesh, N. Hemadri, V. Vijay, V. Koteswara. A Comprehensive Review on *Eclipta alba* (L.) Hassk.: Phytochemistry, Pharmacology,

- and Therapeutic Potential. Asian Journal of Pharmaceutics • Apr-Jun 2025 • 19 (2) | 456.
3. Andrea Cecilia Parrado, Andrea Canellada, Teresa Gentile, Estela Beatriz Rey-Roldán. Dopamine agonists upregulate IL-6 and IL-8 production in human keratinocytes. *Neuroimmunomodulation*, 2012; 19(6): 359-66.
 4. Sandra R. Georgetti, Rúbia Casagrande, Fabiana T. M. C. Vicentini, Marcela M. Baracat, Waldiceu A. Verri Jr, and Maria J. V. Fonseca. Protective Effect of Fermented Soybean Dried Extracts against TPA-Induced Oxidative Stress in Hairless Mice Skin. *Hindawi Publishing Corporation BioMed Research International* Volume 2013.
 5. Jienny Lee, SaeWoong Oh, SeoungWoo Shin, KyungWoo Lee, JaeYoul Cho, Jongsun g Lee. Zingerone protects keratinocyte stem cells from UVB-induced damage. *Volume 279*, 5 January 2018, Pages 27-33.
 6. Kyoo-Ri Kwon, Md Badrul Alam, Ji-Hyun Park, Tae-Ho Kim and Sang-Han Lee. Attenuation of UVB-Induced Photo-Aging by Polyphenolic-Rich *Spatholobus Suberectus* Stem Extract Via Modulation of MAPK/AP-1/MMPs Signaling in Human Keratinocytes. *Nutrients* 2019, 11, 1341.
 7. Rufi Tambe, Aditi Patil, Pankaj Jain, Jayant Sancheti, Gauresh Somani and Sadhana Sathaye. Assessment of luteolin isolated from *Eclipta alba* leaves in animal models of epilepsy. *Pharmacuticle Biology*, 2017, VOL. 55, NO. 1, 264–268.
 8. Imran Kazmi, Fahad A. Al-Abbasi, Muhammad Shahid Nadeem, Hisham N. Altayb, Sultan Alshehri and Syed Sarim Imam. Formulation, Optimization and Evaluation of Luteolin-Loaded Topical Nanoparticulate Delivery System for the Skin Cancer. *Pharmaceutics* 2021, 13, 1749.
 9. Khimara Naidoo and Mark A. Birch-Machin. Oxidative Stress and Ageing: The Influence of Environmental Pollution, Sunlight and Diet on Skin. *Cosmetics* 2017, 4, 4; doi:10.3390.
 10. Mark Rinnerthaler, Johannes Bischof, Maria Karolin Streubel, Andrea Trost and Klaus Richter. Oxidative Stress in Aging Human Skin. *Biomolecules* 2015, 5, 545-589.
 11. Hui-Min Liu, Ming-Yan Cheng, Meng-Han Xun, Zhi-Wei Zhao, Yun Zhang, Wei Tang, Jun Cheng, Jia Ni and Wei Wang. Possible Mechanisms of Oxidative Stress-Induced Skin Cellular Senescence, Inflammation, and Cancer and the Therapeutic Potential of Plant Polyphenols. *Int. J. Mol. Sci.* 2023, 24, 3755.

12. Antero Salminen, Kai Kaarniranta, Anu Kauppinen. Photoaging: UV radiation-induced inflammation and immunosuppression accelerate the aging process in the skin. *Inflammation Research* (2022) 71:817–831.
13. Rownak Jahan, Abdullah Al-Nahain, Snehal Majumder, and Mohammed Rahmatullah. Ethnopharmacological Significance of *Eclipta alba* (L.) Hassk. (Asteraceae). *International Scholarly Research Notices Volume* 2014.
14. Monali Patel, Ramtej Verma and Pranav Srivastav. Antioxidant activity of *Eclipta alba* extract. *Journal of Medicinal Plants Studies* 2016; ISSN 2320-3862.
15. Hla Myo, Desy Liana and Anuchit Phanumartwiwath. Unlocking Therapeutic Potential: Comprehensive Extraction, Profiling, and Pharmacological Evaluation of Bioactive Compounds from *Eclipta alba* (L.) Hassk. for Dermatological Applications. *Plants* 2024, 13, 33.
16. Fabian Gendrisch, Philipp R Esser, Christoph M Schempp, Ute Wolfle. Luteolin as a modulator of skin aging and inflammation.
17. Yu Yan, Haiting Huang, Tongshan Su, Wenyi Huang, Xinyu Wu, Xianxian Chen, Sen Ye, Jun Zhong, Chun Li and Yu Li. Luteolin Mitigates Photoaging Caused by UVA-Induced Fibroblast Senescence by Modulating Oxidative Stress Pathways. *Int. J. Mol. Sci.* 2025, 26, 1809.
18. Gary J. Fisher, Taihao Quan, Trupta Purohit, Yuan Shao, Moon Kyun Cho, Tianyuan He, James Varani, Sewon Kang and John J. Voorhees. Collagen Fragmentation Promotes Oxidative Stress and Elevates Matrix Metalloproteinase-1 in Fibroblasts in Aged Human Skin. *The American Journal of Pathology*, Vol. 174, No. 1, January 2009.
19. Hongqiao Zhang, Kelvin J. A. Davies, and Henry Jay Forman. Oxidative stress response and Nrf2 signalling in aging. *Free Radic Biol Med.* 2015 November; 88(0): 314–336.
20. Chao Feng, Xianglong Chen, Xiuqing Yin, Yanfei Jiang, Chunyue Zhao. Matrix Metalloproteinases on Skin Photoaging. *Journal of Cosmetic Dermatology*, 2024; 23:3847–3862.
21. Pavida Pittayapruek, Jitlada Meephansan, Ornicha Prapapan, Mayumi Komine and Mamitaro Ohtsuki. Role of Matrix Metalloproteinases in Photoaging and Photocarcinogenesis. *Int. J. Mol. Sci.* 2016, 17, 868; doi:10.3390/ijms17060868.
22. Mohd. Farooq Shaikh, Jayant Sancheti, Sadhana Sathaye. Phytochemical And Pharmacological Investigations Of *Eclipta Alba* (Linn.) Hassak Leaves For Antiepileptic Activity. *Int J Pharm Pharm Sci*, Vol 4, Suppl 4, 319-323.

23. Qi-Mei Liu, Hai-Yan Zhao, Xian-Ke Zhong, Jian-Guo Jiang, *Ecliptaprostrata* L. phytochemicals: isolation, structure elucidation, and their antitumor activity. 012 Nov;50(11):4016-22.
24. Hanumanth Srikanth Cheruvu, Navneet K Yadav, Guru R Valicherla, Rakesh K Arya, Zakir Hussain, Chetan Sharma, Kamal R Arya, Rama K Singh, Dipak Datta, Jiaur R Gayen, LC-MS/MS method for the simultaneous quantification of luteolin, wedelolactone and apigenin in mice plasma using hansen solubility parameters for liquid-liquid extraction: Application to pharmacokinetics of *Eclipta alba* chloroform fraction. *J Chromatogr B Analyt Technol Biomed Life Sci* 2018 Apr 1;1081-1082:76-86.
25. Dinesh Manvar, Mahesh Mishra, Suriender Kumar, and Virendra N. Pandey. Identification and evaluation of anti-Hepatitis C Virus phytochemicals from *Eclipta alba*, *J Ethnopharmacol.* 2012 December 18; 144(3): 545–554.
26. Ryunosuke Sato, Yuto Nishidono, and Ken Tanaka. Comprehensive Analysis of Sulfated Flavonoids in *Ecliptaprostrata* for Quality Evaluation. *Molecules* 2024, 29, 4888.
27. Ute Woßfle, Anja Heinemann, Philipp R. Esser, Birgit Haarhaus, Stefan F. Martin and Christoph M. Schempp. Luteolin Prevents Solar Radiation-Induced Matrix Metalloproteinase-1 Activation in Human Fibroblasts: A Role for p38 Mitogen-Activated Protein Kinase and Interleukin-20 Released from Keratinocytes. *REJUVENATION RESEARCH* Volume 15, Number 5, 2012.
28. ZulfanZazuli , Rika Hartati, Cornelia Rosasepti Rowa, SukmadjajaAsyarie and Satrialdi. The Potential Application of Nanocarriers in Delivering Topical Antioxidants. *Pharmaceuticals* 2025, 18, 56.
29. María Pilar Vinardell and Montserrat Mitjans, Nanocarriers for Delivery of Antioxidants on the Skin. *Cosmetics* 2015, 2, 342-354.
30. Meigui Huang, Erzheng Su, Fuping Zheng, Chen Tan. Encapsulation of flavonoids in liposomal delivery systems: the case of quercetin, kaempferol and luteolin. *Food Funct* 2017 Sep 20;8(9):3198-3208.
31. Shymaa Hatem, Maha El-Kayal. Novel anti-psoriatic nanostructured lipid carriers for the cutaneous delivery of luteolin: A comprehensive in-vitro and in-vivo evaluation. *European Journal of Pharmaceutical Sciences* 191 (2023) 106612.
32. ZulfanZazuli , Rika Hartati, Cornelia Rosasepti Rowa, SukmadjajaAsyarie and Satrialdi. The Potential Application of Nanocarriers in Delivering Topical Antioxidants. *Pharmaceuticals* 2025, 18, 56.

33. Klaudia Jomova, Lenka Hudecova, Peter Lauro. The effect of Luteolin on DNA damage mediated by a copper catalyzed Fenton reaction. *Journal of Inorganic Biochemistry* Volume 226, January 2022, 111635.
34. Arakere C. Udayashankar¹, Sollepura B. Rajini, Murali Nandhini¹, Y. S. Suhas, Siddapura R. Niranjana¹, Ole S. and Harischandra S. Prakash. Acute Oral Toxicity, Dermal Irritation and Eye Irritation Study Of *Eclipta alba* aqueous Extract In Sprague Dawley Rats And Newzealand White Rabbits. *Int. Res. J. Pharm.* 2016, 7.
35. P. Powthra Mahalakshmi, P. Sangeetha and K. Ramesh Kumar. GC-MS analysis of *Eclipta prostrata* leaf extracts in relation to larvicidal activity against the mosquito *Aedes aegypti*. *Indian J. Pharm. Biol. Res.* 2018; 6(1):65-72.
36. Ravindra S. Beedimani^{1*}, Shivkumar Shetkar. Hepatoprotective activity of *Eclipta alba* against carbon tetrachloride induced hepatotoxicity in albino rats. *International Journal of Basic & Clinical Pharmacology* | May-June 2015 | Vol 4 | Issue 3.
37. Vladimir Chobot, Lenka Kubicova, Gert Bachmann and Franz Hadacek. Versatile Redox Chemistry Complicates Antioxidant Capacity Assessment: Flavonoids as Milieu-Dependent Anti and Pro-Oxidants. *Int. J. Mol. Sci.* 2013, 14, 11830-11841.
38. Patil SS, Kumar SS, Chavan S. Phytochemistry and pharmacology of *Eclipta alba* (L.) Hassk: A comprehensive review. *J Herb Med* 2012;2:84-93.
39. Sharma R, Verma A, Tiwari A. A review on medicinal properties and pharmacological activities of *Eclipta alba*. *Pharmacogn Rev* 2016;10:174-8.
40. Singh G, Singh N, Kaur A. Luteolin and its derivatives: A novel approach to the treatment of cancer and inflammation. *Int J Mol Sci* 2010;11:3166-81.
41. Prajapati P, Singh P, Yadav S. Apigenin: A potent chemopreventive agent for cancer. *Mol* 2013;18:15756-72.
42. Ravindran PN, Nair MS, Pillai SM. *Eclipta alba* - a review on pharmacological aspects. *Phytochem Anal* 2007;18:407-17.
43. Sharma A, Gupta R, Verma P. Extraction methods for active constituents from *Eclipta alba* (L.) Hassk. *Phytochem Rev* 2015;14:191-9.
44. Mothana RA, Lindequist U, Schmid M. Alkaloids and flavonoids from *Eclipta alba* with antimicrobial activity. *Afri J Tradit Complement Altern Med* 2013;10:45-50.
45. Saxena A, Singh P, Kumar A. Triterpenoids and saponins of *Eclipta alba* and their effects on human liver cells. *J Herb Med* 2014;4:24-30.
46. Kamboj VP, Arora DS, Purohit SD. Phytosterols: Mechanisms of action, potential applications in medicine. *Mol Med Rep* 2011;4:12-7.

47. Singh A, Chauhan S, Sharma P. Anticancer potential of *Eclipta alba*: A comprehensive review of its chemical and biological properties. *J Phytomed* 2011;7:27-34.
48. Patil RH, Nanjappa V, Goud AV. Bioactive compounds from *Eclipta alba* and their potential for skin and hair care. *Pharmacogn Mag* 2012;8:209-13.
49. Hussein K, Nisar MF, Majeed A, Nawaz K, Bhatti KH. Ethnomedicinal survey for important plants of Jalalpur Jattan, District Gujrat, Punjab, Pakistan. *Ethnobotanical Lealf* 2010;14:807-25.
50. M. Neurath, M. Leppkes, Resolution of ulcerative colitis, *Semin. Immunopathol.* 41 (2019) 747–756.

Chapter 10

Isolation of Antibiotic-Resistant Bacteria from Municipal Sewage Water

Ashwani Kumar*, Shubham Raj, Anupriya Rana, Ritika Yadav, Ravi Kumar

Department of Life Sciences, Swami Vivekanand Subharti University, Meerut, India

*Corresponding author. Email: amritdhra1981@gmail.com

Abstract:

Bacteria were isolated from sewage water collected from different urban locations to evaluate the presence and spread of antibiotic resistance in the environment. The membrane filtration technique was applied, and the isolates were cultured on selective media including MacConkey agar, Salmonella–Shigella agar, Sodium azide agar, Mannitol salt agar, and Pseudomonas isolation agar. Identification of the microorganisms was carried out using Gram staining, observation of colony morphology and color, motility test, sugar utilization tests, and other biochemical assays. The bacterial isolates were identified as *Escherichia coli*, *Enterobacter* spp., *Klebsiella* spp., *Proteus* spp., *Pseudomonas aeruginosa*, & *Enterococcus faecalis*. Antibiotic susceptibility was tested using trimethoprim, streptomycin, rifampin, erythromycin, cephalothin, ciprofloxacin, carbenicillin, amoxiclav, amoxicillin, and ampicillin. The isolates demonstrated 50–100% resistance to the antibiotics tested; all isolates were resistant to rifampin, amoxiclav, and amoxicillin, while *Pseudomonas aeruginosa* showed resistance to all antibiotics used. These findings suggest a significant level of antibiotic resistance in sewage water, which could pose challenges in treating infections if such multidrug-resistant bacteria spread to human and animal pathogens. Municipal sewage water is an important reservoir of diverse microorganisms, including antibiotic-resistant bacteria that may pose a risk to public health. These findings indicate that municipal sewage water may act as a significant source of antibiotic-resistant bacteria, which could contribute to the spread of resistance to human and animal pathogens and create challenges in the treatment of infectious diseases.

Key words: Salmonella–Shigella, Antibiotic-Resistant Bacteria, Municipal Sewage Water, multidrug-resistant

Introduction

Microorganisms have evolved resistance to nearly all available antibiotics through the acquisition of antibiotic resistance genes, which are often carried on extrachromosomal elements known as plasmids. [1] This resistance occurs through several mechanisms, including mutations at the antibiotic target site, decreased drug availability due to altered cell

permeability or active efflux systems that expel antibiotics from the bacterial cell, production of enzymes that inactivate or degrade antibiotics, and the use of alternative metabolic pathways to bypass the antibiotic's target. [2] Environmental bacteria serve as important reservoirs of antibiotic resistance genes. [3] A study by Al-Berfkani et al. (2014) on water samples from treatment plants in Duhok city, Iraq, reported that *Staphylococcus aureus*, *Micrococcus varians*, and *Aeromonas hydrophila* exhibited resistance to penicillin, lincomycin, and amoxicillin. Similarly, research conducted on antibiotic-resistant pathogens isolated from environmental water near hospitals in Ahmedabad, India, revealed that *Escherichia coli* showed resistance rates of 33.34% to tetracycline, 16.67% to co-trimoxazole, and 8.34% to ciprofloxacin.[4] The present study aims to determine the antibiotic resistance patterns of bacteria isolated from sewage systems in Meerut city, India. [5]

Materials and methods

The careful selection of this region for detailed investigation is highly significant, as it provides an excellent opportunity to evaluate the overall sanitation conditions of the city.[6] The sampling site is situated at the confluence where sewage water mixes with the freshwater source, the Sutlej River. [7] This location represents the point at which urban wastewater enters and interacts with river water. [8] Samples were collected from both the entry and exit points of the sewage flow.[9]

Additionally, this site offers strong potential for identifying environmental hazards associated with the prolonged movement of contaminants.[10] These pollutants originate mainly from effluent discharge into the Sutlej River and may have serious consequences for both nearby and downstream ecosystems.[11] Therefore, this study plays an important role in assessing the hygienic status of the city and detecting potential risks linked to the long-distance transport of pollutants along the river.[12]

As outlined in the schematic representation of the methodology, wastewater samples were collected and cultured on appropriate growth media.[13] The isolates were then identified using morphological and biochemical tests.[14] Further genetic characterization was carried out using specific primers followed by sequence alignment.[15] Finally, the identified bacterial strains were subjected to culture sensitivity testing.[16]

Sampling

Types of samples

In this cross-sectional study, a total of 36 water samples were collected from the River at various critical points, including 26 from wastewater efflux and 10 from receiving waters. The study was conducted around the urban area of Meerut, where the river collects effluents from treatment systems.[17]

Sample collection and transportation

Sample collection involved the use of plastic containers that were sterilized with 70% ethanol and were pre-rinsed with the sampling water to avoid contamination and to adapt the containers to the water environment.[18] Once collected, samples were immediately sealed in these sterilized containers and were protected from sunlight.[19] They were transported in a cooler maintained at 4 °C to preserve their integrity and were analyzed within 24 h to ensure the reliability of the results.

Microbiological Analysis

Sample Processing- The isolation of bacterial strains was carried out through a series of steps. Initially, 3 mL of each water sample was transferred into tubes containing 5 mL of sterile peptone water, which acted as an enrichment medium. These tubes were then incubated at 37 °C for 24 hours to promote bacterial growth.[20]

Cultural Isolation and Identification- After incubation, a 1 µL loopful from each enriched culture was streaked onto blood agar, MacConkey agar, and CLED agar plates.[21] The plates were incubated overnight at 37 °C. Following this, subculturing was performed to obtain pure colonies, which were then examined for their colony morphology based on size, shape, color, and texture.[22]

Biochemical Confirmation- Suspected colonies of *Salmonella spp.*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Pseudomonas spp.* were further analyzed using microscopic examination and biochemical tests.[23] These included oxidase test, urease test, triple sugar iron (TSI) test, and IMViC tests (indole, methyl red, Voges–Proskauer, and citrate) following standard protocols.[24]

Antimicrobial Susceptibility Testing

After identification, the isolates were tested for antibiotic sensitivity using the Kirby–Bauer disk diffusion method.[25] Bacterial inoculum was prepared by suspending fresh colonies in 4–5 mL normal saline and adjusting turbidity to 0.5 McFarland standard. This suspension was evenly spread on Mueller-Hinton agar plates to achieve uniform growth.[26]

Antibiotic discs were placed on the inoculated plates, and a total of 16 antibiotics were tested, including ciprofloxacin, ampicillin, imipenem, gentamicin, co-trimoxazole, tetracycline, ceftriaxone, piperacillin/tazobactam, doxycycline, amikacin, meropenem, sulfamethoxazole,

ceftazidime, fosfomycin, cephalixin, and amoxicillin.[27] Plates were incubated at 37 °C for 16–18 hours.[28]

After incubation, zones of inhibition were measured and interpreted as sensitive, resistant, or intermediate based on CLSI (2020) guidelines.[29] Quality control was maintained using standard strains such as *Salmonella enterica* ATCC 14028, *Pseudomonas aeruginosa* ATCC 27853, *Klebsiella pneumoniae* ATCC 700603, and *Escherichia coli* ATCC 25922 to ensure accuracy and reliability.[30]

Molecular Analysis

DNA Isolation-Genomic DNA was extracted using a heat lysis method. A 1 mL culture grown in tryptic broth was centrifuged, washed, and resuspended in nuclease-free water. The suspension was heated at 95 °C for 5 minutes, followed by rapid cooling on ice for 5 minutes. [31] This cycle was repeated twice, and the sample was centrifuged at 10,000 rpm for 10 minutes at 4 °C. The extracted DNA was analyzed on 1% agarose gel and quantified using a NanoDrop spectrophotometer, then stored at –20 °C for further use.

Molecular Identification of Bacteria-Previously identified isolates were subjected to PCR using universal primers targeting conserved regions of the 16S rRNA gene. Amplified products of approximately 1500 base pairs were confirmed by gel electrophoresis.[32]

Detection of Resistance Genes- PCR was also performed on phenotypically resistant isolates to detect specific resistance genes. Both positive and negative controls were used where available. The PCR reaction mixture (25 µL) included PCR master mix, primers, template DNA, and nuclease-free water.[33]

Thermal cycling conditions involved initial denaturation at 95 °C for 5 minutes, followed by 35 cycles of denaturation (95 °C, 30 sec), annealing (55 °C, 30 sec), and extension (72 °C, 1 min), with a final extension at 72 °C for 10 minutes. The study targeted genes such as *Sul1*, *Sul3*, *aadA*, *tet (A/B/D)*, and *blaCTX-M*, and PCR products were analyzed on 1.5% agarose gel.[34]

Sequence Alignment

To better understand resistance mechanisms, sequence alignment of resistance genes was performed. The Needleman–Wunsch algorithm, implemented through ClustalW software, was used for multiple sequence alignment. Pairwise comparisons were first conducted, followed by construction of a guide tree and progressive alignment of sequences. Iterative refinement improved alignment accuracy, helping to identify similarities and evolutionary relationships among resistance genes.[35]

Results

Isolation and Identification of Antibiotic-Resistant Bacteria

Morphological examination revealed distinct colony characteristics among isolates. Some colonies appeared greenish, medium to large in size, with a characteristic “bull’s eye” appearance. These were non-lactose fermenters on MacConkey agar and appeared as Gram-negative short rods arranged singly. Positive oxidase results confirmed them as *Pseudomonas aeruginosa*.

In contrast, other isolates produced pink, smooth, shiny, and mucoid colonies on MacConkey agar, indicating lactose fermentation. These colonies were generally non-hemolytic on blood agar, though some showed swarming. They were Gram-negative and varied in size. Oxidase testing distinguished *Pseudomonas* (positive) from *Salmonella* (negative).

Further biochemical testing, including IMViC and TSI, confirmed the identity of isolates suspected to be *Escherichia coli* and *Klebsiella pneumoniae*.

Antibiotic Susceptibility Tests

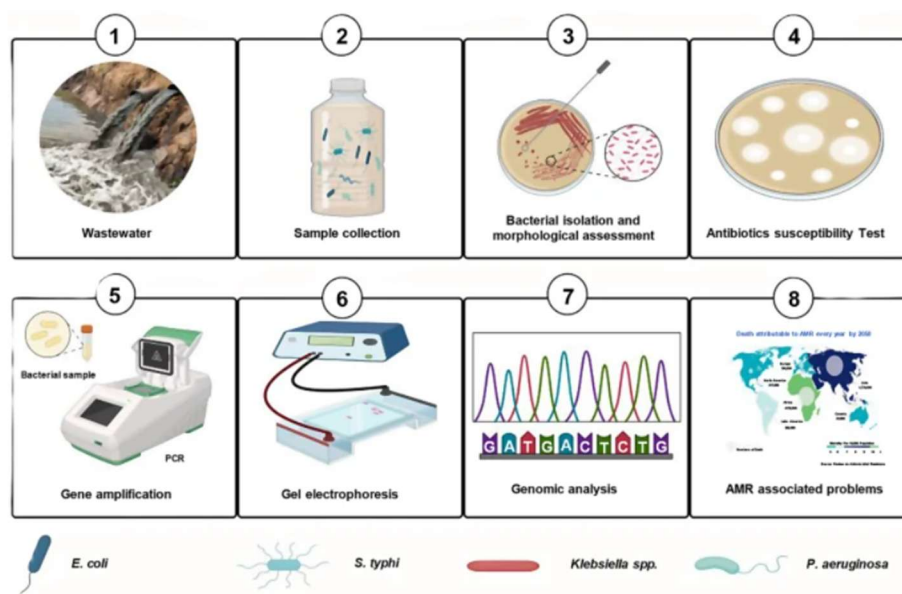
The antibiotic resistance patterns of the bacterial isolates were evaluated. The results indicated that a high level of resistance was present, with 90% of *Escherichia coli* isolates showing resistance, followed by 58% of *Klebsiella pneumoniae*, 55% of *Pseudomonas aeruginosa*, and 53% of *Salmonella* spp. against the six antibiotics tested. Moreover, all four bacterial species demonstrated significant resistance to ciprofloxacin. The results revealed significant variations in MDR rates among the species, with *E. coli* displaying the highest rate of resistance, followed by *K. pneumoniae*, *P. aeruginosa*, and *Salmonella* spp. These findings underscore an alarming pattern of increasing antibiotic resistance within these bacterial groups.[36]

Molecular identification of resistance genes in bacterial species

Universal primers targeting the 16 S rRNA gene were employed to amplify DNA from a cohort of 17 bacterial isolates, facilitating their molecular identification. Genomic analysis revealed significant findings regarding antibiotic resistance genes among the bacterial samples. *K. pneumoniae* displayed the highest prevalence, accounting for 44% of all detected resistance genes, followed by *E. coli* and *Salmonella* spp., each contributing 24%. *P. aeruginosa* was found to harbor 8% of the resistance genes. A significant proportion of the isolates, 70% (12 out of 17), were found to carry sulphonamide resistance genes. Among these, six isolates contained the *SulI* gene, while the remaining six harbored the *Sul3* gene.[37] Furthermore, 41% of the isolates (7 out of 17) were positive for aminoglycoside resistance genes. Tetracycline resistance was detected in 29% of the isolates, associated with the presence of *Tet A/B/D* genes. In addition, β -lactamase genes, including *bla CTX-M*, were

identified in 12% of the isolates (2 out of 17). Notably, *Klebsiella pneumoniae* exhibited a higher frequency of these resistance genes compared to *Escherichia coli*. [38]

Fig. 1



Schematic illustration of Characterization of Antibiotic Resistance Bacteria and Genes from Sewage Water. (1) wastewater (2) Sample collection (3) Bacterial isolation and morphological assessment (4) Antibiotic susceptibility test (5) Gene amplification (6) Gel electrophoresis (7) Genomic analysis (8) AMR associated problems

DISCUSSION

This study investigated the occurrence of antimicrobial-resistant (AMR) bacteria in the Sutlej River, particularly in areas influenced by urban wastewater discharge. The objective was to evaluate how contaminants from municipal sources contribute to the growth and spread of antibiotic-resistant bacteria. Such investigations are essential for understanding the ecological impact of urban waste on river systems and for assessing the public health risks associated with waterborne AMR pathogens. [39]

On MacConkey agar, *Pseudomonas aeruginosa* was identified as non-lactose fermenting, Gram-negative short rods showing a positive oxidase reaction. In contrast, pink, mucoid colonies with variable sizes and occasional swarming behavior were identified as Gram-negative bacteria. [40] The oxidase test played a key role in distinguishing *P. aeruginosa* from oxidase-negative *Salmonella* spp., which also showed no hemolysis on blood agar. These conventional identification characteristics remain important for differentiating bacterial isolates. *P. aeruginosa* is a facultative organism capable of surviving in aerobic conditions and is known to infect both humans and plants. The increasing occurrence of AMR in clinically relevant bacteria may be associated with enhanced gene exchange within

environmental resistance gene pools. Although many strains of *Escherichia coli* are harmless and beneficial to gut flora, certain pathogenic strains can cause symptoms such as diarrhea, abdominal pain, fever, and vomiting. Similarly, *Klebsiella pneumoniae*, typically a harmless inhabitant of the human intestine, can become pathogenic and infect various organs including the lungs, liver, bloodstream, and urinary tract.[41]

The results indicated that *K. pneumoniae* was the most dominant organism, accounting for 32.8% of isolates, followed by *P. aeruginosa* (28.1%), *E. coli* (25.0%), and *Salmonella* spp. (14.0%). All these bacteria exhibited resistance to at least three of the six antibiotics tested. Among the antibiotics, ciprofloxacin showed the highest level of resistance, whereas imipenem demonstrated comparatively lower resistance. These observations are consistent with earlier studies reporting higher resistance in *K. pneumoniae* and *P. aeruginosa*, followed by *E. coli*. [42]

The high level of resistance observed, particularly against ciprofloxacin, is alarming. The fact that 90% of *E. coli* isolates and more than half of the other bacterial isolates were resistant to multiple antibiotics highlights a serious challenge in treating infections caused by these pathogens. However, the relatively lower resistance to imipenem and gentamicin suggests that these antibiotics may still remain effective treatment options. Previous studies have also reported that extended-spectrum β -lactamase (ESBL)-producing isolates tend to be multidrug-resistant, especially against commonly used antibiotics such as trimethoprim-sulfamethoxazole and ciprofloxacin. This indicates a decline in the effectiveness of several conventional antibiotics, posing major challenges in clinical management and contributing to the growing burden of multidrug resistance (MDR). [43]

Molecular analysis further confirmed the widespread presence of antibiotic resistance genes (ARGs) among the isolates. The use of universal primers targeting the 16S rRNA gene enabled accurate identification of bacterial species. Among all isolates, *K. pneumoniae* was found to carry resistance genes more frequently than *E. coli* and *Salmonella* spp. The high prevalence of genes associated with resistance to sulphonamides, aminoglycosides, and tetracyclines is particularly concerning. In addition, β -lactamase genes such as *blaCTX-M* were detected in some isolates, reflecting diverse resistance mechanisms. The spread of these resistance genes is often linked to poor sanitation and inadequate healthcare practices, which increase exposure of bacteria to antibiotics. Both *E. coli* and *Salmonella* spp. were found to harbor aminoglycoside resistance gene (*aadA*) and multiple tetracycline resistance genes (*tet A/B/D*), indicating a high level of genetic resistance. The distribution of these genes varied among species, with *K. pneumoniae* showing a greater prevalence of β -lactamase genes compared to *E. coli*. [44] These findings are important for understanding resistance patterns

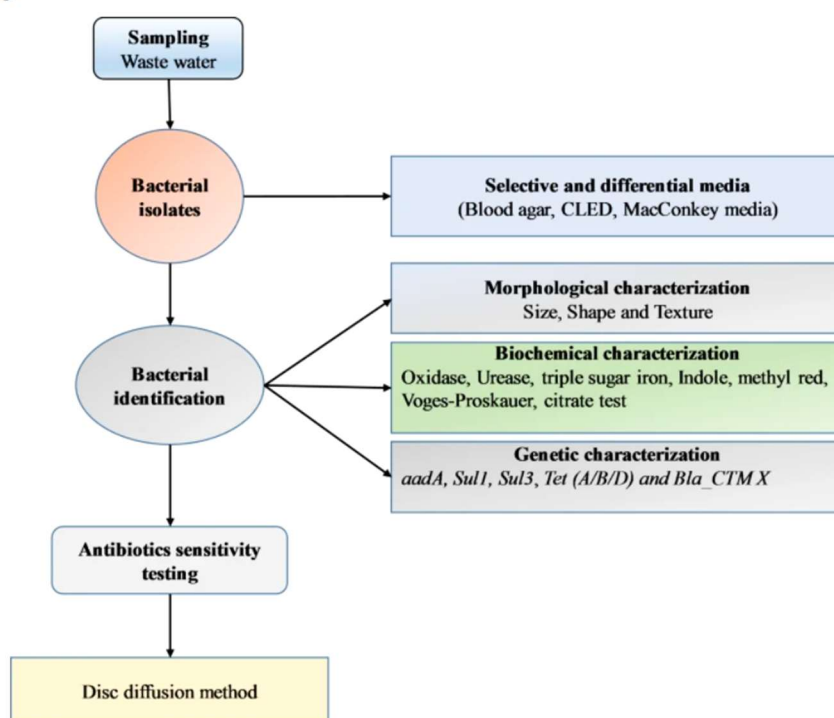
and for developing future control strategies. Additionally, resistance genes can spread among bacterial populations through mechanisms such as bacteriophage-mediated transfer and uptake of free DNA from the environment.

Antimicrobial resistance is further amplified as bacteria circulate through different environments, including soil, water, air, and within human and animal hosts. Urban wastewater systems, which receive inputs from households, hospitals, and pharmaceutical industries, act as major reservoirs and dissemination points for antibiotic-resistant bacteria. Wastewater is known to contain a wide range of contaminants, including pharmaceuticals, pesticides, and personal care products, which complicate treatment processes and contribute to the persistence of resistant microorganisms.[45]

The findings of this study have significant public health implications. The presence of antibiotic-resistant bacteria (ARB) and resistance genes in wastewater suggests that these contaminants can enter natural water bodies and potentially contaminate drinking water sources. This may lead to an increase in infections that are difficult to treat due to limited antibiotic options. Furthermore, horizontal gene transfer can accelerate the spread of resistance, increasing the likelihood of emergence of multidrug-resistant bacterial strains.[46]

To mitigate these risks, several measures can be adopted. Improving wastewater treatment technologies is essential to effectively remove resistant bacteria and genes. Advanced methods such as membrane bioreactors, advanced oxidation processes, and bioaugmentation can be incorporated into existing systems. In addition, stricter regulations on antibiotic use in healthcare and agriculture are necessary to reduce their entry into wastewater. Public awareness campaigns and antibiotic stewardship programs can also help minimize misuse of antibiotics. Together, these strategies can help control the spread of antibiotic resistance and protect public health.[47]

However, this study has certain limitations. The relatively small sample size and focus on a specific geographical region may restrict the broader applicability of the findings. [48]A larger dataset and inclusion of multiple locations along the river would provide a more comprehensive understanding of antibiotic resistance patterns.[49] Future studies should therefore aim to expand both the sample size and geographical coverage to gain deeper insights into the distribution and dynamics of antibiotic resistance.[50]



Conclusions

This study underscores the serious issue of antibiotic resistance in wastewater by detecting a variety of antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs) across different wastewater samples. The findings reveal that wastewater acts as both a reservoir and a transmission pathway for antibiotic resistance, posing significant risks to environmental and public health.[51]

A key outcome of this research is the identification of several clinically important ARB and ARGs, suggesting that existing wastewater treatment methods may not be fully effective in eliminating these contaminants. These results emphasize the urgent need for stricter regulations on antibiotic use and the implementation of more advanced wastewater treatment technologies to limit the spread of resistance.

Furthermore, the study highlights the importance of continuous monitoring and surveillance of ARB and ARGs in wastewater systems to evaluate the effectiveness of control strategies and make necessary improvements. Overall, the findings point toward the need for coordinated efforts involving government authorities, scientific communities, and public health sectors. Future research should focus on improving treatment systems and developing innovative approaches to reduce antibiotic resistance, thereby safeguarding public health and preserving water resources.

References

- [1] Abayneh M, Zeynudin A, Tamrat R, Tadesse M, Tamirat A (2023) Drug resistance and extended-spectrum β -lactamase (ESBLs)-producing Enterobacteriaceae,

Acinetobacter and Pseudomonas species from the views of one-health approach in Ethiopia: a systematic review and meta-analysis. One Health Outlook 5(1):12. <https://doi.org/10.1186/s42522-023-00088-z>

[2] Abu-Sini MK, Maharmah RA, Abulebdah DH, Al-Sabi MN (2023) Isolation and identification of coliform bacteria and multidrug-resistant Escherichia coli from water intended for drug compounding in community pharmacies in Jordan. Healthcare 11(3):299. <https://doi.org/10.3390/healthcare11030299>

[3] Altschul SF (1997) Gapped BLAST and PSI-BLAST: a new generation of protein database search programs. Nucleic Acids Res 25:3389–3402. <https://doi.org/10.1093/nar/25.17.3389>

[4] Altschul SF (2012) Gapped BLAST and PSI-BLAST: a new generation of protein database search programs. Bioinformatics 28:3389. <https://doi.org/10.1093/nar/25.17.3389>

[5] Bashir N, Dabool AS, Khan MI, Almalki MG, Ahmed A, Mir MA, Hamdoon AAE, Elawad MA, Mosa OF, Niyazov LN (2023) Antibiotics resistance as a major public health concern: a pharmaco-epidemiological study to evaluate prevalence and antibiotics susceptibility-resistance pattern of bacterial isolates from multiple teaching hospitals. J Infect Public Health 16:61–68. <https://doi.org/10.1016/j.jiph.2023.09.019>

[6] Cantón R, Horcajada JP, Oliver A, Garbajosa PR, Vila J (2013) Inappropriate use of antibiotics in hospitals: the complex relationship between antibiotic use and antimicrobial resistance. Enferm Infec Microbiol 31:3–11. [https://doi.org/10.1016/S0213-005X\(13\)70126-5](https://doi.org/10.1016/S0213-005X(13)70126-5)

[7] Carriero MM, Mendes Maia A, Moro Sousa R, Henrique-Silva F (2016) Characterization of a new strain of Aeromonas dhakensis isolated from diseased pacu fish (Piaractus mesopotamicus) in Brazil. J Fish Dis 39(11):1285–1295. <https://doi.org/10.1111/jfd.12457>

[8] Castañeda-Barba S, Top EM, Stalder T (2024) Plasmids, a molecular cornerstone of antimicrobial resistance in the One Health era. Nat Rev Microbiol 22(1):18–32. <https://doi.org/10.1038/s41579-023-00926-x>

[9] Chauhan A, Jindal T, Chauhan A, Jindal T (2020) Biochemical and molecular methods for bacterial identification. *Microbiological Methods for Environment, Food*

and Pharmaceutical Analysis. Springer, Cham., 425–468. https://doi.org/10.1007/978-3-030-52024-3_10.

[10] Costa BF, Zarei-Baygi A, Iskander SM, Smith AL (2023) Antibiotic resistance genes fate during food waste management–comparison between thermal treatment, hyperthermophilic composting, and anaerobic membrane bioreactor. *Bioresour Technol* 388:129771. <https://doi.org/10.1016/j.biortech.2023.129771>

[11] Easrat Jahan T, Aungshi TF (2023) Determination of isolation & antibiotic susceptibility pattern of *Salmonella* spp. from fresh vegetables collected from local markets of Dhaka city. <http://hdl.handle.net/10361/19391>

[12] Elgendy MY, Sherif AH, Kenawy AM, Abdelsalam M (2022) Phenotypic and molecular characterization of the causative agents of edwardsiellosis causing Nile tilapia (*Oreochromis niloticus*) summer mortalities. *Microb Pathog* 169:105620. <https://doi.org/10.1016/j.micpath.2022.105620>

[13] Estaleva CE, Zimba TF, Sekyere JO, Govinden U, Chenia HY, Simonsen GS, Haldorsen B, Essack SY, Sundsfjord A (2021) High prevalence of multidrug resistant ESBL-and plasmid mediated AmpC-producing clinical isolates of *Escherichia coli* at Maputo Central Hospital, Mozambique. *BMC Infect Dis* 21:1–6. <https://doi.org/10.1186/s12879-020-05696-y>

[14] Farhadi M, Ahanjan M, Goli HR, Haghshenas MR, Gholami M (2021) High frequency of multidrug-resistant (MDR) *Klebsiella pneumoniae* harboring several β -lactamase and integron genes collected from several hospitals in the north of Iran. *Ann clin Microbiol Antimicrob* 20:1–9. <https://doi.org/10.1186/s12941-021-00476-1>

[15] Ferguson RM, Garcia-Alcega S, Coulon F, Dumbrell AJ, Whitby C, Colbeck I (2019) Bioaerosol biomonitoring: sampling optimization for molecular microbial ecology. *Mol Ecol Resour* 19(3):672–690. <https://doi.org/10.1111/1755-0998.13002>

[16] Foxman B, Salzman E, Gesierich C, Gardner S, Ammerman M, Eisenberg M, Wigginton K (2024) Wastewater surveillance of antibiotic resistant bacteria for public health action: potential and challenges. medRxiv. 24305136 <https://doi.org/10.1101/2024.03.31.24305136>.

[17] Ghenea AE, Zlatian OM, Cristea OM, Ungureanu A, Mititelu RR, Balasoiu AT, Vasile CM, Salan A-I, Iliuta D, Popescu M (2022) TEM, CTX-M, SHV genes in ESBL-producing *Escherichia coli* and *Klebsiella pneumoniae* isolated from clinical samples in a county clinical emergency hospital Romania-predominance of CTX-M-15. *Antibiotics*, 11(4), 503. <https://doi.org/10.3390/antibiotics11040503>

- [18] Guo Y, Gao J, Wang Z, Cui Y, Li Z, Wu Z, Zhao Y, Li D, Dai H (2022) The fate and behavior mechanism of antibiotic resistance genes and microbial communities in flocs, aerobic granular and biofilm sludge under chloroxyleneol pressure. *J Hazard Mater* 438:129465. <https://doi.org/10.1016/j.jhazmat.2022.129465>
- [19] Habib A, Lo S, Villageois-Tran K, Petitjean M, Malik SA, Armand-Lefevre L, Ruppe E, Zahra R (2022) Dissemination of carbapenemase-producing enterobacterales in the community of Rawalpindi, Pakistan. *PLoS ONE* 17(7):e0270707. <https://doi.org/10.1371/journal.pone.0270707>
- [20] Havenga B, Ndlovu T, Clements T, Reyneke B, Waso M, Khan W (2019) Exploring the antimicrobial resistance profiles of WHO critical priority list bacterial strains. *BMC Microbiol* 19:1–16. <https://doi.org/10.1186/s12866-019-1687-0>
- [21] Hendriksen RS, Bortolaia V, Tate H, Tyson GH, Aarestrup FM, McDermott PF (2019) Using genomics to track global antimicrobial resistance. *Front Public Health* 7:242. <https://doi.org/10.3389/fpubh.2019.00242>
- [22] Hill JA, Ammar R, Torti D, Nislow C, Cowen LE (2013) Genetic and genomic architecture of the evolution of resistance to antifungal drug combinations. *PLoS Genet* 9(4):e1003390. <https://doi.org/10.1371/journal.pgen.1003390>
- [23] Humphries R, Bobenchik AM, Hindler JA, Schuetz AN (2021) Overview of changes to the clinical and laboratory standards institute performance standards for antimicrobial susceptibility testing, M100. *J Clin Microbiol* 59(12):10–1128. <https://doi.org/10.1128/jcm.00213-21>
- [24] Kayode-Afolayan SD, Ahuekwe EF, Nwinyi OC (2022) Impacts of pharmaceutical effluents on aquatic ecosystems. *Sci Afr* 17:e01288. <https://doi.org/10.1016/j.sciaf.2022.e01288>
- [25] Khan SS, Ullah I, Ullah S, An R, Xu H, Nie K, Liu C, Liu L (2021) Recent advances in the Surface Functionalization of nanomaterials for Antimicrobial Applications. *Materials* 14(22):6932. <https://doi.org/10.3390/ma14226932>
- [26] Klatte S, Schaefer HC, Hempel M (2017) Pharmaceuticals in the environment—a short review on options to minimize the exposure of humans, animals and ecosystems. *Sustain Chem Pharm* 5:61–66. <https://doi.org/10.1016/j.scp.2016.07.001>
- [27] Kollaran AM, Joge S, Kotian HS, Badal D, Prakash D, Mishra A, Varma M, Singh V (2019) Context-specific requirement of forty-four two-component loci in *Pseudomonas aeruginosa* swarming. *IScience* 13:305–317. <https://doi.org/10.1016/j.isci.2019.02.028>

- [28] Li X, Rensing C, Vestergaard G, Arumugam M, Nesme J, Gupta S, Brejnrod AD, Sørensen SJ (2022) Metagenomic evidence for co-occurrence of antibiotic, biocide and metal resistance genes in pigs. *Environ Int* 158:106899. <https://doi.org/10.1016/j.envint.2021.106899>
- [29] Liu X, Shao Z, Wang Y, Liu Y, Wang S, Gao F, Dai Y (2023) New use for *Lentinus edodes* bran biochar for tetracycline removal. *Environ Res* 216:114651. <https://doi.org/10.1016/j.envres.2022.114651>
- [30] Ma Q, Pan H, Li D, Wang J (2024) Chloroxyleneol positively affects the aerobic sequencing batch reactor performance and reshapes microbial communities and antibiotic resistance genes. *J Water Proc Eng* 57:104642. <https://doi.org/10.1016/j.jwpe.2023.104642>
- [31] Makaye A, Ripanda AS, Miraji H (2022) Transport behavior and risk evaluation of pharmaceutical contaminants from Swaswa Wastewater Stabilization Ponds. *J Biodivers Environ Sci* 20(2):30–41
- [32] Mozhi A, Prabhakar AK, Mohan BC, Sunil V, Teoh JH, Wang CH (2022) Toxicity effects of size fractions of incinerated sewage sludge bottom ash on human cell lines. *Environ Int* 158:106881. <https://doi.org/10.1016/j.envint.2021.106881>
- [33] Mumtaz MN, Irfan M, Siraj S, Khan A, Khan H, Imran M, Khan IA, Khan A (2024) Whole-genome sequencing of extensively drug-resistant *Salmonella enterica* serovar Typhi clinical isolates from the Peshawar region of Pakistan. *J Infect Public Health* 17(2):271–282. <https://doi.org/10.1016/j.jiph.2023.12.002>
- [34] Munita JM, Arias CA (2016) Mechanisms of antibiotic resistance. *Virulence Mech Bacterial Pathogens* 481–511. <https://doi.org/10.1128/9781555819286.ch17>
- [35] Murray CJ, Ikuta KS, Sharara F, Swetschinski L, Aguilar GR, Gray A, Han C, Bisignano C, Rao P, Wool E (2022) Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. *Lancet* 399(10325):629–655. [https://doi.org/10.1016/S0140-6736\(21\)02724-0](https://doi.org/10.1016/S0140-6736(21)02724-0)
- [36] Mustafai MM, Hafeez M, Munawar S, Basha S, Rabaan AA, Halwani MA, Alawfi A, Alshengeti A, Najim MA, Alwarthan S (2023) Prevalence of carbapenemase and extended-spectrum β -lactamase producing Enterobacteriaceae: a cross-sectional study. *Antibiotics* 12(1):148. <https://doi.org/10.3390/antibiotics12010148>
- [37] Nakkarach A, Foo HL, Song AA-L, Nitisinprasert S, Withayagiat U (2020) Promising discovery of beneficial *Escherichia coli* in the human gut. *3 Biotech* 10(7):296. <https://doi.org/10.1007/s13205-020-02289-z>

- [38] Noaman KA, Alharbi NS, Khaled JM, Kadaikunnan S, Alobaidi AS, Almazyed AO, Aldosary MS, Al Rashedi S (2023) The transmutation of *Escherichia coli* ATCC 25922 to small colony variants (SCVs) *E. coli* strain as a result of exposure to gentamicin. J Infect Public Health 16(11):1821–1829. <https://doi.org/10.1016/j.jiph.2023.08.024>
- [39] Pan F (2022) Fighting antimicrobial resistant (AMR) bacteria: from bacteriophage-based specific capture to controlled killing. https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/536896/8/Abstract_28226.pdf
- [40] Pearl M, Weng PL, Chen L, Dokras A, Pizzo H, Garrison J, Butler C, Zhang J, Reed EF, Kim IK (2022) Long term tolerability and clinical outcomes associated with tocilizumab in the treatment of refractory antibody mediated rejection (AMR) in pediatric renal transplant recipients. Clin Transpl 36(8):e14734. <https://doi.org/10.1111/ctr.14734>
- [41] Pintor-Cora A, Alegría Á, Ramos-Vivas J, García-López ML, Santos JA, Rodríguez-Calleja JM (2023) Antimicrobial-resistant *Enterobacter cloacae* complex strains isolated from fresh vegetables intended for raw consumption and their farm environments in the Northwest of Spain. LWT 188:115382. <https://doi.org/10.1016/j.lwt.2023.115382>
- [42] Rahim K, Saleha S, Basit A, Zhu X, Ahmed I, Huo L, Zhang P, Usman B, Munir S, Franco OL (2017) *Pseudomonas aeruginosa* as a powerful biofilm producer and positive action of amikacin against isolates from chronic wounds. Jundishapur J Microbiol 10(10). <https://doi.org/10.5812/jjm.57564>
- [43] Ram B, Kumar M (2020) Correlation appraisal of antibiotic resistance with fecal, metal and microplastic contamination in a tropical Indian river, lakes and sewage. NPJ Clean Water 3(1):3. <https://doi.org/10.1038/s41545-020-0050-1>
- [44] Ripanda AS, Rwiza MJ, Nyanza EC, Miraji H, Bih NL, Mzula A, Mwega E, Njau KN, Vuai SAH, Machunda RL (2023) Antibiotic-resistant microbial populations in urban receiving waters and wastewaters from Tanzania. J Environ Chem Ecotoxicol 5:1–8. <https://doi.org/10.1016/j.eneco.2022.10.003>
- [45] Schmiede D, Haselhoff T, Thomas A, Kraiselburd I, Meyer F, Moebus S (2024) Small-scale wastewater-based epidemiology (WBE) for infectious diseases and antibiotic resistance: a scoping review. Int J Hyg Environ Health 259:114379. <https://doi.org/10.1016/j.ijheh.2024.114379>
- [46] Shaikh OA, Asghar Z, Aftab RM, Amin S, Shaikh G, Nashwan AJ (2023) Antimicrobial resistant strains of *Salmonella typhi*: the role of illicit antibiotics sales,

misuse, and self-medication practices in Pakistan. *J Infect Public Health*. <https://doi.org/10.1016/j.jiph.2023.08.003>

[47] Shao Z, Wu S, Gao Y, Liu X, Dai Y (2024) Two-step pyrolytic preparation of biochar for the adsorption study of tetracycline in water. *Environ Res* 242:117566. <https://doi.org/10.1016/j.envres.2023.117566>

[48] Ullah I, Khan SS, Ahmad W, Liu L, Rady A, Aldahmash B, Yu C, Wang Y (2024a) Silver incorporated SeTe nanoparticles with enhanced photothermal and photodynamic properties for synergistic effects on anti-bacterial activity and wound healing. *RSC Adv* 14(27):18871–18878. <https://doi.org/10.1039/D4RA01343C>

[49] Ullah I, Khan SS, Ahmad W, Liu L, Rady A, Aldahmash B, Yu Y, Wang J, Wang Y (2024b) NIR light-activated nanocomposites combat biofilm formation and enhance antibacterial efficacy for improved wound healing. *Commun Chem* 7(1):131. <https://doi.org/10.1038/s42004-024-01215-1>

[50] Yang X, Niu Y, Yang Y, Zhou H, Li J, Fu X, Shen Z, Wang J, Qiu Z (2023) Pheromone effect of estradiol regulates the conjugative transfer of pCF10 carrying antibiotic resistance genes. *J Hazard Mater* 451:131087. <https://doi.org/10.1016/j.jhazmat.2023.131087>

[51] Zankari E, Hasman H, Cosentino S, Vestergaard M, Rasmussen S, Lund O, Aarestrup FM, Larsen MV (2012) Identification of acquired antimicrobial resistance genes. *J Antimicrob Chemother* 67(11):2640–2644. <https://doi.org/10.1093/jac/dks261>

Chapter 11

Plant-Derived Bioenzymes: Efficacy, Extraction Strategies, and Versatile Applications – A Comprehensive Review

¹Unaiza Hashmi, ^{2*}Ashwani Kumar, ³Ravindra Kumar Jain, ⁴Dheer Pal Singh, ⁵Neeru Singh, ⁶Anchal Sharma

¹Ph.D Scholar Biotechnology, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

^{2*}HOD & Associate Professor, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

³Professor, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

⁴Associate Professor ^{5,6}Assistant Professor, Department of Life sciences, Keral Verma Subharti College of Science, Swami Vivekanand Subharti University, Meerut (250005) Uttar Pradesh, India

*Corresponding Author- Dr. Ashwani Kumar, amritdhra1981@gmail.com

Abstract

Bioenzymes derived from plant components have emerged as sustainable and economically viable alternatives to microbial and animal-derived enzymes for a wide range of industrial, biotechnological, and environmental applications. This comprehensive review summarizes recent advancements (2020–2025) in the extraction, purification, characterization, and utilization of plant-derived bioenzymes. Major enzyme classes such as proteases (e.g., bromelain and papain), oxidoreductases (including peroxidases and polyphenol oxidases), phosphatases, and lyases are discussed with emphasis on their botanical sources, biochemical properties, catalytic efficiency, and functional performance. Recent studies demonstrate improved extraction and purification strategies capable of achieving enzyme recovery yields ranging from 60–93% with purification levels of approximately 4–7 folds. Advances in biochemical characterization have also provided insights into optimal operational conditions, including pH, temperature stability, and substrate specificity. Furthermore, the review highlights diverse applications of plant bioenzymes in detergent formulation, wastewater bioremediation, food processing, pharmaceutical production, and fine chemical synthesis. Particular attention is given to the valorization of agricultural and agro-industrial residues, such as pineapple peels and cabbage processing waste, as cost-effective and sustainable sources of bioenzymes. Despite these promising developments, several challenges remain,

including the need for standardized activity assays, improved enzyme stability, and economic feasibility for large-scale production. Overall, this review provides an updated perspective on the efficacy and versatile applications of plant-derived bioenzymes and outlines future research directions for their integration into sustainable biotechnological and bioeconomic systems.

Keywords: Bioenzymes; Plant-derived enzymes; Proteases; Oxidoreductases; Enzyme purification; Industrial biotechnology; Waste valorization; Sustainable bioprocessing

Introduction

Enzymes are biological catalysts that accelerate biochemical reactions with high specificity and efficiency under mild conditions. Industrial enzymes constitute a multi-billion dollar global market, with applications spanning detergents, textiles, food processing, pharmaceuticals, biofuels, and environmental remediation [1]. Traditionally, industrial enzymes have been sourced from microbial fermentation and animal tissues. However, plant-derived bioenzymes are gaining prominence due to several compelling advantages: Plants are renewable resources that can be cultivated sustainably without the ethical concerns associated with animal-derived enzyme. Agricultural waste streams and processing residues provide low-cost feedstocks. Plant enzymes generally have GRAS (Generally Recognized as Safe) status for food applications. Many plant enzymes exhibit distinctive substrate specificities and stability profiles. Enzyme extraction from agro-waste valorizes materials that would otherwise require disposal.

Historical Perspective- The use of plant enzymes dates back centuries, with papain from papaya latex being one of the earliest documented applications for meat tenderization. The 20th century saw systematic scientific investigation of plant enzymes, leading to commercial production of papain, bromelain, and ficin. Recent decades (2020-2025) have witnessed renewed interest driven by:

1.4 Classification of Plant Bioenzymes

Plant bioenzymes can be classified according to the Enzyme Commission (EC) nomenclature:

MAJOR PLANT-DERIVED BIOENZYMES: SOURCES & PROPERTIES

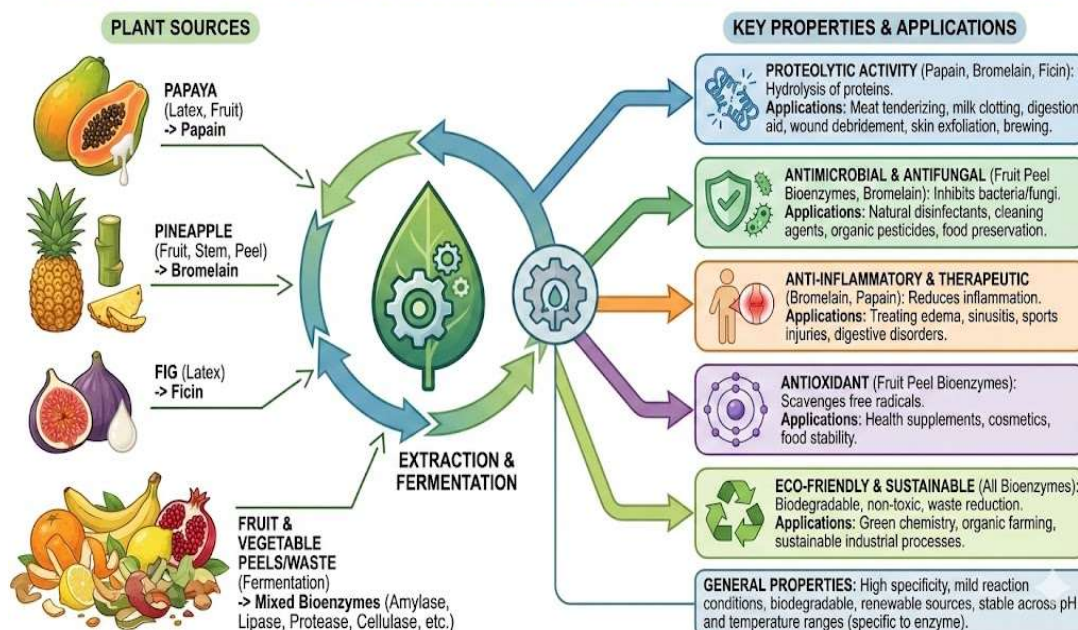


Fig. 1 Major Plant-Derived Bioenzymes: Sources and Properties

Proteases

Proteases (peptidases, proteinases) catalyze the hydrolysis of peptide bonds in proteins and represent the largest segment of industrial enzyme applications. Plant proteases are classified based on their catalytic mechanism:

2.1.1 Cysteine Proteases

Bromelain

Bromelain is a mixture of cysteine proteases derived from various parts of pineapple (*Ananas comosus*). Recent research has demonstrated that waste fractions from pineapple processing are viable enzyme sources, supporting circular economy principles [2].

Table 2: Purification Performance Summary

Enzyme	Source	Method	Yield (%)	Purification Fold	Specific Activity	Reference
Bitter leaf peroxidase	<i>V. amygdalina</i>	ATPS + Gel filtration	76	7.1	3010.6 U/mg	[6]
Bromelain	Pineapple stem	Salt precipitation + Diafiltration	60-93	4-7	1.4 U/mg	[2]

Enzyme	Source	Method	Yield (%)	Purification Fold	Specific Activity	Reference
Bromelain	Pineapple peel (Josapine)	Precipitation + Freeze-dry	-	-	15,234 CDU/mg	[3]
Papain	Papaya parts	Two-step salt precipitation	-	1.56	-	[4]
Cabbage peroxidase	Cabbage legs	Crude extraction	-	-	High activity	[7]

Table 3: pH and Temperature Optima of Selected Plant Enzymes

Enzyme	Source	pH Optimum	Temperature Optimum	Reference
Bitter leaf peroxidase	<i>V. amygdalina</i>	6.0	30°C	[6]
Cabbage peroxidase	Cabbage legs	6.0	40°C	[7]
Papain	<i>C. papaya</i>	8.0	60°C	[4]
Bromelain	<i>A. comosus</i>	7.0-8.0	50-60°C	[2,3]
Tea PPO	<i>C. sinensis</i>	5.0-7.0	25-40°C	[8]

The biological catalysis of chemical reactions is a fundamental prerequisite for life. Enzymes, the proteinaceous biocatalysts that drive these reactions, have transcended their physiological roles to become the cornerstone of modern industrial biotechnology. As the global economy pivots towards "Green Chemistry" and sustainable manufacturing, the demand for environmentally benign, biodegradable, and non-toxic catalysts has surged. The global market for industrial enzymes was valued at approximately USD 5.9 billion in 2020 and is

projected to expand at a compound annual growth rate (CAGR) of 6% through 2027¹¹. While microbial enzymes (derived from bacteria and fungi) currently dominate over 80% of this market due to the ease of recombinant fermentation and scalability, plant-derived bioenzymes represent a vital, yet underutilized, niche with unique biochemical properties.

Plant bioenzymes are catalytic proteins extracted from various plant organs—leaves, stems, fruits, latex, seeds, and agro-industrial residues (peels, husks). Unlike microbial enzymes, which often require stringent purification to remove endotoxins, plant enzymes are generally considered "Generally Recognized As Safe" (GRAS), making them particularly attractive for food, pharmaceutical, and cosmetic applications. Furthermore, the extraction of enzymes from agricultural waste streams—such as bromelain from pineapple peels or peroxidase from potato skins—aligns seamlessly with the principles of the Circular Bioeconomy, transforming biomass waste into high-value bioactive compounds¹².

Historical Perspective: From Ancient Practices to Enzymology- The utilization of plant bioenzymes predates the understanding of their molecular nature by millennia. The history of plant enzymology is inextricably linked to food preservation and medicine. Ancient civilizations empirically utilized plant extracts for their proteolytic and coagulating properties. In the *Iliad*, Homer (c. 8th century BC) describes the use of fig juice (latex containing the protease **ficin**) to curdle milk for cheese production¹³. Similarly, native populations in Central and South America traditionally used the latex of the papaya tree (*Carica papaya*) and the fruit of the pineapple (*Ananas comosus*) to treat wounds and tenderize tough game meat long before the discovery of papain and bromelain. These practices represent the earliest applications of plant cysteine proteases.

The Birth of Enzymology (19th Century)- The scientific formalization of plant enzymes marks the birth of biochemistry itself. In 1833, French chemists Anselme Payen and Jean-François Persoz isolated a substance from barley malt that converted starch into sugar. They named it "diastase" (now known as amylase). This was the first enzyme ever isolated, establishing plants as the original source of enzymology research¹⁴.

The Crystallization Milestone (20th Century)- A pivotal moment occurred in 1926 when James B. Sumner succeeded in crystallizing urease from the Jack bean (*Canavalia ensiformis*). Sumner proved that enzymes were proteins, a concept previously debated. His work, which won the Nobel Prize in Chemistry in 1946, relied entirely on a plant source, underscoring the high concentration and accessibility of enzymes in plant seeds¹⁵. Despite the mid-20th century shift toward microbial fermentation, these historical milestones highlight the fundamental importance of phytochemistry in defining biocatalysis.

Structural and Functional Classification of Plant Bioenzymes

Plant enzymes are highly diverse, evolving to regulate metabolism, defense mechanisms, and senescence. They are classified according to the Enzyme Commission (EC) number system based on the reaction they catalyze. The most industrially relevant categories are Proteases (Hydrolases) and Oxidoreductases.

Plant Proteases (Peptidases)- Proteases (EC 3.4) hydrolyze peptide bonds in proteins. Plant proteases are the most commercially significant group, dominating the therapeutic and food sectors. They are categorized based on the critical amino acid residue at their active site.

Cysteine Proteases - This is the most abundant family in the plant kingdom, often found in latex and fruits as a defense mechanism against herbivory.

Papain (EC 3.4.22.2): Extracted from the latex of green papaya. It is a single-chain polypeptide with a molecular weight of 23.4 kDa. It contains a catalytic dyad of Cysteine-25 and Histidine-159. Papain is an endopeptidase with broad specificity, capable of cleaving basic, acidic, and hydrophobic amino acid residues. It exhibits remarkable physicochemical stability, remaining active between pH 3.0 and 9.0¹⁶.

Bromelain (EC 3.4.22.32/33): A complex mixture of proteases found in the *Bromeliaceae* family. It is distinctively categorized into Stem Bromelain (EC 3.4.22.32) and Fruit Bromelain (EC 3.4.22.33). Stem bromelain is a glycosylated protease, whereas fruit bromelain is not. Bromelain differs from papain in its specificity for arginine residues and its potent anti-inflammatory capability¹⁷. **Ficin (EC 3.4.22.3):** Found in the latex of fig trees (*Ficus carica*). Ficin is distinguished by its high cystine content and its unique ability to hydrolyze native collagen and elastin at neutral pH, making it a powerful anthelmintic and meat tenderizer.

Zingibain (EC 3.4.22.67): A lesser-known but highly potent protease from ginger (*Zingiber officinale*) rhizomes. It has a higher proteolytic activity against collagen than papain or bromelain but suffers from lower stability¹⁸.

Aspartic Proteases (EC 3.4.23)- These proteases function optimally at acidic pH and rely on two aspartic acid residues for catalysis.

- **Cardosins and Cyprosims:** Extracted from the flowers of the cardoon thistle (*Cynara cardunculus*). These enzymes possess high milk-clotting activity (specifically cleaving κ -casein) but low general proteolytic activity, making them ideal vegetable rennet substitutes for cheese production¹⁹.

Serine Proteases (EC 3.4.21)- While common in animals (trypsin) and bacteria (subtilisin), serine proteases are rarer in plants but exist in fruits like *Cucumis trigonus* (Kachri).

Cucumisin (EC 3.4.21.25): Extracted from melon varieties. It is stable at high temperatures and alkaline pH, sharing structural homology with bacterial subtilisin.

Oxidoreductases- These enzymes catalyze biological oxidation-reduction reactions. In plants, they play critical roles in lignification, wound healing, and defense against pathogens.

Peroxidases (EC 1.11.1.7) Plant peroxidases are heme-containing glycoproteins that catalyze the oxidation of various substrates using hydrogen peroxide (H_2O_2) as an electron acceptor. **Horseradish Peroxidase (HRP):** The most studied plant peroxidase, derived from the roots of *Armoracia rusticana*. HRP is characterized by a protoporphyrin IX heme group. It is extensively used in diagnostic immunoassays (ELISA) and bioremediation of phenolic pollutants. **Soybean Peroxidase (SBP):** Found in the seed coat (hull) of soybeans. SBP is notably more thermostable and stable at acidic pH compared to HRP, making it a superior candidate for industrial wastewater treatment²⁰.

Polyphenol Oxidases (PPO) (EC 1.14.18.1)- PPOs are copper-containing metalloenzymes found in plastids. They catalyze the hydroxylation of monophenols to o-diphenols and the oxidation of o-diphenols to o-quinones. High concentrations are found in banana peels, potato skins, and eggplant. While PPO is often viewed negatively due to "enzymatic browning" in cut fruits, industrially, it is valuable for the synthesis of pharmacological pigment precursors and the detoxification of phenolic wastewaters²¹.

Carbohydrases- Amylases hydrolyze glycosidic bonds in starch molecules. **Alpha-Amylase (EC 3.2.1.1):** An endo-enzyme that cleaves internal α -1,4-glycosidic bonds in amylose and amylopectin. It is abundant in germinating cereal seeds (barley, wheat, maize). The biochemical onset of germination (malting) activates these enzymes to mobilize starch reserves, a process exploited for millennia in brewing and distilling. **Beta-Amylase (EC 3.2.1.2):** An exo-enzyme common in sweet potatoes and soybeans. It cleaves maltose units from the non-reducing end of starch chains.

3.4 Lipases (EC 3.1.1.3)

Lipases catalyze the hydrolysis of triacylglycerols into glycerol and free fatty acids.

- **Sources:** Plant lipases are concentrated in oilseeds such as castor bean (*Ricinus communis*), rapeseed, and oats.
- **Specific Features:** Unlike microbial lipases, plant lipases often exhibit specificity for certain fatty acid chain lengths. For example, the lipase from *Vernonia galamensis* seeds discriminates between vernolic acid and other fatty acids, offering potential for specific lipid modifications in the oleochemical industry²² (Barros et al., 2010).

Part 2: Extraction Methodologies, Purification Strategies, and Kinetic Characterization

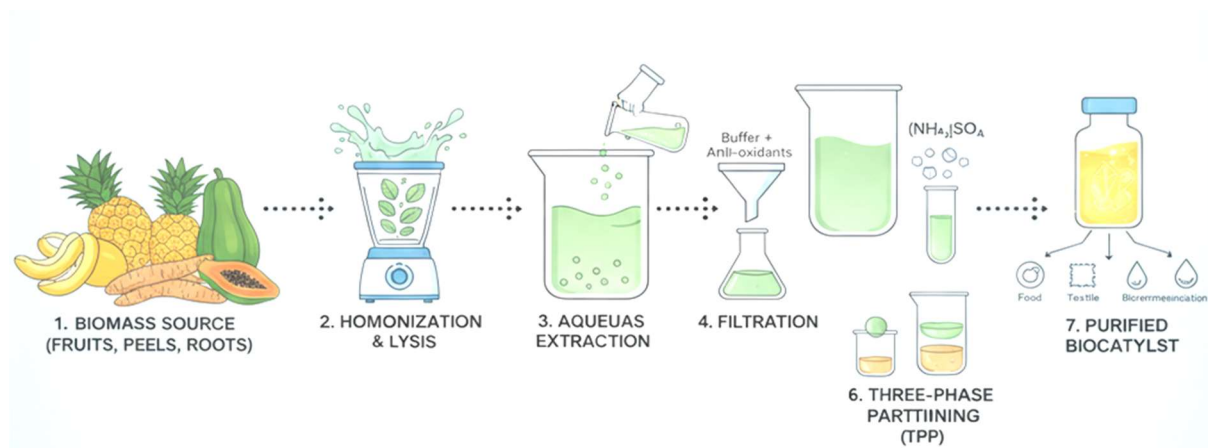


Fig. 2 Bioenzyme Extraction Methodologies: From Biomass to Biocatalyst

Extraction Methodologies: From Biomass to Biocatalyst

The extraction of enzymes from plant tissues presents unique challenges compared to microbial fermentation. While bacteria secrete enzymes into the culture medium (extracellular), plant enzymes are often intracellular (cytosolic) or bound to cell organelles (chloroplasts, mitochondria) or the cell wall. Consequently, the extraction process must disrupt the robust cellulosic cell wall while preserving the tertiary structure of the protein.

Pre-treatment and Homogenization

The first step involves the mechanical disruption of plant tissues.

- **Mechanical Disruption:** For soft tissues like papaya or pineapple fruit, simple blending or maceration is sufficient. For harder tissues like horseradish roots or soybean hulls, grinding with liquid nitrogen (cryogenic grinding) is often employed to prevent heat-induced denaturation during processing.
- **Inhibition of Phenolic Oxidation:** A major hurdle in plant enzyme extraction is the presence of phenolic compounds. Upon tissue disruption, endogenous Polyphenol Oxidase (PPO) oxidizes phenols into quinones, which irreversibly bind to the target enzymes, causing inactivation and "browning." To counteract this, extraction buffers are supplemented with reducing agents such as β -mercaptoethanol, cysteine, or ascorbic acid, and phenol-adsorbing agents like Polyvinylpolypyrrolidone (PVPP)²³.

Aqueous and Buffer Extraction

The standard method involves suspending the homogenized tissue in a buffer solution with a pH optimized for the specific enzyme's stability (e.g., pH 6.0–7.0 for proteases). The ratio of biomass to solvent typically ranges from 1:3 to 1:10 (w/v).

- **Saline Extraction:** The addition of NaCl (0.1–0.5 M) can enhance the solubility of globulin-type proteins.

- **Surfactants:** Non-ionic surfactants like Triton X-100 are occasionally used to solubilize membrane-bound enzymes, although this complicates downstream purification.

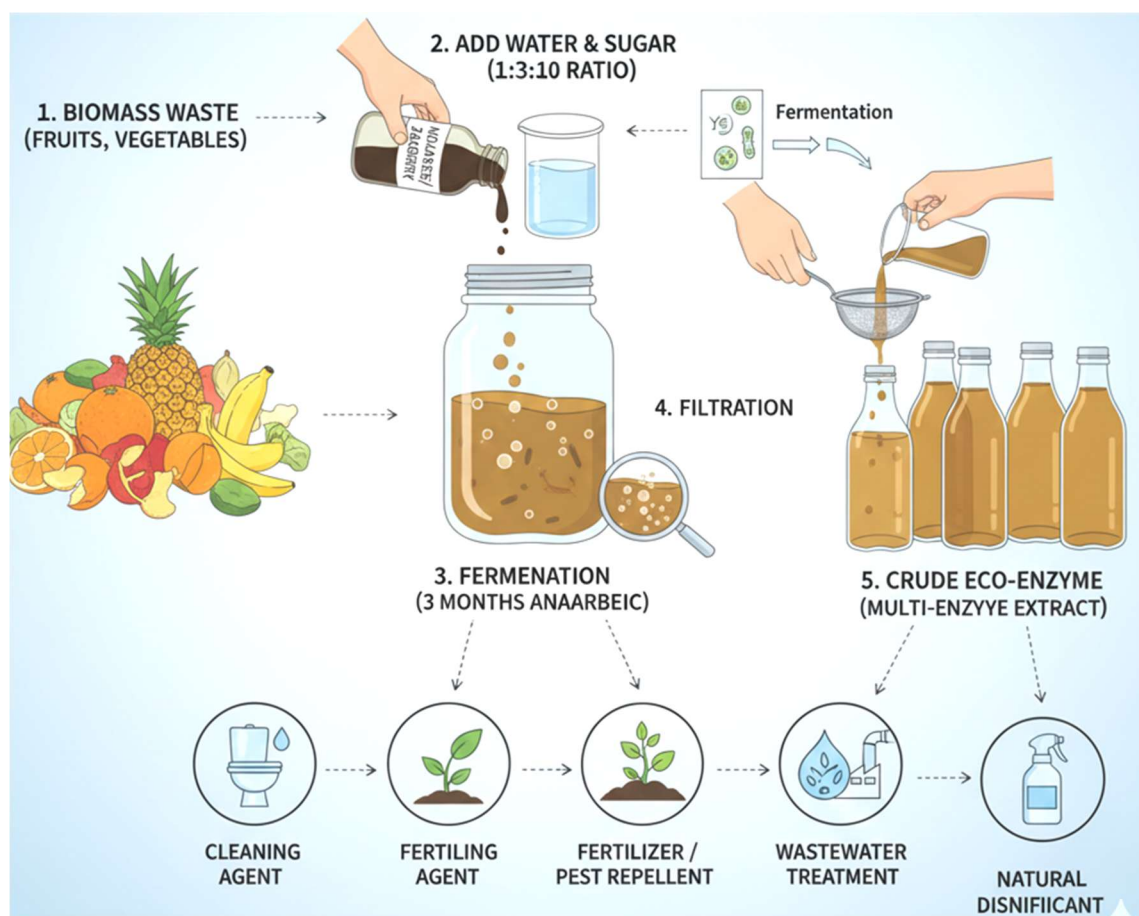


Fig. 3 Fermentation of Agro-Industrial Waste (The "Eco-Enzyme" Approach)

A paradigm shift in recent years involves the production of "Eco-enzymes" or "Garbage Enzymes" via the fermentation of fruit and vegetable waste. This method requires no sophisticated buffering.

Agro-waste (citrus peels, carrot tops, pineapple skins) is mixed with a carbon source (molasses or jaggery) and water in a strict ratio of **1:3:10** (Sugar:Waste:Water). The mixture is fermented anaerobically for 3 months. Yeast and lactic acid bacteria naturally present on the peels drive the fermentation. The resulting brownish liquid is a crude multienzyme cocktail rich in amylases, proteases, and lipases, stabilized by the acidic pH (approx. 3.5) and organic acids (acetic acid) produced during fermentation.²⁴ Vama & Cherekar (2020) reported that these crude extracts exhibit significant hydrolytic activity, making them viable for wastewater treatment without further purification.

Advanced Extraction Technologies

To improve yield and reduce solvent usage, novel techniques are being adopted:

- **Ultrasound-Assisted Extraction (UAE):** Uses acoustic cavitation to disrupt cell walls, enhancing mass transfer.
- **Supercritical Fluid Extraction (SFE):** While more common for extracting bioactive small molecules, modified SFE is being explored for lipid-associated enzymes.

7. Purification Strategies

Following extraction, the crude lysate contains the target enzyme mixed with other proteins, polysaccharides, and phytochemicals. The level of purification depends on the application: low purity is acceptable for detergent/leather industries, while high purity is mandatory for pharmaceutical use.

7.1 Ammonium Sulfate Precipitation (Salting Out)

This is the primary concentration step. Ammonium sulfate $(\text{NH}_4)_2\text{SO}_4$ is added to the crude extract. As the salt concentration increases, water molecules are sequestered by salt ions, removing the hydration shell around proteins and causing them to precipitate via hydrophobic interactions.

- **Fractionation:** Different proteins precipitate at different salt saturations. For example, bromelain typically precipitates at 40–60% saturation.

7.2 Three-Phase Partitioning (TPP)

TPP is an elegant, scalable, and economical purification method specifically suited for plant enzymes.

- **Principle:** The crude extract is mixed with a salt (usually ammonium sulfate) and a water-miscible organic solvent (t-butanol).
- **Mechanism:** The mixture separates into three phases:
 1. **Bottom:** Aqueous phase (containing polar contaminants).
 2. **Top:** Organic phase (t-butanol, containing pigments and lipids).
 3. **Middle:** Interfacial precipitate (containing the concentrated enzyme).
- **Efficacy:** TPP not only purifies but often delipidates the enzyme, which can increase specific activity. It has been successfully applied to purify ficin, papain, and tomato peroxidase with yields often exceeding 100% (due to the removal of endogenous inhibitors)²⁵(Gagaoua et al., 2014).

7.3 Chromatographic Techniques

For high-value applications, the precipitate from TPP or salting out is re-dissolved and subjected to chromatography.

- **Ion Exchange Chromatography (IEC):** Separates based on charge. Since papain is a basic protein (isoelectric point, $\text{pI} \approx 8.75$), it binds to cation exchangers (like CM-Cellulose) at neutral pH.

- **Gel Filtration (Size Exclusion):** Separates based on molecular weight. Used for desalting and final polishing.

8. Kinetic Characterization and Stability

Understanding the catalytic behavior of plant bioenzymes is essential for process design. This is governed by Michaelis-Menten kinetics.

8.1 Michaelis-Menten Parameters

The reaction rate v is described by the equation:

$$v = \frac{V_{\max}[S]}{K_m + [S]}$$

Where:

- $V_{\max}$: The maximum velocity of the reaction when the enzyme is saturated with substrate.
- K_m (Michaelis Constant): The substrate concentration at which the reaction rate is half of $V_{\max}$.
 - **Significance:** A low K_m indicates high affinity for the substrate. For instance, plant peroxidases generally exhibit low K_m values for phenolic substrates in the micromolar range (10^{-6} M), indicating high efficiency even at low pollutant concentrations in wastewater²⁶ (Hamid & Rehman, 2009).

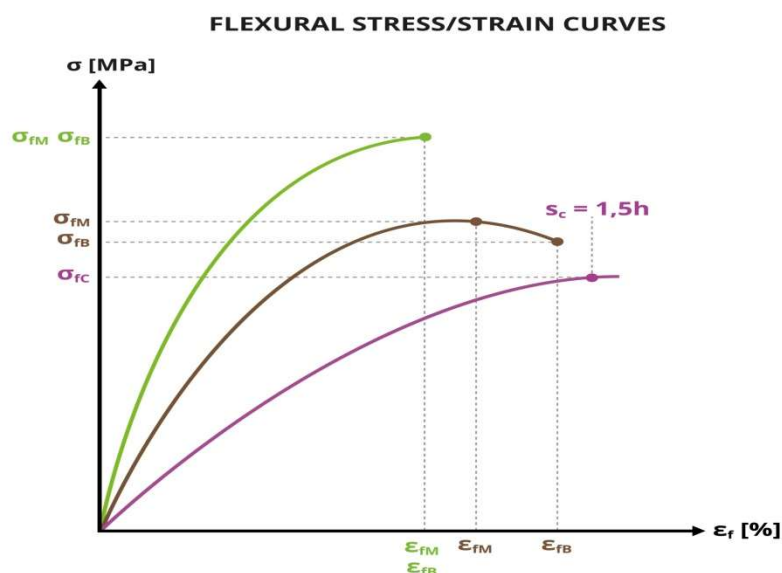


Fig. 4 Effect of Temperature and Thermodynamics

Temperature affects enzyme activity in two opposing ways: increasing the kinetic energy of molecules (increasing rate) and destabilizing the protein structure (decreasing rate/denaturation).

- **Optimum Temperature:** Most plant enzymes operate optimally between 40°C and 60°C.
 - *Example:* Papain shows exceptional thermal stability, retaining activity up to 65°C, unlike many animal proteases that denature above 45°C.
- **Arrhenius Equation:** The temperature dependence is modeled by:

$$k = A \cdot e^{-E_a / RT}$$

Where E_a is the activation energy. Plant enzymes typically lower the E_a of hydrolysis reactions from ~100 kJ/mol (uncatalyzed) to ~30-50 kJ/mol.

8.3 Effect of pH

The ionization state of amino acids in the active site dictates activity.

- **Bell-Shaped Curve:** Most enzymes show a bell-shaped activity profile.
- **Specific Profiles:**
 - *Pepsin-like plant proteases:* Acidic optimum (pH 3–5).
 - *Papain/Bromelain:* Broad neutral to alkaline optimum (pH 6–8.5).
 - *Lipases:* Often favor alkaline conditions (pH 8–9).

8.4 Inhibition Patterns

Plant enzymes are often regulated by endogenous inhibitors (e.g., cystatins inhibit cysteine proteases).

- **Competitive Inhibition:** Inhibitor binds to the active site ($V_{\max}$ unchanged, K_m increases).
- **Non-Competitive Inhibition:** Inhibitor binds elsewhere, changing enzyme conformation ($V_{\max}$ decreases, K_m unchanged).
- **Metal Ions:** Many plant enzymes are metalloenzymes or require metal cofactors (Ca^{2+} , Mg^{2+}). However, heavy metals (Hg^{2+} , Pb^{2+}) are potent irreversible inhibitors, disrupting sulfhydryl groups in cysteine proteases.

The commercial viability of any biocatalyst is determined by its applicability. While microbial enzymes dominate the market due to volume, plant bioenzymes hold a monopoly in specific niche applications where their unique substrate specificity and "clean label" status are required. The versatility of plant enzymes ranges from the hydrolysis of complex proteins in food processing to the polymerization of hazardous pollutants in environmental management. This section provides a critical analysis of these applications, categorized by industry.

12. Applications in the Food and Beverage Industry

The food sector acts as the primary consumer of plant bioenzymes. The global push for vegetarian/vegan-certified ingredients has accelerated the replacement of animal-derived enzymes (like bovine chymosin or pancreatic trypsin) with plant-based alternatives.

- **Comparative Efficacy:**

- *Papain*: The industry standard due to low cost. It is effective on myofibrils but less active on collagen.
- *Ficin*: Unique among plant proteases for its high elastase and collagenase activity. It is capable of degrading Type I collagen, making it the most potent tenderizer for older, tougher meat cuts, although its commercial availability is lower than papain²⁷.
- *Bromelain*: Often preferred for high-end applications as it imparts a milder flavor profile compared to the occasionally bitter peptides generated by papain hydrolysis.

12.2 Dairy: Vegetable Rennet Substitutes

Traditional cheese production relies on rennet (chymosin) extracted from the fourth stomach of unweaned calves. With the rise of vegetarianism and the scarcity of calf rennet, plant aspartic proteases have emerged as vital substitutes.

- **Cardosins (*Cynara cardunculus*):** Aqueous extracts from the flowers of the cardoon thistle contain cardosins A and B. These enzymes exhibit specific milk-clotting activity similar to chymosin. They cleave the Phe105-Met106 bond of κ -casein, destabilizing the casein micelle and causing precipitation (curd formation).
- **Application:** These are exclusively used in the production of Protected Designation of Origin (PDO) cheeses in the Mediterranean, such as *Serra da Estrela* (Portugal) and *Torta del Casar* (Spain). The intense proteolytic activity of cardosins during ripening contributes to the unique creamy texture and slightly bitter, piquant flavor profile of these cheeses²⁸ (Roseiro et al., 2003).

12.3 Brewing and Baking

- **Brewing (Chill Haze Prevention):** In beer production, proteins and polyphenols can interact at low temperatures to form a cloudy precipitate known as "chill haze." **Papain** is added during the finishing stage to hydrolyze these proteins into smaller soluble peptides, ensuring the beer remains clear upon refrigeration.
- **Baking (Gluten Modification):** Proteases are used to weaken the gluten network in biscuit and cracker doughs, reducing elasticity and preventing shrinkage, thereby ensuring uniform shape and texture.

13. Clinical, Therapeutic, and Dental Applications

Plant bioenzymes possess potent biological activities that have been translated into modern therapeutic agents. Unlike food applications which utilize crude extracts, pharmaceutical applications require high-purity enzyme preparations.

13.1 Anti-Inflammatory and Fibrinolytic Agents

Bromelain is the most significant anti-inflammatory plant enzyme. It is absorbed from the gastrointestinal tract in a functionally intact form (up to 40% bioavailability).

- **Mechanism:** Bromelain acts via multiple pathways:
 1. **Fibrinolysis:** It activates plasminogen to plasmin, breaking down fibrin clots that wall off inflammation sites, thereby improving drainage and reducing edema.
 2. **Bradykinin Reduction:** It lowers the levels of bradykinin and plasma kinins, which are mediators of pain and vascular permeability.
- **Clinical Use:** It is prescribed for reducing post-operative swelling (e.g., after molar extraction or rhinoplasty) and treating osteoarthritis. A meta-analysis by²⁹ Brien et al. (2004) indicated that bromelain supplements significantly reduced WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) pain scores in knee arthritis patients.

13.2 Wound Debridement

Necrotic tissue (eschar) in chronic wounds (diabetic ulcers, bedsores) prevents healing and breeds infection.

- **Papain-Urea Preparations:** Papain acts as a debriding agent by digesting non-viable protein matter without harming healthy granulation tissue (which contains α_1 -antitrypsin, a natural inhibitor of papain, thus protecting live cells). Urea functions as a denaturant, unfolding the proteins in the necrotic tissue to make them more accessible to papain.
- **Regulatory Note:** While historically popular (e.g., Accuzyme), the FDA requested the withdrawal of some unapproved topical papain products in 2008 due to hypersensitivity concerns, pushing research towards more standardized, hypoallergenic formulations³⁰.

13.3 Chemical-Mechanical Caries Removal (CMCR)

In dentistry, minimizing the removal of healthy tooth structure is a priority.

- **Papacárie®:** This is a gel formulation containing papain, chloramine, and toluidine blue.
- **Mechanism:** The gel is applied to the carious dentin. Papain degrades the collagen fibers of the infected dentin (which are already partially denatured by bacterial acids)

but leaves the intact collagen of healthy dentin untouched. The softened infected tissue can then be scraped away with a blunt instrument, avoiding the need for anesthesia or drilling. This technique is particularly valuable in pediatric dentistry³¹.

13.4 Digestive Aids

Multi-enzyme supplements containing papain and plant-derived amylases are standard treatments for dyspepsia and pancreatic insufficiency. They function effectively across the broad pH range of the stomach and intestine to assist in the breakdown of heavy meals.

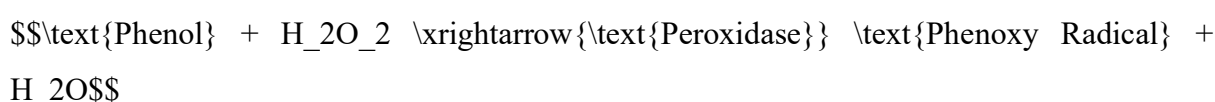
14. Environmental Bioremediation

The use of enzymes for environmental cleanup (White Biotechnology) is growing due to the ability of plant oxidoreductases to target recalcitrant pollutants that bacteria cannot metabolize.

14.1 Treatment of Phenolic Wastewater

Industries such as petroleum refining, coal conversion, and resin manufacturing generate wastewater rich in phenols. Phenols are toxic to aquatic life and difficult to remove via conventional activated sludge processes.

- **Enzyme:**Horseradish Peroxidase (HRP) and Soybean Peroxidase (SBP).
- **Mechanism:** The Peroxidase-Catalyzed Polymerization process involves:
 1. The peroxidase oxidizes soluble phenolic compounds using H_2O_2 , generating phenoxy radicals.
 2. These free radicals spontaneously couple to form insoluble oligomers and polymers.
 3. The polymers precipitate out of the solution and can be removed by simple sedimentation or filtration.



- **Advantages:** SBP is preferred over HRP in industrial settings due to its higher conformational stability at acidic pH and high temperatures³².

14.2 "Eco-Enzymes" for Water Purification

As discussed in the extraction section, crude fermented enzyme solutions ("Garbage Enzymes") are increasingly used in decentralized wastewater treatment in developing nations.

- **Application:** The addition of eco-enzymes to polluted river water has been shown to reduce Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Ammonia Nitrogen.

- **Action:** The hydrolytic enzymes (proteases/amylases) digest organic sludge, while the organic acids produced during fermentation act as natural chelating agents for heavy metals³³.

Conclusion

The field of plant-derived bioenzymes is experiencing a renaissance driven by sustainability imperatives, technological advances, and market demand for natural products. The period 2020-2025 has witnessed significant progress in waste valorization, rapid purification technologies, and demonstration of efficacy in diverse applications. However, realizing the full potential of plant bioenzymes requires continued research, development, and translation efforts. With systematic bioprospecting, enzyme engineering, process optimization, and supportive policy frameworks, plant-derived bioenzymes can become mainstream industrial catalysts, contributing to a more sustainable and circular bioeconomy. The convergence of scientific innovation, environmental necessity, and economic opportunity positions plant bioenzymes as key enabling technologies for 21st-century biotechnology.

The classification of plant bioenzymes reveals a sophisticated biological arsenal designed for metabolic regulation and defense. From the robust cysteine proteases of tropical fruits to the versatile peroxidases of root vegetables, nature provides a diverse toolkit of biocatalysts. Unlike the generic "one-size-fits-all" approach of some microbial enzymes, plant enzymes often possess unique specificities (such as the collagenolytic activity of ficin or the thermostability of soybean peroxidase) that dictate their industrial utility. Understanding the structural classification is the prerequisite for optimizing their extraction. The physicochemical properties described here—such as the hydrophobic nature of lipases or the thermal stability of HRP—directly influence the purification strategies and stabilization techniques, which will be discussed in the subsequent section.

The extraction and characterization of plant bioenzymes represent a balance between yield, purity, and cost. While traditional aqueous extraction is simple, it is often plagued by low yields and phenolic interference. Innovations like Three-Phase Partitioning (TPP) and the fermentation of agro-waste (Eco-enzymes) have revolutionized this field, offering pathways for both high-purity pharmaceutical production and low-cost, bulk industrial applications. Kinetically, plant enzymes demonstrate robust profiles, often surpassing their animal counterparts in thermal stability and pH tolerance. These physicochemical attributes make them resilient candidates for the harsh conditions found in industrial processing, which will be detailed in the applications section. The application spectrum of plant bioenzymes is vast, characterized by a dichotomy between high-volume/low-purity uses (wastewater, food processing) and low-volume/high-purity uses (therapeutics). The efficacy of these enzymes

often surpasses their microbial counterparts in specific contexts: Papain's heat stability in brewing, Bromelain's oral bioavailability in medicine, and Soybean Peroxidase's resilience in wastewater treatment. The clear trend is a movement towards "Green Processing." In textiles and leather, plant enzymes are not just alternatives but superior replacements that reduce pollution load. In medicine, they offer non-narcotic pain management and minimally invasive surgical options. The exploration of bioenzymes from plant components reveals a compelling narrative of rediscovery and innovation. Historically anchored in the domestic practices of cheese-making and meat preservation, plant enzymes have evolved into sophisticated tools for modern biotechnology. This review has demonstrated that plant bioenzymes—specifically the proteases (papain, bromelain, ficin) and oxidoreductases (peroxidases)—offer unique physicochemical properties that are distinct from microbial alternatives. Their broad substrate specificity, diverse pH profiles, and "GRAS" status make them indispensable in food formulations, therapeutic interventions, and green manufacturing processes.

However, the transition from niche to mainstream industrial dominance is contingent upon overcoming the limitations of biological variability and extraction costs. The data presented herein suggests that the solution lies in the convergence of disciplines:

- **Engineering** (Immobilization) to enhance stability and reusability.
- **Genetics** (Recombinant DNA) to ensure consistent, high-yield supply independent of climate.
- **Sustainability** (Eco-enzymes) to align production with waste reduction goals.

As the global industry moves inexorably towards sustainable development, plant bioenzymes stand not merely as alternatives to chemical catalysts, but as essential architects of a greener, bio-based economy. The future of catalysis is not just biological; it is botanical.

23. References

- [1] Sharma, L., Kahandal, A., Kanagare, A. B., et al. (2023). The multifaceted nature of plant acid phosphatases: purification, biochemical features, and applications. *Journal of Enzyme Inhibition and Medicinal Chemistry*, DOI: 10.1080/14756366.2023.2282379
- [2] Javaid, F. (2022). Purification and Characterization of Bromelain from Waste Parts of *Ananas comosus* for its Application in Detergent Industry. *Pakistan Journal of Zoology*, DOI: 10.17582/journal.pjz/20220407200451
- [3] Halim, M. A., Zainal Abidin, S. A. S., & Ab Mutalib, S. R. (2025). Purification and Characterization of Bromelain from Pineapple Variety Josapine. *Malaysian Journal of Science*, 44(2), DOI: 10.22452/mjs.vol44no2.1

- [4] Khatun, M., Saeid, A., Mozumder, N. H. M. R., et al. (2023). Extraction, purification and characterization of papain enzyme from papaya. *Food Research*, 7(2), DOI: 10.26656/fr.2017.7(2).723
- [5] Qadir, N., & Ali, A. (2024). Isolation and characterization of protease from *Wisteria sinensis* and *Chloris barbata*. *Biological & Clinical Sciences Research Journal*, DOI: 10.54112/bcsrj.v2024i1.1130
- [6] Ilesanmi, O. S., & Adedugbe, O. F. (2023). Novel peroxidase from bitter leaf (*Vernonia amygdalina*): Purification, biochemical characterization and biotechnological applications. *Biocatalysis and Agricultural Biotechnology*, DOI: 10.1016/j.bcab.2023.102662
- [7] Mohammed, W. A., & Ridha, M. J. M. (2023). Extraction of peroxidase enzyme from cabbage legs for catalytic biodegradation of textile dyes and bisphenol A in wastewater: Purification and characterization technologies. DOI: 10.21203/rs.3.rs-3210800/v1
- [8] Zou, C., Zhang, X., Xu, Y., et al. (2024). Recent Advances Regarding Polyphenol Oxidase in *Camellia sinensis*: Extraction, Purification, Characterization, and Application. *Foods*, 13(4), 545, DOI: 10.3390/foods13040545
- [9] Sabarre, D. C., & Yagonia-Lobarbio, C. F. (2021). Extraction and Characterization of Polyphenol Oxidase from Plant Materials: A Review. *Journal of Applied Biotechnology Reports*, DOI: 10.30491/JABR.2021.255549.1308
- [10] Sahu, M., & Balachandar, M. (2023). Expression, Purification and Biocatalytic Studies of a Plant (*Arabidopsis thaliana*) Hydroxynitrile Lyase. *International Journal of Science and Research*, DOI: 10.21275/sr23404114629
11. Grand View Research. (2021). *Enzymes Market Size, Share & Trends Analysis Report*. San Francisco: Grand View Research, Inc.
12. Ravindran, R., Hassan, S. S., Williams, G. A., & Jaiswal, A. K. (2018). A review on bioconversion of agro-industrial wastes to industrially important enzymes. *Bioengineering*, 5(4), 93.
13. Whitaker, J. R. (1994). *Principles of Enzymology for the Food Sciences* (2nd Ed.). Marcel Dekker, Inc.
14. Hill, A. W., & Hill, A. (1933). The history of the discovery of the enzymes. *Isis*, 19(1), 115-120.
15. Karplus, P. A. (2011). Comparison of the first crystal structures of urease and those of other nickel metalloenzymes. *Accounts of Chemical Research*, 44(2), 113-121.
16. Uhlig, H. (1998). *Industrial Enzymes and their Applications*. John Wiley & Sons.
17. Pavan, R., Jain, S., Shraddha, & Kumar, A. (2012). Properties and therapeutic application of bromelain: a review. *Biotechnology Research International*, 2012, 976203

18. Gagaoua, M., Zhu, S., Hafid, K., & Dai, B. (2014). Three phase partitioning of zingibain, a milk-clotting enzyme from *Zingiber officinale* Roscoe rhizomes. *International Journal of Biological Macromolecules*, 60, 48-54.
19. Roseiro, L. B., Barbosa, M., Ames, J. M., & Wilbey, R. A. (2003). Cheesemaking with vegetable coagulants—the use of *Cynara L.* for the production of ovine milk cheeses. *International Journal of Dairy Technology*, 56(2), 76-85.
20. Pandey, V. P., Awasthi, M., Singh, S., Tiwari, S., & Dwivedi, U. N. (2017). A Comprehensive Review on Function and Application of Plant Peroxidases. *Biochemistry & Analytical Biochemistry*, 6(1), 308.
21. Mayer, A. M. (2006). Polyphenol oxidases in plants and fungi: going places? A review. *Phytochemistry*, 67(21), 2318-2331.
22. Barros, M., Fleuri, L. F., & Macedo, G. A. (2010). Seed lipases: sources, applications and properties – a review. *Brazilian Journal of Chemical Engineering*, 27(1), 15-29.
23. Vetter, J., et al. (2012). Plant Peroxidases: Extraction and Purification. In *Methods in Enzymology* (Vol. 510, pp. 189-201). Academic Press.
24. Vama, L., & Cherekar, M. N. (2020). Production, Extraction and Uses of Eco-Enzyme Using Citrus Fruit Waste: Wealth from Waste. *Asian Journal of Microbiology, Biotechnology & Environmental Sciences*, 22(2), 1-6.
25. Gagaoua, M., Zhu, S., Hafid, K., & Dai, B. (2014). Three phase partitioning of zingibain, a milk-clotting enzyme from *Zingiber officinale* Roscoe rhizomes. *International Journal of Biological Macromolecules*, 60, 48-54.
26. Hamid, M., & Rehman, K. (2009). Potential applications of peroxidases. *Food Chemistry*, 115(4), 1177-1186.
27. Sullivan, G. A., & Calkins, C. R. (2010). Application of exogenous enzymes to beef muscle of high and low connective tissue. *Meat Science*, 85(4), 730-735.
28. Roseiro, L. B., Barbosa, M., Ames, J. M., & Wilbey, R. A. (2003). Cheesemaking with vegetable coagulants—the use of *Cynara L.* for the production of ovine milk cheeses. *International Journal of Dairy Technology*, 56(2), 76-85.
29. Brien, S., Lewith, G., Walker, A., Hicks, S. M., & Middleton, D. (2004). Bromelain as a Treatment for Osteoarthritis: a Review of Clinical Studies. *Evidence-based complementary and alternative medicine*, 1(3), 251–257.
30. Telgenhoff, D., et al. (2007). The effect of papain-urea therapeutic agents on wound healing in a porcine model of burn injury. *Wound Repair and Regeneration*, 15(5), 727-735.
31. Sandra, S., et al. (2013). Evaluation of the efficacy of a new chemomechanical caries removal agent: Papacarie. *Journal of International Oral Health*, 5(3), 7.

32. Pandey, V. P., et al. (2017). A Comprehensive Review on Function and Application of Plant Peroxidases. *Biochemistry & Analytical Biochemistry*, 6(1), 308.
33. Janarthanan, M., & Mani, S. (2020). Utilization of Citrus Peel as a Bio-Enzyme for the Treatment of Domestic Wastewater. *International Journal of Recent Technology and Engineering*, 9(2), 2277-3878.

Chapter 12

AI-Driven Personalized Learning and Its Impact on Sustainable Education in Business Schools

Archana Singh

Research Scholar

Suresh Gyan Vihar University, Jaipur

Ph: 8107395559, Email: arch.udaipur@gmail.com

Dr. Neha Saini

Assistant Professor

Suresh Gyan Vihar University, Jaipur

Ph: 8441880755, Email: Neha.saini@mygyanvihar.com**Abstract**

The rapid advancement of Artificial Intelligence (AI) is transforming the environment of higher education, particularly in professional programs such as PGDM/MBA where skill development is central to employability. Business Schools are increasingly exploring AI-driven learning tools to create personalized, adaptive, and student-centric learning environments. Such approaches align strongly with the broader goal of sustainable education, which emphasizes inclusive, continuous, and skills-oriented learning systems that prepare students for evolving workplace requirements. This paper examines the role of AI-driven personalized learning in enhancing sustainable education within business schools, with a particular focus on the development of communication and interview skills among management students. The study is contextualized through integration of AI-enabled learning tools implemented at a business school in Ahmedabad, India, where AI tools incorporated into PGDM/MBA training modules to support students in improving their business communication, presentation abilities, and interview preparedness. These tools provide individualized feedback, simulate real-time interview scenarios, and enable students to practice and refine their professional communication skills at their own pace. The research explores how AI-supported personalized learning contributes to improved student engagement, self-directed learning, and continuous skill enhancement, which are critical pillars of sustainable education. It also examines the perceived effectiveness of AI tools in helping students overcome communication barriers, build confidence, and prepare for competitive corporate recruitment processes. The findings suggest that AI-driven personalized learning can significantly enhance the effectiveness of skill-development

programs in management education by offering scalable, flexible, and learner-centric training solutions. The study highlights the potential of AI as a strategic enabler for business schools seeking to create **future-ready graduates equipped with essential professional competencies**. The paper concludes by discussing implications for integrating AI-enabled learning ecosystems in management education and their role in supporting sustainable skill development for the workforce of tomorrow.

Keywords: Artificial Intelligence, Personalized Learning, Sustainable Education, Management Education, Communication Skills Development.

Introduction

The convergence of Artificial Intelligence (AI) and education has introduced a new paradigm in teaching and learning. Traditional educational models, often characterized by standardized instruction, are increasingly being replaced by adaptive and learner-centered approaches. AI technologies play a central role in this transformation by enabling data-driven decision-making and personalized instruction. Personalized learning, supported by AI, allows educational experiences to be tailored to individual learners' needs, preferences, and progress. This approach addresses the limitations of conventional teaching methods by accommodating diverse learning styles and paces. At the same time, AI-enhanced educational technologies—such as intelligent tutoring systems, virtual learning environments, and interactive platforms—are expanding the boundaries of education beyond physical classrooms. Despite these advancements, the integration of AI in education presents significant challenges. Ethical considerations, including privacy, fairness, and accessibility, must be carefully addressed. This paper explores the multifaceted role of AI in education, examining its benefits, limitations, and future potential.

Personalized Learning with AI

Personalized learning represents a shift toward student-centered education, where instructional strategies are tailored to individual learners. AI enables this approach by analyzing data on student performance, engagement, and preferences to deliver customized learning experiences. Adaptive content delivery ensures that learners receive material appropriate to their proficiency level, preventing both cognitive overload and disengagement. Real-time feedback systems allow students to identify and correct errors immediately, while also providing educators with insights into learning progress. Intelligent Tutoring Systems further enhance personalization by simulating one-on-one instruction, offering targeted guidance and support. These systems adapt dynamically to individual learning needs, improving comprehension and retention. Overall, AI-driven personalized learning has been shown to increase student motivation, engagement, and academic achievement. Additionally,

it supports diverse learning styles and promotes inclusivity by offering multiple modes of content delivery.

Educational Technology Enhanced by AI

AI-enhanced educational technology has transformed the way educational content is created, delivered, and assessed. These technologies leverage data and machine learning to create adaptive and interactive learning environments. In curriculum development, AI analyzes large datasets to identify gaps and recommend improvements, ensuring that content remains relevant and effective. AI-driven content creation enables the generation of customized learning materials, reducing the workload for educators while enhancing scalability. Assessment methods have also evolved through AI, with adaptive systems providing personalized evaluations and immediate feedback. Additionally, immersive technologies such as virtual reality and interactive simulations offer experiential learning opportunities that improve engagement and understanding. AI also plays a significant role in automating administrative tasks, such as grading and scheduling, thereby increasing institutional efficiency and allowing educators to focus more on teaching.

Challenges and Ethical Considerations

Despite its benefits, the integration of AI in education raises several ethical and practical challenges. Data privacy is a major concern, as AI systems rely on extensive student data for personalization. Ensuring secure data storage and transparent usage policies is essential for maintaining trust. Algorithmic bias presents another challenge, as AI systems may reflect and reinforce existing inequalities if trained on biased data. Addressing this issue requires diverse datasets and continuous monitoring. The digital divide further complicates AI adoption, as unequal access to technology can exacerbate educational disparities. Bridging this gap is crucial for ensuring equitable access to AI-driven learning tools. To address these challenges, the development of ethical frameworks is necessary. These frameworks should guide responsible AI implementation, emphasizing transparency, fairness, and accountability.

Impact on Educational Equity

AI has the potential to significantly enhance educational equity by addressing diverse learning needs and improving accessibility. Personalized learning enables tailored instruction, ensuring that all students receive appropriate support. AI technologies also improve access to education through online platforms and assistive tools, benefiting learners in remote or underserved communities. Furthermore, AI contributes to inclusive learning environments by accommodating diverse learning styles and promoting cultural representation. However, the impact of AI on equity depends on equitable access to technology and the elimination of

biases within AI systems. Without careful implementation, AI may inadvertently widen existing gaps. Therefore, a balanced and inclusive approach is essential.

Future Directions and Innovations

The future of AI in education is characterized by rapid innovation and expanding possibilities. Emerging trends include adaptive learning platforms, AI-powered virtual assistants, and immersive technologies such as virtual and augmented reality. Emotion AI is another promising area, enabling systems to detect and respond to learners' emotional states, thereby enhancing engagement and well-being. Additionally, future developments may extend personalization beyond academic content to areas such as career guidance and social-emotional learning. Ongoing research is needed to address ethical challenges, improve assessment methods, and enhance accessibility. Collaboration among educators, policymakers, and technologists will be essential for shaping the future of AI in education.

The integration of artificial intelligence (AI) into education has significantly transformed traditional pedagogical approaches, particularly in business and management disciplines. Recent studies highlight a paradigm shift from standardized, teacher-centered models to adaptive, learner-centric systems that emphasize personalization, engagement, and skill development. For instance, Bhattacharya et al. (2025) argue that conventional accounting and business education often fails to accommodate diverse learner needs, resulting in disengagement and limited practical understanding. They propose AI-driven personalized learning as a solution, where adaptive algorithms, intelligent tutoring systems, and real-time feedback mechanisms enable customized learning experiences that enhance both academic performance and industry readiness. Similarly, Singh et al. (2024) emphasize the growing role of AI-powered virtual assistants in reshaping educational delivery. According to their study, AI tools facilitate instant feedback, personalized study plans, and data-driven insights that help educators tailor their instructional strategies. The authors further note that the integration of technologies such as virtual reality, online learning platforms, and collaborative tools has expanded the scope of education beyond traditional classrooms, fostering global learning environments and intercultural competence. However, they caution that challenges such as the digital divide and lack of technological infrastructure may hinder equitable access to these advancements. Expanding on the broader educational landscape, the EDUDIA Conference Proceedings (Fabunmi et al., 2025) provide a multidisciplinary perspective on AI in education and sustainable development. The collection of studies consistently highlights AI as a catalyst for enhancing student engagement, improving instructional delivery, and supporting inclusive education. Several contributions within the proceedings underscore the importance of aligning AI-driven educational practices with Sustainable Development Goals

(SDGs), particularly in developing regions. Furthermore, issues such as teacher readiness, ethical considerations, and policy support emerge as critical factors influencing the successful implementation of AI in educational institutions. Empirical evidence supporting the effectiveness of AI-driven personalized learning is presented by Ezeani et al. (2025), who conducted a mixed-method study involving undergraduate business students. Their findings indicate significant improvements in knowledge retention and student satisfaction when AI-based adaptive learning systems are employed. The study demonstrates that personalized feedback, dynamic content delivery, and real-world business simulations enhance critical thinking and decision-making skills. Despite these benefits, the authors highlight challenges related to data privacy, technological infrastructure, and the need for faculty training, suggesting that successful adoption requires a holistic institutional approach. In the context of entrepreneurship education, Syed et al. (2025) further reinforce the value of AI-driven personalized learning. Their study reveals that adaptive learning systems significantly improve entrepreneurial skills, student engagement, and learning outcomes by tailoring content to individual learner profiles. The authors also identify student engagement as a mediating factor that strengthens the relationship between personalized learning and academic performance. Additionally, they note that while AI enhances flexibility and scalability in education, factors such as institutional support and technological accessibility play a moderating role in its effectiveness. From a broader and more analytical perspective, Strielkowski et al. (2024) examine the role of AI-driven adaptive learning in achieving sustainable educational transformation. Through a comprehensive bibliometric analysis, the authors highlight the rapid growth of AI applications in education, particularly following the COVID-19 pandemic. They argue that adaptive learning technologies contribute to sustainable development by promoting inclusive, accessible, and high-quality education. Moreover, AI facilitates innovation, enhances decision-making capabilities, and prepares learners to address complex global challenges. However, the study also underscores the importance of addressing ethical concerns, data security issues, and infrastructure limitations to ensure responsible and effective implementation. Collectively, the reviewed literature demonstrates that AI-driven personalized learning has the potential to revolutionize business and management education by enhancing engagement, improving learning outcomes, and aligning education with industry demands. While the benefits are substantial, recurring challenges such as digital inequality, ethical concerns, and the need for institutional readiness highlight the importance of a balanced and strategic approach to AI integration. These insights provide a strong foundation for further research, particularly in exploring how AI-based pedagogical models can be effectively implemented in diverse educational contexts.

Theoretical Framework

This study is grounded in several key learning theories that inform the design and evaluation of pedagogical approaches using AI tools students development. These include constructivist learning theory, experiential learning theory (Kolb), self-determination theory (SDT), and social cognitive theory.

Constructivist Learning Theory

Constructivism posits that learners actively construct knowledge rather than passively receiving it (Nyenno, 2020). This theory emphasizes the role of experience, reflection, and interpersonal relationships in the learning process. Constructivism proposes that students actively participate in problem-solving, teamwork, and reflection to integrate and use these skills effectively. Project-based learning, case studies, and simulations are all examples of constructivist pedagogical approaches that enable students to build their skills in areas of study.

Experiential Learning Theory (Kolb)

Kolb's experiential learning theory (ELT) emphasizes the cyclical nature of learning through experience (Nyenno, 2020). The ELT model consists of four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Effective learning involves progressing through all four stages, allowing learners to connect theory to practice and vice versa (Nyenno, 2020). In soft skills development, experiential learning can be facilitated through role-playing, simulations, and real-world projects that provide students with opportunities to experience, reflect on, conceptualize, and apply these skills.

Self-Determination Theory (SDT) and Motivation in Gamification

Self-determination theory (SDT) explores the role of intrinsic motivation in learning and behavior (Fu & Clarke, n.d.). According to SDT, individuals are more likely to be engaged and motivated when their autonomy, competence, and relatedness demands are addressed (Stepanova & Zeer, 2019). Gamification, when executed well, can tap into these intrinsic motivators by offering learners a sense of leadership, challenge, and interpersonal relationships. Points, badges, and leaderboards are examples of elements of gaming that can increase a sense of competence and achievement, whereas participatory activities can develop relationships and teamwork (Fu and Clarke, n.d.). Using critical thinking skills helps managers to evaluate complicated data and come up with creative solutions to problems. Emotional intelligence enables leaders to understand and manage their own emotions while also building effective relationships with diverse teams. In today's swiftly evolving business scenario, flexibility and adaptability are important which allows managers to embrace change

and overcome failures with a positive attitude. However, the development of these soft skills in higher education faces considerable challenges, including an excessive emphasis on technical skills, limited academic development, and an embellished student perception that overlooks these skills. Management colleges in India use a variety of methodologies, including seminars and group exercises; nevertheless, many struggle with divergent implementation and a lack of structured assessments that connect theoretical skills to real-world implications. Traditional pedagogical approaches, such as lectures and case studies, as well as role-playing and group discussions, are still widely used, giving basic learning opportunities but frequently failing to completely engage students and prepare them for the intricacies of modern management challenges. Addressing these gaps through innovative and effective techniques is essential for building the next generation of proficient and versatile leaders.

Comparative Analyses of Pedagogical Approaches

Existing Research Comparing Traditional vs. Innovative/AI based Pedagogies

Research relentlessly reveals that gamified learning outperforms traditional approaches in skill development. Gamification significantly boosts motivation and engagement, resulting in improved learning outcome. It effectively encourages problem-solving, critical thinking, and teamwork. However, the benefits of gamification are dependent on effective game design and the characteristics of the students participating (2020a).

The literature review highlights the importance of soft skills in management education, as well as the importance for innovative approaches to learning that are consistent with the NEP 2020 objectives. While both traditional and gamified approaches have the potential of encouraging soft skill development, effectiveness is based on effective planning, implementation, and alignment with learning objectives. There are research gaps in the comparative analysis of these approaches in Indian management educational institutions the assessment of their effects on student engagement and motivation, and the evaluation of their alignment with the goals of NEP 2020. This research strives to address these gaps through conducting a comprehensive assessment of gamified and traditional approaches for developing soft skills in management education in India.

The Model proposed:

AI-Integrated Hybrid Soft Skills Development Model (AI-HSSDM)

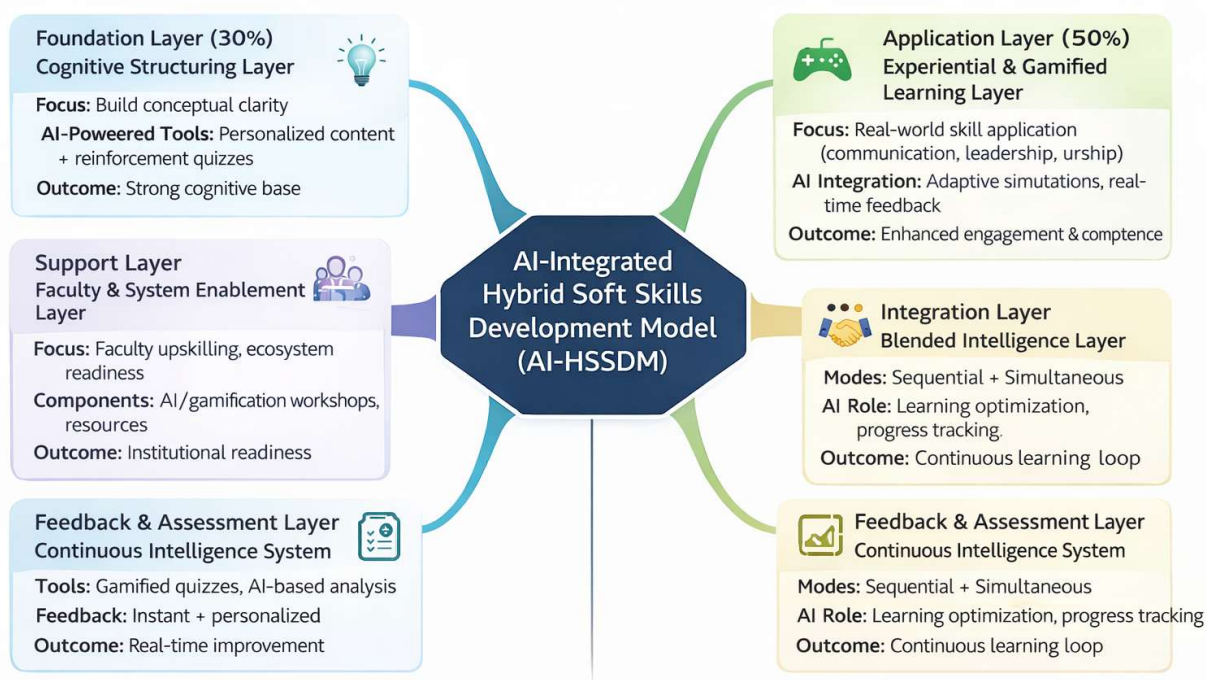


Diagram 1: Source:-AI tool(Whimsical Diagrams)

1. Foundation Layer: Traditional Methods (30%)

- Focus: Building conceptual clarity and foundational understanding.
- Techniques: Lectures, presentations, theoretical discussions.
- Purpose: Provide structured knowledge and theoretical frameworks.

2. Application Layer: Gamified Methods (70%)

- Focus: Practical application of soft skills in real-world contexts.
- Techniques: Role plays, simulations, problem-solving games, interactive feedback.
- Purpose: Enhance engagement, retention, and real-life preparedness.

3. Integration Layer: Blended Learning Approach

- Sequential Implementation: Start with foundational concepts (Traditional), followed by interactive practice (Gamified).
- Simultaneous Implementation: Combine elements within the same session (e.g., a brief lecture followed by a simulation exercise).
- Adaptive Modules: Tailor content based on student readiness and background diversity.

4. Support Layer: Trainer Capacity Building

- Training workshops on gamification techniques.
- Resource development to support interactive learning.

5. Feedback and Assessment Layer

- Gamified Assessment: Peer evaluations, interactive quizzes, scenario-based assessments.
- Traditional Assessment: Written reflections and presentations to ensure conceptual clarity.
- Blended Feedback: Immediate, formative feedback during gamified sessions, followed by summative evaluation through written reports or presentations.

In conclusion, the findings demonstrate that gamified approaches are more effective than traditional approaches in fostering soft skills in management education, which aligns with India's National Education Policy (NEP 2020). Gamification clearly improves student engagement and skill retention, as trainers strongly prefer these innovative methods. However, challenges such as limited resources and assessment complications must be addressed. The proposed AI-Hybrid Soft Skills Development Model (AI-HSSDM) offers a potential alternative by combining traditional and gamified methods to get optimal results. Institutions can significantly boost the effectiveness of soft skills training by incorporating a combination of methods, improving trainer abilities, and creating flexible curricula, which will eventually more adequately prepare students for the changing demands of the workplace.

Conclusion of the AI-HSSDM Diagram

The AI-Integrated Hybrid Soft Skills Development Model (AI-HSSDM) diagram illustrates a comprehensive and structured approach to enhancing soft skills in management education through the integration of traditional pedagogy, gamification, and AI-driven learning. The layered framework highlights how foundational knowledge, when combined with experiential and interactive learning methods, leads to deeper understanding and practical skill acquisition. The model demonstrates that the strategic balance between traditional teaching (30%) and gamified learning (70%) creates an optimal learning environment that fosters engagement, motivation, and continuous improvement. The integration layer ensures seamless connectivity between theory and practice, while the support layer emphasizes the critical role of faculty readiness in successful implementation. Furthermore, the assessment layer reinforces the importance of combining formative and summative evaluation techniques to capture both conceptual understanding and applied competencies. The diagram also

reflects the adaptability of the model, allowing customization based on learner needs through AI-enabled feedback and personalization. Overall, the AI-HSSDM framework provides a scalable and sustainable solution for business schools aiming to develop industry-relevant soft skills. It aligns with the objectives of sustainable education and the National Education Policy (2020), offering a future-ready pedagogical model that bridges the gap between academic learning and real-world professional requirements.

Recommendations

Based on this review, several recommendations can be proposed: Develop and enforce ethical guidelines for AI use in education Ensure equitable access to AI technologies to bridge the digital divide Provide training and professional development for educators Continuously evaluate and improve AI systems to reduce bias Foster collaboration among stakeholders to promote responsible innovation These measures are essential for maximizing the benefits of AI while minimizing potential risks.

Conclusion

The integration of Artificial Intelligence in education represents a transformative advancement with the potential to reshape learning experiences. AI-driven personalized learning and educational technology offer significant benefits, including improved engagement, enhanced accessibility, and better academic outcomes. However, these opportunities are accompanied by challenges related to privacy, fairness, and accessibility. Addressing these issues requires commitment to ethical practices, inclusive policies, and continuous collaboration among stakeholders. Ultimately, the future of education lies in the responsible integration of AI, where innovation is balanced with ethical considerations. By adopting a thoughtful and inclusive approach, AI can contribute to a more equitable, effective, and dynamic educational landscape.

References

- [1.] Ayeni, O. O., Al Hamad, N. M., Chisom, O. N., Osawaru, B., & Adewusi, O. E. (2024). AI in education: A review of personalized learning and educational technology. *GSC Advanced Research and Reviews*, 18(2), 261-271. <https://doi.org/10.30574/gscarr.2024.18.2.0062>
- [2.] Singh, Ajit, The Future of Learning: AI-Driven Personalized Education (December 28, 2024). <http://dx.doi.org/10.2139/ssrn.5076438>
- [3.] Taylor, E. (2016). Investigating the Perception of Stakeholders on Soft Skills Development of Students: Evidence from South Africa. In *Interdisciplinary Journal of*

- e-Skills and Lifelong Learning* (Vol. 12, pp. 001–018). Informing Science Institute.
<https://doi.org/10.28945/3412>
- [4.] Meenakshi Sundaram, K. (2020). A Study on National Education Policy 2020 Concerning Career Opportunities. In *Shanlax International Journal of Economics* (Vol. 9, Issue 1, pp. 63–67). Shanlax International Journals.
<https://doi.org/10.34293/economics.v9i1.3497>
- [5.] Agustin, F., Oganda, F. P., Lutfiani, N., & Harahap, E. P. (2020). Manajemen Pembelajaran Daring Menggunakan Education Smart Courses. In *Technomedia Journal* (Vol. 5, Issue 1 Agustus, pp. 40–53). iLearning Journal Center.
<https://doi.org/10.33050/tmj.v5i1.1315>
- [6.] Opportunities for Gamified Learning in Purchasing and Supply Management Education. In *Proceedings of the 13th European Conference on Game Based Learning*. ACI. <https://doi.org/10.34190/gbl.20.149>
- [7.] Nyenno, I. (2020). METHODOLOGY OF MANAGERIAL EDUCATION. In *Economics: time realities* (Vol. 2, Issue 48, pp. 59–65). Odessa Polytechnic National University. <https://doi.org/10.15276/etr.02.2020.8>
- [8.] Fu, Y., & Clarke, P. (n.d.). Gamification-Based Cyber-Enabled Learning Environment of Software Testing. In *2016 ASEE Annual Conference & Exposition Proceedings*. ASEE Conferences. <https://doi.org/10.18260/p.27000>
- [9.] Stepanova, L. N., & Zeer, E. F. (2019). Soft Skills as Predictors of Students' Life Self-Fulfillment. In *The Education and science journal* (Vol. 21, Issue 8, pp. 65–89). Russian State Vocational Pedagogical University. <https://doi.org/10.17853/1994-5639-2019-8-65-89>
- [10.] Weber, M. R., Crawford, A., Rivera, D., & Finley, D. A. (2011). Using Delphi Panels to Assess Soft Skill Competencies in Entry Level Managers. In *Journal of Tourism Insights* (Vol. 1, Issue 1). Grand Valley State University Libraries - DIGITAL COMMONS JOURNALS. <https://doi.org/10.9707/2328-0824.1011>
- [11.] Pradhananga, P., ElZomor, M., Santi, G., & Zhang, L. (n.d.). Fostering Virtual Reality Environments to Advance Construction and Engineering Students' Interpersonal Skills. In *2020 ASEE Virtual Annual Conference Content Access Proceedings*. ASEE Conferences. <https://doi.org/10.18260/1-2--34686>
- [12.] Daley, J., & Baruah, B. (2020). Leadership skills development among engineering students in Higher Education – an analysis of the Russell Group universities in the UK. In *European Journal of Engineering Education* (Vol. 46, Issue 4, pp. 528–556). Informa UK Limited. <https://doi.org/10.1080/03043797.2020.1832049>

- [13.] Stephenson, S. S. (2016). Accounting Community of Practice pedagogy: a course management invention for developing personal competencies in accounting education. In *Accounting Education* (Vol. 26, Issue 1, pp. 3–27). Informa UK Limited. <https://doi.org/10.1080/09639284.2016.1247008>
- [14.] Kruse-Weber, S., & Parncutt, R. (2014). Error management for musicians: an interdisciplinary conceptual framework. In *Frontiers in Psychology* (Vol. 5). Frontiers Media SA. <https://doi.org/10.3389/fpsyg.2014.00777>
- [15.] Bayless, D. (n.d.). Assessing the Effectiveness of Leadership Education for Engineering Students. In *2014 ASEE Annual Conference & Exposition Proceedings* (p. 24.207.1-24.207.10). ASEE Conferences. <https://doi.org/10.18260/1-2--20098>
- [16.] Cavique, C., Cláudio, A. P., Carmo, M. B., Guerreiro, M. P., Cavaco, A., & Mateus, E. (2019). OP0286 PARE DEVELOPING A VIRTUAL ASSISTANT TO PROMOTE EDUCATION ON OSTEOARTHRITIS. In *Annals of the Rheumatic Diseases* (Vol. 78, pp. 224–225). Elsevier BV. <https://doi.org/10.1136/annrheumdis-2019-eular.967>
- [17.] Angolia, M. (n.d.). An Active Learning Approach to Core Project Management Competencies. In *2016 ASEE Annual Conference & Exposition Proceedings*. ASEE Conferences. <https://doi.org/10.18260/p.26555>
- [18.] (2020c). The Soft Skills Hidden in Educational Escape Experiences for Middle School Students: A Case Study in South Texas, USA. In *Journal of Education and Practice*. International Institute for Science, Technology and Education. <https://doi.org/10.7176/jep/11-14-04>
- [19.] (2020a). A Reinvented Education in Business and Accounting using a GBL Approach for soft skills. In *Proceedings of the 13th European Conference on Game-Based Learning*. ACI. <https://doi.org/10.34190/gbl.20.047>
- [20.] Goorts, K. (2020). Replacing Final Exams with Open-Ended Course Projects in Engineering Education. In *Teaching Innovation Projects* (Vol. 9, Issue 1, pp. 1–18). University of Western Ontario, Western Libraries. <https://doi.org/10.5206/tips.v9i1.10328>

Chapter 13

Industrial Applications of Microbes in Bioremediation of Polluted Environments

Preeti Yadav and Ravindra Kumar Jain*

Department of Life Sciences

Keral Verma Subharti College of Science

Swami Vivekanand Subharti University Meerut. Uttar Pradesh. India

*Corresponding author (rkjbiotech20@gmail.com)

Abstract

Microorganisms play an indispensable role in numerous industrial sectors due to their remarkable metabolic diversity and adaptability. This review highlights the beneficial applications of microbes in industries such as pharmaceuticals, agriculture, environmental management, food processing, and bioenergy production. Industrial microbiology has evolved from traditional fermentation processes to advanced biotechnological innovations involving genetic engineering, metabolic pathway optimization, and synthetic biology. Microbes such as *Bacillus*, *Aspergillus*, *Saccharomyces*, *Pseudomonas*, and *Streptomyces* are utilized for large-scale production of enzymes, biofuels, antibiotics, organic acids, biofertilizers, and bioplastics. Furthermore, microbial bioremediation offers sustainable solutions for detoxifying industrial effluents and heavy metal contaminants. Recent advancements in omics technologies and bioinformatics have enhanced the identification and manipulation of microbial strains with industrial potential, promoting a circular and green bioeconomy. This paper provides a comprehensive overview of microbial applications in modern industries, emphasizing their contribution to sustainable development and environmental conservation.

Keywords: industrial microbiology, bioremediation, biofertilizers, microbial biotechnology, sustainable industry, bioeconomy

Introduction

Microbes are a diverse group of microscopic organisms, with bacteria representing the most extensively studied members. They play crucial roles across multiple domains, including agriculture, healthcare, environmental remediation, and industrial manufacturing. Their applications range from pollution mitigation to the production of enzymes, metabolites, and biosensors. This review focuses on compiling and analyzing information regarding microbial applications in contaminated water treatment, as well as their roles in the dairy, food, pharmaceutical, and cosmetic industries. Given that microbes represent primary sources of

industrial enzymes, they are frequently cultured on a large scale and genetically modified by transferring target enzyme-encoding genes into well-characterized and manageable microbial hosts. Industrial microorganisms, particularly environmental isolates, possess the inherent ability to synthesize enzymes when provided with appropriate nutrient media. Their rapid growth and ease of clonal expansion make them ideal candidates for large-scale applications. Historically, the first industrial exploitation of microbial enzymes was achieved by Dr. Jokichi Takamine, who derived them from fungi, followed by Boidin and Effront, who reported bacterial enzymes approximately two decades later. In industries such as food, dairy, and leather processing, microorganisms like *Saccharomyces cerevisiae* are directly applied to raw materials to initiate fermentation processes. In contrast, the pharmaceutical industry often cultures microbes to harvest medically significant compounds such as amino acids and enzymes, which are subsequently purified through techniques including bio-affinity chromatography and other advanced separation methods. In addition to industrial production, microbes play a pivotal role in environmental remediation, particularly through bioremediation strategies. Industrial effluents discharged into soil and water bodies can be effectively degraded using bacteria, algae, and fungi. For instance, a study conducted in Prabumulih, South Sumatra, Indonesia, examined the bioremediation of liquid petroleum waste, assessing both process efficiency and degradation rates. Similarly, *Pseudomonas putida* and *Bacillus cereus* have been shown to degrade crude oil, with *P. putida* achieving 60% degradation of petroleum hydrocarbons in water samples within seven days. These findings underscore their potential as reliable bioremediation tools for addressing oil-contaminated environments.

Microbes in Various Industries

Dairy Industry

Lactococcus lactis

Lactococcus lactis is a Gram-positive, non-motile, facultatively anaerobic bacterium, widely recognized as one of the most important lactic acid bacteria (LAB) in the dairy sector. Its industrial relevance lies in its ability to ferment lactose into lactic acid via the hexose diphosphate pathway. The acidification process lowers the pH of milk, causing protein coagulation, which is a critical step in cheese production. Beyond coagulation, *L. lactis* contributes significantly to the development of flavor, aroma, and texture in a wide variety of cheeses. This bacterium thrives optimally at around 10 °C, but becomes immotile at temperatures exceeding 45 °C. It also demonstrates tolerance to acidic environments and saline conditions, making it highly adaptable for industrial fermentation. Together with *Streptococcus thermophilus*, *L. lactis* is used in yogurt production. Its applications extend

beyond cheese and yogurt to fermented milk, sour cream, kefir, and butter. The widespread use of *L. lactis* in starter cultures makes it a cornerstone of dairy biotechnology.

Streptococcus thermophilus

Streptococcus thermophilus is a Gram-positive, thermophilic lactic acid bacterium capable of fermenting lactose, sucrose, glucose, and fructose. It is widely applied in the production of yogurt, Swiss cheese, and hard Italian cheeses. Its resilience against bacteriophage infection is enhanced by the CRISPR-Cas system, although it remains relatively sensitive to antibiotics and sanitizers. Optimal growth occurs at 40–45 °C, with growth slowing at 20–25 °C and inhibited above 50 °C. *S. thermophilus* plays a dual role in dairy fermentation: (i) it produces lactic acid, thereby lowering pH and suppressing pathogenic microbes, and (ii) it enhances sensory qualities such as flavor and texture. Additionally, it is recognized as a probiotic, contributing to gut health when consumed in fermented products.

Propionibacterium freudenreichii

Propionibacterium freudenreichii is a Gram-positive bacterium best known for its role in Swiss cheese fermentation. During lactate metabolism, it releases carbon dioxide, producing the characteristic “eyes” (holes) in Swiss cheese. Its metabolic activity generates flavor-enhancing compounds such as propionate, acetate, short-chain fatty acids from amino acid catabolism, and free fatty acids from milk fat hydrolysis. Beyond organoleptic contributions, *P. freudenreichii* synthesizes bioactive compounds including vitamin B12 and folate, improving the nutritional quality of dairy products. The antimicrobial action of propionic acid helps extend shelf life by inhibiting spoilage organisms. Its subspecies, *P. freudenreichii shermanii*, is highly resilient to environmental fluctuations and can grow at temperatures as low as 3.8 °C, making it ideal for cheese maturation.

Lactobacillus helveticus

Lactobacillus helveticus is a proteolytic lactic acid bacterium extensively used in the manufacture of hard and extra-hard cheeses such as Parmesan and Swiss varieties. Its proteolytic activity enhances cheese flavor and texture during ripening. Moreover, *L. helveticus* produces bioactive peptides with antioxidant, antihypertensive, and antimicrobial properties. These peptides contribute to the health-promoting effects of fermented dairy products, such as improved cardiovascular health and enhanced immune defense. In vitro studies have also shown its antagonistic action against pathogenic fungi and bacteria, highlighting its role in natural food preservation.

Leather Industry

Microbes producing proteases and lipases play a crucial role in eco-friendly leather processing. They replace harsh chemicals in dehairing, degreasing, and bating, thus

minimizing environmental pollution. Examples include *Bacillus subtilis*, which produces both proteases and lipases ; *Bacillus licheniformis*, a major source of proteases; *Pseudomonas fluorescens*, known for thermolabile lipases ; and *Aspergillus niger*, a fungal source of lipases used in leather treatment. These microbial enzymes improve leather quality by enhancing softness, flexibility, and appearance, while reducing chemical hazards in tannery operations.

Food Industry

Saccharomyces cerevisiae

Saccharomyces cerevisiae, a unicellular eukaryotic fungus with 16 chromosomes, is one of the most extensively studied eukaryotic organisms due to its genetic tractability.. It is employed in baking and brewing industries to produce bread, beer, wine, and other alcoholic beverages . Fermentation by *S. cerevisiae* converts sugars into ethanol, carbon dioxide, and flavor compounds, imparting desirable sensory qualities to foods and beverages. In bread making, CO₂ production creates air pockets that give bread its soft, porous texture, while flavor compounds such as phenylethanol and δ -decalactone contribute to its aroma . Due to its high protein and vitamin B content, *S. cerevisiae* is also used as a nutritional supplement. Furthermore, its antimicrobial metabolites serve as natural preservatives in fruit juices, alcoholic beverages, and processed foods .

Lactobacillus plantarum

Lactobacillus plantarum is a versatile Gram-positive lactic acid bacterium found in fermented foods such as pickles, kimchi, sauerkraut, and sourdough . It is also abundant in the human gastrointestinal tract, where it exhibits probiotic properties. *L. plantarum* enhances food quality by improving antioxidant capacity, scavenging hydroxyl and oxygen radicals, and enhancing nutritional content through increased vitamin and amino acid availability . It is also used in food preservation; for example, when combined with chitosan, *L. plantarum* extends the shelf life of fresh-cut apples by reducing microbial spoilage . Its dual role in food quality improvement and human health promotion makes it a valuable microorganism in functional food development.

Lactobacillus acidophilus

Lactobacillus acidophilus is a Gram-positive, microaerophilic LAB frequently applied in the fermentation of vegetables, fish, sausages, and silage . In addition to imparting characteristic flavor and texture, it acts as a biopreservative by producing lactic acid and bacteriocins that inhibit foodborne pathogens. *L. acidophilus* demonstrates strong acid tolerance, enabling survival in gastrointestinal conditions, and is widely consumed as a probiotic supplement . Its probiotic activity contributes to gut microbiome balance and overall human health.

Role of Microbes in Pollutant Removal Process

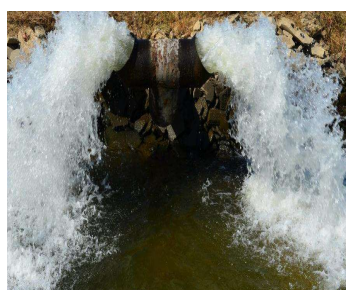
Degradation of Organic Pollutants

Microorganisms are widely recognized as effective bio-remediators owing to their ability to degrade a broad spectrum of organic pollutants . Degradation typically occurs through co-metabolism, where microbial communities in the rhizosphere of aquatic and terrestrial plants break down complex carbon-based compounds to acquire organic carbon and electron acceptors. In aquatic systems, the rate of biodegradation depends on both the density of microbial populations and the concentration of xenobiotics present . The abundance and activity of these microbes are strongly influenced by the species of macrophytes present . Plant roots provide organic carbon that supports microbial degradation of pollutants such as hydrocarbons and aromatic hydrocarbons . Additionally, many rhizospheric bacteria produce indole acetic acid (IAA), which not only enhances plant growth but also supports pollutant degradation . Biofilms associated with aquatic plants play a particularly significant role in breaking down organic compounds, including phenolics, amines, aliphatic aldehydes, polychlorinated biphenyls (PCBs), and atrazine . Moreover, methanotrophic bacteria enriched in wetland rhizospheres utilize methane as a carbon and energy source . These methanotrophs are capable of degrading a wide range of hazardous organic contaminants, including chlorinated ethenes, through enzymatic reactions . For instance, *Eichhornia crassipes* has been shown to remediate eutrophic waters by stimulating nitrogen gas production, thereby contributing to both pollutant removal and ecosystem restoration.[30]

Removal of Heavy Metals

The rhizospheric and endophytic **microbes** (including bacteria, fungi, algae, and cyanobacteria) play a prominent role in the removal and detoxification of heavy metals (Table1). Microbes promote the removal of metals through biosorption, bioaccumulation, biotransformation, and biomineralization processes. The microbial cell wall, rich in functional groups such as carboxyl, hydroxyl, and amino groups, can bind and immobilize toxic metal ions. In addition, some microbes enhance metal uptake in plants by increasing metal bioavailability in the rhizosphere. Specific metal-binding proteins and peptides, such as **metallothioneins** and **phytochelatins**, produced by microbes, help in the sequestration of heavy metals. Transcription factors regulating these proteins facilitate hormonal and redox signaling under metal stress conditions. **Cyanobacteria** such as *Anabaena spiroides* mitigate heavy metal toxicity by producing proteins that bind Cd, Cu, and Cr. **Fungi**, including *Aspergillus niger* and *Penicillium chrysogenum*, have strong biosorption capacities for Pb, Ni, and Zn. **Yeasts** like *Saccharomyces cerevisiae* accumulate Cu and Cd via intracellular sequestration. Genetically modified microbes further improve remediation potential. For instance, *Ralstonia eutropha* reduces Cd(II) toxicity by expressing metallothionein on its cell

surface, while *Escherichia coli* regulates Cd stress by producing detoxification proteins. Mercury-resistant microbes such as *Pseudomonas aeruginosa* and *Bacillus cereus* contain the **mer operon**, which reduces toxic Hg^{2+} to less toxic elemental mercury. Some endophytic microbes, including *Enterobacter cloacae* and *Bacillus licheniformis*, influence plant phenotypic and functional traits, enhancing antioxidant enzyme activities to combat oxidative stress caused by heavy metals. Certain fungi also detoxify metals via **methylation** and redox transformations, converting highly toxic forms into less toxic species. Thus, microbial interactions augment phytoremediation by supporting plant metal tolerance, producing stress-related proteins, and establishing active transport mechanisms such as efflux pumps to alleviate metal stress.



Source of
microbes

Agricultural
fertilizers

Mining ore and
industries

Wastewater from
industries

Metallurgic and
electronic

Impacts on
human and

Change in soil
quality

Genetic
mutation

Lung cancer
,ulcer

Accumulate
food chain

Table 1. Removal of Heavy Metals by Microbes

Microbe	Metal(s)	Reference
<i>Lactobacillus delbrueckii</i> , <i>Streptococcus thermophilus</i>	Fe, Zn	[04]
<i>Acinetobacter sp.</i> , <i>Bacillus megaterium</i> , <i>Sphingobacterium sp.</i>	Fe, Mn	[05]
<i>Anoxybacillus flavithermus</i>	Fe, Cu	[06]
<i>Leptothrix</i> , <i>Pseudomonas</i> , <i>Hyphomicrobium</i> , <i>Planctomyces</i>	Mn	[07]
<i>Methylobacterium organophilum</i>	Cu, Pb	[08]
<i>Herminiimonas arsenicoxydans</i>	As	[09]
<i>Enterobacter cloacae</i>	Cd	[010]
<i>Acetobacter sp.</i>	Cu, Cr	[011]
<i>Chryseomonas luteola</i>	Pb, Cu, Mn	[12]
<i>Ochrobactrum anthropic</i>	Zn, Co	[13]
<i>Anabaena spiroides</i> (cyanobacterium)	Cd, Co, Cu, Ni	[14]
<i>Ralstonia solanacearum</i>	Cr, Cu	[15]
<i>Proteobacteria</i> and <i>Bacteroidetes</i>	Mn	[16]
<i>Bacillus cereus</i>	Pb	[17]
<i>Bacillus licheniformis</i>	Cu	[19]
<i>Saccharomyces cerevisiae</i> (yeast)	Cd, Cu	[20]
<i>Aspergillus niger</i> (fungus)	Pb, Zn	[21]
<i>Penicillium chrysogenum</i> (fungus)	Ni, Cd	

Table2: Pathogen Risk and Health Concerns from Industrial Use of Microbes

Microbial Group / Species	Industrial Application	Potential Risk / Pathogenic Concern	Health or Environmental Impact	Preventive Measures / Biosafety

				Level
<i>Bacillus subtilis</i>	Enzyme and probiotic production	Generally regarded as safe (GRAS), but some strains may cause opportunistic infections in immunocompromised individuals	Rare allergic reactions or respiratory irritation	BSL-1; standard lab hygiene
<i>Aspergillus niger</i>	Citric acid and enzyme production	Certain strains can produce mycotoxins	Allergic reactions and respiratory issues upon exposure	BSL-1/2; dust control and PPE
<i>Pseudomonas aeruginosa</i>	Bioremediation and biosurfactant production	Opportunistic human pathogen	Infections in wounds, lungs (especially in cystic fibrosis patients)	BSL-2; strict containment and waste sterilization
<i>Escherichia coli</i> (non-pathogenic strains)	Recombinant protein and enzyme production	Risk of contamination with pathogenic strains (e.g., <i>E. coli</i> O157:H7)	Gastrointestinal illness if contamination occurs	BSL-1 for lab strains; BSL-2 for environmental strains
<i>Streptomyces spp.</i>	Antibiotic and enzyme production	Generally non-pathogenic, but can cause actinomycetoma in rare cases	Minor skin or respiratory infection	BSL-1; controlled air circulation
<i>Clostridium acetobutylicum</i>	Solvent (acetone-butanol) fermentation	Some <i>Clostridium</i> species are pathogenic (<i>C. botulinum</i>)	Neurotoxic risk if mishandled strains mix	BSL-2; anaerobic handling safety
<i>Saccharomyces cerevisiae</i>	Brewing, baking, and	Rare infections in immunocompromised	Fungemia in susceptible	BSL-1; good air filtration

	bioethanol production	individuals	patients	
<i>Penicillium chrysogenum</i>	Antibiotic (penicillin) production	Spore inhalation may cause allergies or respiratory issues	Hypersensitivity reactions	BSL-1; controlled spore dispersion
<i>Mycobacterium smegmatis</i>	Model organism for bioremediation research	Non-pathogenic but related to <i>M. tuberculosis</i>	Minimal risk under controlled use	BSL-2; PPE and biosafety cabinet
<i>Rhodococcus erythropolis</i>	Hydrocarbon degradation	Generally safe, but misidentified strains may be opportunistic	Mild skin infection (rare)	BSL-1; periodic strain verification

Bioremediation Process

Bioremediation is a sustainable and eco-friendly approach for the detoxification of hazardous pollutants, including heavy metals, by converting them into less harmful forms or by completely eliminating the agents responsible for toxicity. The process involves the utilization of microbial biomass, either living or dead, to degrade, transform, or immobilize recalcitrant contaminants. Ultimately, these conversions result in the formation of stable, non-toxic end products such as carbon dioxide (CO₂), water (H₂O), nitrogen gas (N₂), and other benign compounds. Bioremediation specifically targets toxic substances with minimal adverse effects on the environment and living organisms, making it a cost-effective alternative to conventional remediation methods. For any successful bioremediation strategy, three essential components are required: **microorganisms, nutrients, and energetics**. In certain environmental settings, contaminants themselves can serve as carbon and energy sources through microbial redox reactions. Under aerobic conditions, contaminants act as electron donors, while microorganisms utilize oxygen as the terminal electron acceptor. Conversely, in anaerobic environments, microbes degrade pollutants using alternative electron acceptors such as nitrate, sulfate, or carbon dioxide [22]. Based on the site of application, bioremediation can be broadly classified into **in situ** and **ex situ** processes.

- **In situ bioremediation** is conducted directly at the contaminated site without excavation. It involves the delivery of oxygen and nutrients into the polluted

environment, thereby stimulating indigenous microbial communities to degrade contaminants. Techniques under this category include *bioventing*, *biosparging*, *bioslurping*, and *phytoremediation*. Two approaches exist within in situ bioremediation:

- *Intrinsic bioremediation*, which relies on the natural attenuation potential of native microorganisms, enhanced through nutrient and oxygen supplementation.
- *Engineered bioremediation*, which involves the deliberate introduction of specific microorganisms into the contaminated site to accelerate pollutant degradation.
- **Ex situ bioremediation**, on the other hand, requires removal of contaminated material from the site, followed by treatment under controlled conditions. Popular methods include *biopiles*, *windrows*, *bioreactors*, and *landfarming*, where microbial activity is optimized for efficient pollutant degradation (Kulshreshtha et al. [23]).

In the context of heavy metal pollution, bioremediation employs two key mechanisms: **bioaccumulation** and **biosorption**. Bioaccumulation is a metabolism-driven process in which living microbial cells actively transport and sequester metal ions within their intracellular compartments [94]. In contrast, biosorption is a physicochemical process wherein dead or metabolically inactive biomass binds and concentrates heavy metals on cell surface structures such as polysaccharides, proteins, and lipids (Fomina & Gadd, 2014). Both processes are increasingly recognized as emerging tools for wastewater treatment due to their **cost-effectiveness, environmental compatibility, and high removal efficiency**

Conclusion

Microorganisms play a central role in industrial processes, offering applications ranging from food fermentation, biofuel production, and pharmaceuticals to wastewater treatment and bioremediation. While their use has provided immense benefits to society, the large-scale deployment of microbes also raises ecological and health concerns. Certain industrial strains may contribute to the dissemination of antibiotic resistance, toxin production, or ecological imbalance if not carefully regulated. At the same time, microbial activity can also improve environmental quality by mitigating pollutants through natural or engineered pathways. Bioremediation techniques, including bioaccumulation, biosorption, and microbial immobilization, have emerged as eco-friendly and cost-effective solutions for reducing the toxic impact of heavy metals and organic pollutants. In situ approaches such as bioventing, biosparging, and phytoremediation exploit native microbial communities, while ex situ

methods such as biopiles, landfarming, and bioreactors provide controlled environments for optimized degradation. The success of these processes depends on selecting appropriate microbial strains, providing essential nutrients, and integrating innovative carriers for microbial immobilization.

References

1. Schatz A, Bugie E, Waksman S. Streptomycin, a substance exhibiting antibiotic activity against gram-positive and gram-negative bacteria. 1944. *Clin Orthop Relat Res*. 2005;437:3-6.
2. Koch W. Erythromycin. *Analy Prof Drug Subst*. 1979;8:159-77.
3. Enna S, Bylund D. . *XPharm : the comprehensive pharmacology reference (Internet)*. 2008.
4. Sofu, A.; Sayilgan, E.; Guney, G. Experimental design for removal of Fe (II) and Zn (II) ions by different lactic acid bacteria biomasses. *Int. J. Environ. Res*. 2015, 9, 93–100.
5. Li, C.; Wang, S.; Du, X.; Cheng, X.; Fu, M.; Hou, N.; Li, D. Immobilization of iron- and manganese-oxidizing bacteria with a biofilm-forming bacterium for the effective removal of iron and manganese from groundwater. *Bioresour. Technol*. 2016, 220, 76–84. [Cross Ref] *Sustainability* 2020, 12, 5559 26 of 29
6. Franzblau, R.E.; Daughney, C.J.; Swedlund, P.J.; Weisener, C.G.; Moreau, M.; Johannessen, B.; Harmer, S.L. Cu (II) removal by *Anoxybacillus flavithermus*–iron oxide composites during the addition of Fe (II) aq. *Geochim. Cosmochim. Acta* 2016, 172, 139–158. [CrossRef]
7. Guo, Y.; Huang, T.; Wen, G.; Cao, X. The simultaneous removal of ammonium and manganese from groundwater by iron-manganese co-oxide filter film: The role of chemical catalytic oxidation for ammonium removal. *Chem. Eng. J*. 2017, 308, 322–329. [CrossRef] Kim, S.-Y.; Kim, J.-H.; Kim, C.-J.; Oh, D.-K. Metal adsorption of the polysaccharide produced from *Methylobacterium organophilum*. *Biotechnol. Lett* 1996, 18, 1161–1164. [CrossRef]
8. Marchal, M.; Briandet, R.; Koechler, S.; Kammerer, B.; Bertin, P. Effect of arsenite on swimming motility delays surface colonization in *Herminiimonas arsenicoxydans*. *Microbiology* 2010, 156, 2336–2342. [CrossRef]
9. Iyer, A.; Mody, K.; Jha, B. Biosorption of heavy metals by a marine bacterium. *Mar. Pollut. Bull*. 2005, 50, 340–343. [CrossRef] [PubMed]

10. Oshima, T.; Kondo, K.; Ohto, K.; Inoue, K.; Baba, Y. Preparation of phosphorylated bacterial cellulose as an adsorbent for metal ions. *React. Funct. Polym.* 2008, 68, 376–383. [CrossRef]
11. Ozdemir, G.; Ceyhan, N.; Manav, E. Utilization of an exopolysaccharide produced by *Chryseomonas luteola* TEM05 in alginate beads for adsorption of cadmium and cobalt ions. *Bioresour. Technol.* 2005, 96, 1677–1682. [CrossRef]
12. Ozdemir, G.; Ozturk, T.; Ceyhan, N.; Isler, R.; Cosar, T. Heavy metal biosorption by biomass of *Ochrobactrum anthropi* producing exopolysaccharide in activated sludge. *Bioresour. Technol.* 2003, 90, 71–74. [CrossRef]
13. Freire-Nordi, C.S.; Vieira, A.A.H.; Nascimento, O.R. The metal binding capacity of *Anabaena spiroides* extracellular polysaccharide: An EPR study. *Process Biochem.* 2005, 40, 2215–2224. [CrossRef]
14. Pugazhendhi, A.; Boovaragamoorthy, G.M.; Ranganathan, K.; Naushad, M.; Kaliannan, T. New insight into effective biosorption of lead from aqueous solution using *Ralstonia solanacearum*: Characterization and mechanism studies. *J. Clean. Prod.* 2018, 174, 1234–1239. [CrossRef]
15. Wu, Y.; Zhao, X.; Jin, M.; Li, Y.; Li, S.; Kong, F.; Nan, J.; Wang, A. Copper removal and microbial community analysis in single-chamber microbial fuel cell. *Bioresour. Technol.* 2018, 253, 372–377. [CrossRef]
16. Pugazhendhi, A.; Ranganathan, K.; Kaliannan, T. Biosorptive removal of copper (II) by *Bacillus cereus* isolated from contaminated soil of electroplating industry in India. *Water Air Soil Pollut.* 2018, 229, 76. [CrossRef]
17. Wen, X.; Du, C.; Zeng, G.; Huang, D.; Zhang, J.; Yin, L.; Tan, S.; Huang, L.; Chen, H.; Yu, G. A novel biosorbent prepared by immobilized *Bacillus licheniformis* for lead removal from wastewater. *Chemosphere* 2018, 200, 173–179. [CrossRef] [PubMed]
18. Pramanik, K.; Mitra, S.; Sarkar, A.; Maiti, T.K. Alleviation of phytotoxic effects of cadmium on rice seedlings by cadmium resistant PGPR strain *Enterobacter aerogenes* MCC 3092. *J. Hazard. Mater.* 2018, 351, 317–329. [CrossRef] [PubMed]
19. Choińska-Pulit, A.; Sobolczyk-Bednarek, J.; Łaba, W. Optimization of copper, lead and cadmium biosorption onto newly isolated bacterium using a Box-Behnken design. *Ecotoxicol. Environ. Saf.* 2018, 149, 275–283. [CrossRef] [PubMed]
20. Bai, H.-J.; Zhang, Z.-M.; Yang, G.-E.; Li, B.-Z. Bioremediation of cadmium by growing *Rhodobacter sphaeroides*: Kinetic characteristic and mechanism studies. *Bioresour. Technol.* 2008, 99, 7716–7722.

21. Wang, C.-Y.; Sample, D.J.; Bell, C. Vegetation effects on floating treatment wetland nutrient removal and harvesting strategies in urban stormwater ponds. *Sci. Total Environ.* 2014, 499, 384–393. [CrossRef]
22. Chang, N.-B.; Islam, K.; Marimon, Z.; Wanielista, M.P. Assessing biological and chemical signatures related to nutrient removal by floating islands in stormwater mesocosms. *Chemosphere* 2012, 88, 736–743. [CrossRef]
23. Borne, K.E.; Fassman, E.A.; Tanner, C.C. Floating treatment wetland retrofit to improve stormwater pond performance for suspended solids, copper and zinc. *Ecol. Eng.* 2013, 54, 173–182. [CrossRef]
24. Husson, O. Redox potential (Eh) and pH as drivers of soil/plant/microorganism systems: A transdisciplinary overview pointing to integrative opportunities for agronomy. *Plant Soil* 2013, 362, 389–417. [CrossRef]
25. Vitousek, P.M.; Cassman, K.; Cleveland, C.; Crews, T.; Field, C.B.; Grimm, N.B.; Howarth, R.W.; Marino, R.; Martinelli, L.; Rastetter, E.B. Towards an Ecological Understanding of Biological Nitrogen Fixation. In *The Nitrogen Cycle at Regional to Global Scales*; Springer: Berlin/Heidelberg, Germany, 2002; pp. 1–45.
26. Lamers, L.P.; Van Diggelen, J.M.; Op Den Camp, H.J.; Visser, E.J.; Lucassen, E.C.; Vile, M.A.; Jetten, M.S.; Smolders, A.J.; Roelofs, J.G. Microbial transformations of nitrogen, sulfur, and iron dictate vegetation composition in wetlands: A review. *Front Microbiol.* 2012, 3,
27. 154. Bañeras, L.; Ruiz-Rueda, O.; López-Flores, R.; Quintana, X.D.; Hallin, S. The role of plant type and salinity in the selection for the denitrifying community structure in the rhizosphere of wetland vegetation. *Int. Microbiol.* 2012, 15, 89–99.
28. 155. Trias, R.; Ruiz-Rueda, O.; García-Lledó, A.; Vilar-Sanz, A.; López-Flores, R.; Quintana, X.D.; Hallin, S.; Bañeras, L. Emergent macrophytes act selectively on ammonia-oxidizing bacteria and archaea. *Appl. Environ. Microbiol.* 2012, 78, 6352–6356. [CrossRef]
29. Golubev, S.N.; Schelud'ko, A.V.; Muratova, A.Y.; Makarov, O.E.; Turkovskaya, O.V. Assessing the potential of rhizobacteria to survive under phenanthrene pollution. *Water Air Soil Pollut.* 2009, 198, 5–16. [CrossRef]

Chapter 14

Biofilm-Based Fermentation in Dairy Products: Opportunities and Safety Challenges

Imroz khan, Ravindra Kumar Jain*

Department of Life Sciences, Keral Verma Subharti College of Science,
Swami Vivekanand Subharti University, Meerut, Uttar Pradesh India -250005

*Corresponding author Email- rkjbiotech20@gmail.com**Abstract**

Biofilm-based fermentation is emerging as an innovative approach within dairy microbiology because it uses the natural ability of microorganisms to grow as highly organised, surface-attached communities. Unlike conventional planktonic (free-floating) cultures, biofilm-associated microbes show greater resistance, improved metabolic activity, and higher stability under environmental stress. These characteristics make biofilm systems highly attractive for developing consistent, efficient, and sustainable dairy fermentation processes. This review presents an extensive overview of biofilm formation, especially in dairy environments, and highlights their beneficial roles in improving product texture, flavour, and fermentation consistency. Microorganisms such as *Lactobacillus*, *Streptococcus*, *Leuconostoc*, and *Bifidobacterium* often form biofilms that resemble natural fermentation niches and contribute to increased probiotic functionality. However, the same biofilm-supportive conditions may allow colonisation by harmful pathogens like *Listeria monocytogenes* and *Staphylococcus aureus*, posing significant safety risks. Recent advancements in microscopy, biosensors, omics technologies, microbial engineering, and sanitisation strategies have further enhanced our understanding of biofilm behaviour. Yet, challenges remain regarding the detection of mixed biofilms, prevention of resistant pathogens, and establishing regulatory guidelines for biofilm-based dairy production. This review highlights current research trends, discusses industrial opportunities, and outlines future directions to safely integrate biofilm-driven fermentation systems into large-scale dairy operations.

Keywords:

Biofilm, Dairy Fermentation, Starter Cultures, Microbial Ecology, Food Safety, Probiotics, Omics Technologies

1. Introduction:

Biofilms are highly organised groups of microorganisms that attach firmly to a surface and become enclosed within a self-produced matrix of extracellular polymers. This structural arrangement gives them significant protection from environmental

stress and allows the cells inside the biofilm to communicate and function cooperatively.(Flemming & Wingender et.,al, 2010). In dairy processing facilities, such biofilms commonly form on stainless-steel pipelines, milk storage tanks, rubber gaskets, and heat-exchange plates because these surfaces frequently come into contact with nutrient-rich milk residues and moisture.(Kumar & Anand et.,al, 1998; Marchand et.,al., 2012).

Although biofilms were historically regarded only as contamination sources within dairy industries.(Robinson et al., 1981), recent studies have shown that controlled, beneficial biofilms can actually support stable and efficient fermentation. In many traditional dairy products such as dahi, yoghurt, kefir, and artisanal cheeses the microbial communities that drive fermentation naturally develop biofilm-like structures, which help maintain consistency and enhance flavour development.(Jha et al., 2011; Singh et al., 2017). Lactic acid bacteria such as *Lactobacillus plantarum*, *Streptococcus thermophilus*, and *Lactococcus lactis* demonstrate greater survival and metabolic stability when growing in biofilm mode due to the protective nature of the extracellular matrix.(Madeira et al., 2015). With the growing interest in sustainable and continuous fermentation processes, researchers are now exploring biofilm-based fermentation systems where surface-attached LAB biofilms function as natural and reusable starter cultures.(Rodrigues et al., 2008;Wang et al., 2021). These systems can improve efficiency, product consistency, and probiotic viability.

However, biofilm-friendly environments can also support the survival of harmful microorganisms such as *Listeria monocytogenes* and *Staphylococcus aureus*, making safety a major concern for the dairy industry.(Oliveira et al., 2010; Srey et al., 2013). Therefore, a deep understanding of how dairy biofilms develop, function, and interact with pathogens is essential for designing safe and reliable fermentation strategies.

2. Definition of Biofilms:

Biofilms are communities of microorganisms that attach to a surface and grow together in a structured way. Instead of living as single, free-floating cells, the microbes in a biofilm stay close to each other and are covered by a self-produced protective layer called the extracellular polymeric substances (EPS) matrix. This matrix is usually made of polysaccharides, proteins, nucleic acids, and other sticky materials.

In simple words, a biofilm is like a thin, slimy layer of microorganisms on a surface. These surfaces can be natural, like rocks in a river, or man-made, like the inside of a milk storage tank, a pipeline, or the wall of a cheese vat. The biofilm lifestyle gives microorganisms

better protection, improved communication, and more stability compared to free-floating cells.

2.1 Role of Biofilms in Natural and Industrial Fermentation:

Biofilms are not only found in disease or dirty environments; they are a natural form of microbial life. In nature, biofilms help microorganisms survive changing conditions such as temperature variations, dryness, acidity, or lack of nutrients. Many traditional fermented foods and beverages around the world are influenced, directly or indirectly, by biofilm-associated microorganisms.

In natural fermentation, microorganisms present on plant surfaces, animal skins, or equipment surfaces can slowly build biofilms. These biofilms then act as natural starter cultures for repeated fermentation. For example, in some traditional cheese and yoghurt-making systems, the wooden vats or cloths used for draining whey become rich in beneficial biofilms over time. When fresh milk is added, these biofilm microbes start the fermentation quickly and reliably.

In modern industrial fermentation, biofilms can play a dual role. On one side, unwanted biofilms can contaminate equipment and cause hygiene problems.

On the other side, controlled and beneficial biofilms can be used to carry out stable and continuous fermentation. In recent years, researchers have started exploring biofilm-based fermentation systems, where biofilms of useful bacteria are grown on surfaces or carriers and then used to ferment milk and other substrates in a more controlled manner.

1.3 Relevance to Dairy Microbiology:

Dairy microbiology focuses on microorganisms that are present in milk and milk products, as well as on the microbial activities that occur during processing, fermentation, storage, and spoilage. Biofilms are highly relevant to dairy microbiology for several reasons:

- Starter cultures and fermentation: Many lactic acid bacteria (LAB), such as *Lactobacillus*, *Streptococcus*, *Lactococcus*, and *Leuconostoc*, are capable of forming biofilms on dairy equipment surfaces. These biofilms can act as reservoirs of beneficial bacteria that support fermentation in products like dahi/curd, lassi, shrikhand, buttermilk, cheese, and other traditional and industrial dairy products.

- Product quality and functionality: Biofilm-associated LAB often show better survival and metabolic performance. This can lead to more consistent acidification, improved flavour formation, and better texture development in fermented dairy products.
- Spoilage and safety: The same mechanisms that make biofilms useful can also protect harmful or spoilage organisms. Pathogens such as *Listeria monocytogenes* and *Staphylococcus aureus*, or spoilage microbes, may form biofilms in milk processing lines, pasteurisers, storage tanks, and filling machines. Such biofilms can periodically release cells into the product stream, leading to contamination, reduced shelf life, and potential health risks.

Because of these positive and negative roles, understanding biofilms is essential for modern dairy plants, quality assurance teams, and food safety regulators.

1.4 Aim and Scope of the Review

The aim of this review assignment is to provide a comprehensive, yet easy-to-understand, overview of biofilm-based fermentation in dairy products, with special emphasis on:

- What biofilms are and how they form in dairy environments
- Which microorganisms are commonly involved in dairy biofilms
- How beneficial biofilms can be used to improve dairy fermentation and product quality
- What safety risks are associated with biofilms in dairy processing
- Which methods are available to detect, control, and manage undesirable biofilms
- What future research directions and industrial applications are possible in this field

The scope of this review covers both traditional and modern dairy systems, including Indian fermented products (such as dahi, lassi, shrikhand, and makkhan) as well as global products like yoghurt, kefir, sour cream, and cheese. The discussion includes microbiological, technological, safety, and regulatory perspectives, with a focus on how biofilm-based fermentation can contribute to sustainable and efficient dairy production.

2. Biofilms in Dairy Environments:

Biofilms are commonly found throughout dairy processing units because milk and its residues provide nutrients that help microorganisms attach and grow. In dairy plants, these

biofilms can develop on stainless steel pipes, milk storage tanks, pasteurisers, rubber gaskets, valves, and filling equipment, making them important to understand from both quality and safety perspectives.(Kumar & Anand,et,.al 1998; Marchand et al., 2012).

2.1 Formation and Structure of Microbial Biofilms:

Biofilms do not appear suddenly; they develop gradually in a series of steps.

The process usually begins when milk or cleaning liquids leave behind a thin layer of proteins, fats, and minerals on surfaces. This acts as a conditioning layer, which makes it easier for bacteria to attach.(Orgaz et al., 2006).

After this, planktonic (free-floating) bacteria present in raw milk, air, water, or equipment surfaces approach the conditioned area. At first, the attachment is weak and reversible, but once the bacteria start producing sticky substances, the adhesion becomes permanent and small clusters (microcolonies) begin to form.(Costerton, et,.al 1999).

With time, these colonies produce large amounts of extracellular polymeric substances (EPS) made of polysaccharides, proteins, and DNA. This EPS matrix forms a protective 3D structure that helps retain moisture, trap nutrients, and keep cells safe from temperature changes, chemicals, or sanitizers.(Flemming & Wingender, et,.al 2010).

As the biofilm matures, it develops water channels and multilayered cell arrangements. Eventually, some cells detach or break off and spread to other surfaces, starting new biofilms in different parts of the dairy plant.(Bridier et al., 2013).

These steps continue daily, especially when cleaning is insufficient or milk residues remain after processing.

Biofilm formation in dairy environments generally follows a series of steps.

1.Initial conditioning of the surface:

When milk or cleaning solutions flow over a surface such as stainless steel, plastic, or rubber, a thin layer of organic material (proteins, fats, and minerals) first deposits on the surface. This is called a conditioning film. It changes the surface properties and makes it easier for microorganisms to attach.

2.Initial microbial attachment:

Free-floating (planktonic) bacteria from raw milk, water, air, or human contact can come into contact with the conditioned surface. Some of these cells attach loosely using

weak interactions. At this stage, attachment is still reversible; cells may detach if the flow is strong.

3.Irreversible attachment and micro-colony formation:

Attached cells begin to produce adhesive substances and start to divide, forming small clusters or micro-colonies. The attachment becomes stronger and more permanent.

4.EPS production and biofilm maturation:

The microbes produce large amounts of extracellular polymeric substances (EPS), which form a 3D matrix around the cells. This matrix holds water and nutrients, and it protects the cells from environmental stress and cleaning agents. As more cells join and multiply, the micro colony grows into a mature biofilm with channels for fluid flow and waste removal.

5.Dispersal:

Under certain conditions, parts of the biofilm can break off or some cells can return to a free-floating state. These released cells can spread to other parts of the equipment and form new biofilms.

In dairy equipment, these steps can occur repeatedly every day, especially when cleaning and sanitising are not properly optimised. Temperature changes, presence of milk residues, and intermittent flow of liquids all influence how quickly and strongly biofilms develop.

The structure of a biofilm in a dairy plant is highly heterogeneous. It may have layers of different species, with LAB in one section and spoilage or pathogenic microorganisms in another. This mixed community can share nutrients, resist cleaning chemicals together, and adapt to processing conditions.

2.2 Common biofilm-forming Microbes in Dairy.

Dairy environments contain a wide variety of microorganisms. Some are helpful for fermentation, while others cause spoilage or safety concerns.

. Lactic Acid Bacteria (LAB):

These are the main fermentative bacteria used for dairy products. Species such as *Lactobacillus planetarium*, *Lactobacillus casei*, *Streptococcus thermophiles*,

Lactococcus lactis, and *Leuconostoc mesenteroides* are known for forming biofilms that support natural milk fermentation (Rodrigues et al., 2008).

- These LAB biofilms can improve acidification, flavour formation, and fermentation consistency in products like yoghurt and dahi. (Liu et al., 2019).

.Spoilage Bacteria:

Certain *Pseudomonas* species, psychrotrophic bacteria, and heat-resistant spore-formers like *Bacillus* and *Geobacillus* can form strong biofilms. Often grow on dairy equipment, especially in cold storage and pasteurisers. They can survive cleaning cycles, break down proteins and fats, and cause defects like off-flavors, gas production, or curdling. (Teh et al., 2014; Guilbaud et al., 2015).

.Pathogenic Bacteria:

Pathogens such as *Listeria monocytogenes*, *Staphylococcus aureus*, and some *E. coli* strains can form or join biofilms in dairy factories. Once inside the biofilm, these pathogens become harder to remove and may contaminate products over long periods. This is a major concern for ready-to-eat dairy products, especially soft cheeses and fresh dairy items. (Oliveira et al., 2010; Simoes et al., 2010).

.Yeasts and Moulds:

In areas exposed to moisture and air such as drains, storage rooms, and walls yeasts and moulds may join biofilms and contribute to spoilage odors, discoloration, or surface growth. (Puerari et al., 2012).

Because biofilms often contain mixed populations, a surface that looks clean may still harbour complex microbial communities. Regular microbiological monitoring and hygiene checks are therefore essential.

2.3 Surfaces Prone to Biofilm Formation in Dairy Facilities

Dairy plants have several types of surfaces and equipment parts that are especially prone to biofilm formation. Some of the most important are:

- **Storage tanks and soils:**

Raw milk, cream, or fermented products are often stored in large stainless-steel tanks. If cleaning-in-place (CIP) procedures are not properly followed, milk residues can

remain in welds, corners, or dead ends, allowing biofilms to develop.(Gibson et al., 1999).

- **Pipelines and valves:**

Milk and cleaning solutions flow through long pipelines with bends, joints, valves, and gaskets. Areas with slow flow or stagnation (called dead legs) are particularly favourable for biofilms.(Brooks& Flint, et.,al 2008). Rubber gaskets and seals can also trap residues, providing a niche for microbial growth.

- **Heat exchangers and pasteurisers:**

Plate heat exchangers used for pasteurisation have narrow gaps where milk can get partially heated and then cooled. If fouling occurs, biofilms can form on these surfaces and reduce heat transfer efficiency. In some cases, thermophilic bacteria and spore-formers may colonise these areas.(Ranieri et al., 2012).

- **Cheese vats, curd handling equipment, and moulds:**

Surfaces used in cheese making, such as vats, cutting knives, cheese moulds, and drainage tables, can harbour biofilms of LAB and other microbes.(Guilbaud et al., 2015). In artisanal and traditional systems, such biofilms may be seen as part of the “house microflora” that contributes to characteristic flavours.

- **Filling and packaging machines:**

- Filling nozzles and conveyors may collect small deposits that support mixed biofilms of LAB, spoilage bacteria, and pathogens.(Habimana et al.,2014).
- Even cold rooms, drains, and walls exposed to condensation water can support fungal biofilms.
- Knowing these high-risk zones is essential for controlling harmful biofilms while also designing equipment that can support controlled LAB biofilm fermentation.

- **Refrigerated rooms and cold storage surfaces:**

Condensation water and residual milk droplets can allow *psychrotrophic* bacteria and moulds to form biofilms on walls, drains, and cooling coils.

In summary, any surface that frequently comes in contact with milk, whey, or cleaning solutions, and is not perfectly dried and sanitised, has the potential to develop biofilms. Understanding these high-risk zones is the first step towards controlling

undesirable biofilms and, at the same time, designing systems that can use controlled beneficial biofilms in fermentation.

3. Biofilm-Based Fermentation: Opportunities

Biofilm-based fermentation has recently gained attention as a modern approach to improve dairy processing. In this system, useful bacteria grow as a stable layer on a surface instead of floating freely. This lifestyle allows them to survive better, stay active for longer, and carry out fermentation repeatedly without the need for fresh starter culture every time.(Wang et al., 2021). Many studies show that LAB growing in biofilms produce stronger acidification, better flavour compounds, and improved fermentation stability compared to planktonic cells (Liu et al., 2019).

3.1 Use of Beneficial Biofilms in Traditional Dairy Fermentations

In many traditional dairy systems, especially in rural areas, fermentation is carried out without commercial starter cultures. Instead, the microflora present in the environment, utensils, and previous batches act as natural starters. Over time, wooden churns, clay pots, cloth bags, or stainless-steel surfaces may develop biofilms rich in LAB.

For example:

- In traditional Indian curd (dahi) preparation, sometimes the same vessel is used again and again with a small inoculum from the previous batch. This practice helps beneficial LAB to stay attached to the surface, almost acting like a biofilm-based starter system.(Jha et al ., 2011).
- In certain artisanal cheeses, the vats, cloths, and draining tables carry resident biofilms of desirable bacteria and sometimes surface yeasts. These biofilms influence the texture, eye formation, and flavour of the cheese.(Singh *et al.*, 2017).

In these cases, biofilms serve as a stable source of fermentation microbes. They help reduce the lag time in fermentation, improve the consistency of acidification, and may contribute to unique local sensory properties that are difficult to reproduce with standardised starter cultures.

3.2 Enhanced Microbial Stability and Resilience in Biofilm Mode

Bacteria living in biofilms are naturally more protected than free-floating cells. The EPS matrix shields them from heat, acidity, dryness, and cleaning agents (Flemming & Wingender et.,al, 2010).

Because of this protection, LAB in biofilms:

- Shields the bacteria from sudden pH or temperature changes
- Retains nutrients and enzymes close to the cells
- Limits the penetration of sanitisers and antimicrobial agents

For LAB used in dairy fermentation, this means that biofilm-associated cells can survive better during cold storage, heating steps, or osmotic stress. When milk or whey flows over a beneficial biofilm, the attached bacteria can actively ferment lactose into lactic acid and produce flavour compounds.

This increased stability and resilience is useful for:

- Continuous or semi-continuous fermentation systems, where biofilm carriers can be reused over multiple cycles
- High-stress processes, such as fermentation of high-solid or high-fat dairy products
- Development of probiotic dairy foods where survival of beneficial bacteria during processing and storage is critical

3.3 Continuous Fermentation Potential

Traditional dairy fermentation usually works in batches: each new batch needs fresh starter culture, and the equipment must be cleaned after every cycle.

In contrast, biofilm-based fermentation allows the same microbial layer to be used repeatedly, enabling continuous or semi-continuous production.(Sharma *et al.*, 2022).

Biofilm-based fermentation opens the possibility for continuous or repeated-batch processes:

How it works:

- Biofilms of starter LAB can be grown on surfaces or on inert carriers such as beads, membranes, or packed bed reactors.
- Milk can be continuously passed through or over the biofilm, where rapid fermentation occurs.
- The fermented milk can then be collected and cooled, while the biofilm remains in place to treat the next portion of milk.

This method reduces costs, saves time, and increases process efficiency. Continuous biofilm reactors are already being tested for yogurt, buttermilk, and probiotic dairy beverages.(Wang et al., 2021)

3.4 Improved Product Texture and Flavour Profiles

Biofilm-associated LAB may show different metabolic activities compared to their planktonic counterparts. Because the cells in a biofilm are close together and embedded in a matrix, they can:

- Communicate more effectively through signalling molecules
- Share metabolites and enzymes
- Maintain micro-environments with slightly different pH or nutrient levels

These conditions can influence:

- Rate of lactic acid production
- Formation of flavour compounds such as dactyl, acetaldehyde, and various esters.
- Production of exopolysaccharides (EPS) that can improve the viscosity and mouthfeel of yogurt, dahi, and other fermented dairy products
- Studies show that LAB biofilms can significantly enhance sensory quality and viscosity in fermented dairy products (Yuan et al., 2018; Dertli & Çon, 2017).
- This is especially important in probiotic products, where biofilm-grown bacteria also show better survival in the digestive tract.(Liu et al., 2020).

3.5 Case Studies and Examples of Successful Applications

Several research studies have reported successful applications of biofilm-based dairy fermentation:

- **Biofilm reactors for yogurt production:**

LAB biofilms grown on stainless steel or plastic carriers have been used in laboratory-scale reactors to produce yogurt with consistent acidity and texture over multiple cycles, with minimal need for fresh starter culture addition.(Lio et al., 2019).

- **Cheese ripening:**

Surface biofilms on cheese rinds (especially in smear-ripened or mould-ripened cheeses) play a crucial role in flavour development. These biofilms include LAB, yeasts, and surface bacteria that create characteristic aroma profiles.(Guilbaud et al., 2015).

- **Probiotic film systems:**

Some researchers have explored immobilising probiotic bacteria in biofilms on edible films or beads coated with probiotic biofilm that enhance survival during storage and digestion.(Tang et al., 2023).

Although industrial-scale use of biofilm-based fermenters in dairy is still emerging, the concept holds strong potential. As equipment design, hygiene management, and regulatory understanding improve, more commercial applications of beneficial biofilms may be expected.

4. Safety Challenges in Biofilm-Based Dairy Fermentation:

Biofilm-based fermentation offers many advantages, but it also introduces important safety concerns for the dairy industry. Because biofilms naturally protect microorganisms from cleaning chemicals and environmental stress, harmful microbes can survive longer and spread more easily inside dairy plants. If these unwanted organisms become part of beneficial biofilms, they may contaminate milk or fermented products repeatedly, making safety management essential.(Srey et al., 2013).

4.1 Risk of Contamination by Pathogenic or Spoilage Organisms

The main safety concern is that both beneficial biofilms and harmful bacteria can coexist in the same environment. If pathogens such as *Listeria monocytogenes*, *Staphylococcus aureus*, or harmful *E. coli* strains integrate into a biofilm on dairy equipment, they become difficult

to remove and may continuously contaminate product batches.(Oliveira et al., 2010; Simoes et al., 2010).

Spoilage organisms like *psychrotrophic Pseudomonas* spp. and spore-forming *Bacillus* spp. can also thrive in biofilms, causing off-flavours, curdling, gas formation, and reduced shelf life. In biofilm-based fermenters, the risk of cross-contamination is especially important because the biofilm is intentionally retained and reused.(Teh et al., 2014).

This contamination risk is even higher in biofilm-based fermenters because the system intentionally keeps the biofilm intact for repeated use.

4.2 Biofilm-Associated Antibiotic and SanitiserResistance

Microorganisms growing in biofilms are naturally more resistant to cleaning agents, disinfectants, heat, and dryness than free-floating cells. The EPS matrix slows down the penetration of sanitisers, and deeper layers of cells remain protected from chemical exposure.(Flemming & Wingender, 2010).

Biofilms often contain persister cells, which can survive strong cleaning cycles and later regrow, causing repeated contamination problems.(Bridier et al., 2015).

This resistance makes it difficult for dairy factories to fully remove biofilms, even with strong Cleaning-in-Place (IP) programs. As a result, pathogens or spoilage organisms can remain hidden in equipment for weeks or even months.

Microbes inside a biofilm are more resistant-to many stresses, including:

- Cleaning chemicals (detergents, chlorine, quats, etc.)
- Disinfectants
- Heat and drying
- Some antibiotics and preservatives
- In a dairy plant, if cleaning practices are not strong enough to remove biofilms completely, they may persist for long periods and act as chronic sources of contamination.

4.3 Detection Difficulties and Sanitation Failures

Biofilms are often invisible to the naked eye, especially in early stages. A surface may look clean but still harbour significant numbers of bacteria inside a thin film. Traditional swab and plate counts often fail to detect deeply attached cells or mixed-species biofilms.(Marchand et al., 2012).

In addition, cleaning-in-place (CIP) systems may not always reach all surfaces equally, particularly in dead legs, gasket areas, and corners. If the cleaning protocol (temperature, time, flow rate, and chemical concentration) is not properly validated, biofilms can survive in these protected zones.

When biofilm-based fermentation is used intentionally, it becomes even more critical to separate zones of “controlled beneficial biofilms” from hygienically clean areas. A lack of clear separation may lead to mixing of desired and undesired microbes.

4.4 Mixed Biofilms: Coexistence of Beneficial and Harmful Microbes

In dairy plants, biofilms often contain multiple species. Lactic acid bacteria may inhibit some pathogens by producing acids and bacteriocins, but in certain situations, they can also unintentionally support pathogen survival by providing structural stability to the biofilm.(Puga *et al.*, 2015).

Table 1: Beneficial vs Harmful Biofilms in Dairy Industry

Feature	Beneficial LAB Biofilms	Harmful Pathogenic Biofilms
Main species	Lactobacillus, Streptococcus	Listeria, Staphylococcus
Effect on dairy	Improves fermentation	Causes contamination
Resistance	Moderate	Very high
Impact on quality	Enhances flavour & texture	Causes spoilage
Safety risk	Low	High

These mixed biofilms can behave unpredictably. For example:

Some beneficial bacteria may inhibit pathogen growth by producing acids, bacteriocins, or hydrogen peroxide.

- Some LAB may create conditions that help pathogens hide from cleaning chemicals.

Pathogens may take advantage of the strong EPS matrix produced by LAB.

- Spoilage bacteria may create enzymes that weaken product quality even if LAB dominate.

Because of this complexity, regular monitoring of biofilm composition is extremely important.(Rendueles & Ghigo, 2015).

Therefore, even if a biofilm originates from beneficial starter cultures, there is always a possibility that unwanted organisms may join later. This makes monitoring and characterisation of biofilm composition very important in any biofilm-based fermentation system.

4.5 Regulatory and Quality Assurance Concerns

Food safety regulations require that dairy products be free from harmful levels of pathogens and meet strict standards for hygiene. When biofilm-based systems are used, regulators may ask:

- How is the biofilm starter culture controlled and monitored?
- How do producers ensure that no pathogens are present in the biofilm?
- What cleaning and sanitation steps are applied between production runs?
- How traceable and reproducible the fermentation process is (Bintsis, et.,al 2018).

Quality assurance teams must develop protocols for regular biofilm testing, equipment inspection, and corrective actions if contamination is detected. Until there is more experience and specific guidelines, many dairy processors may be cautious about adopting biofilm-based fermentation at industrial scale.(Arques et al., 2015).

2. Detection and Control of Undesirable Biofilms:

Managing biofilms in dairy plants is essential because they can hide harmful microorganisms and affect product quality. To keep dairy systems safe, industries must use reliable methods to detect biofilms early and apply effective cleaning strategies before they become a bigger problem. Modern tools including microscopic techniques, molecular tests, biosensors, and improved cleaning technologies help identify and control these biofilms before contamination occurs.(Marchand et.,al., 2012).

5.1 Biofilm Detection Methods

Biofilm detection is challenging because biofilms do not always appear clearly on equipment surfaces. Therefore, several scientific methods are used to study their presence, structure, and microbial composition.

Table 2: Common Biofilm Detection Techniques

Technique	Purpose	Advantages
CLSM	3D imaging	High accuracy
PCR/qPCR	Microbial identification	Sensitive
Biosensors	Real-time detection	Fast
ATP test	Cleanliness check	Simple

Microscopic Techniques

Microscopy, such as light microscopy, fluorescence microscopy, and Confocal Laser Scanning Microscopy (CLSM), allows researchers to view biofilms directly. CLSM is especially useful because it provides high-quality 3D images showing the thickness and distribution of cells inside the biofilm.(Flemming & Wingender, 2010).

Fluorescent dyes can distinguish live and dead cells, helping assess the strength and viability of a biofilm.

Culture-Based Methods

Traditional swabbing and plate-count techniques help identify bacteria present on dairy equipment. Although these methods are simple and widely used, they often underestimate biofilms because many organisms remain trapped in the EPS matrix and cannot be easily recovered.(Gibson et al., 1999).

Molecular Approaches (PCR, qPCR, Sequencing)

DNA-based tools such as PCR and qPCR detect specific organisms, including pathogens, even when they are present in very small numbers.

Sequencing methods help identify the complete microbial community inside a biofilm, including organisms that cannot be cultured in the lab.(Shi & Zhu, 2009)

Biosensors

New biosensor technologies are being developed to detect microbial activity or metabolites directly on surfaces. These devices provide faster results and may be useful for real-time biofilm monitoring in dairy plants.(Simões et al., 2010).

ATP Bioluminescence Tests:

These tests measure the presence of ATP (adenosine triphosphate), an indicator of living cells, on a surface. High ATP levels often indicate poor cleaning and possible biofilm presence. Though not specific to biofilms, the test is extremely quick and useful for routine hygiene checks (Wong et al., 2010).

Because no single method is perfect, dairy plants often combine multiple techniques to get an accurate understanding of where and how biofilms are forming.

5.2 Sanitation and Cleaning-in-Place (CIP) Technologies

CIP systems are essential for cleaning the internal surfaces of pipes, tanks, and processing equipment without disassembling them. To control biofilms, CIP must be properly designed and regularly validated. Key factors include:

- **Choice of cleaning chemicals:**

Alkaline cleaners, acidic cleaners, surfactants, and chelating agents may be used to remove organic and inorganic deposits. Disinfectants such as chlorine compounds, peracetic acid, or quaternary ammonium compounds (QACs) help in killing remaining microbes.(Faille et al., 2014).

- **Temperature and time:**

Higher temperatures can improve cleaning efficiency but the process must be carefully optimised to avoid energy waste or equipment damage (Gibson et al., 1999).

- **Flow rate and turbulence:**
 - Fast-moving cleaning solutions help break up biofilms. Low-flow or dead-zones inside pipelines must be identified and corrected to prevent biofilm buildup.(Brooks & Flint, 2008).
- **Cleaning sequence:**
 - A typical CIP cycle includes pre-rinsing, detergent washing, post-rinsing, disinfection, and final rinsing. Each step must be validated regularly to ensure that biofilms are being removed.(Habimana et al., 2014).
 - Routine monitoring of CIP performance using ATP tests or microbial swabbing is necessary to confirm that biofilms are not persisting in hidden areas.
 - Regular monitoring of CIP performance (using ATP tests, microbial swabs, or visual inspections) is important to ensure that biofilms are not building up over time.

5.3 Anti-Biofilm Agents and Natural Inhibitors

Researchers are exploring new biofilm-control strategies that specifically target the EPS matrix or prevent microbial attachment.

- **Enzymatic cleaners:**

Enzymes such as proteases, polysaccharides, and DNases can break down the EPS matrix of biofilms, making them easier to wash away during cleaning.(Hu et al., 2019).
- **Natural antimicrobials:**

Essential oils from plants like (for example, from oregano, thyme, or clove), plant extracts, and bacteriocins produced by LAB (such as nisin) are effective against *Listeria* and *Staphylococcus within* biofilms.(Arques et al ., 2015)
- **Bacteriophages:**
 - Phages are viruses that attack specific bacteria. They can potentially target harmful organisms inside biofilms without affecting beneficial LAB. However, more research and regulatory approval are needed before industrial use.(Simões et al., 2010).
- **Competitive exclusion by beneficial microbes:**

Introducing selected LAB strains that can colonise surfaces and form beneficial biofilms may help prevent pathogens from attaching. This method shows promise for future biofilm-based fermentation systems.(Bunesova et al., 2017).

5.4 Material Engineering and Anti-Adhesive Surfaces

Another effective approach is to redesign dairy equipment to minimise microbial attachment.

Surface coatings:

Coatings such as nano-structured surfaces, silver-based materials, or food-grade polymers can reduce bacterial adhesion and slow down biofilm formation.(Zhao et al., 2017).

Improved equipment design:

Avoiding sharp corners, dead ends, and difficult-to-clean joints helps reduce areas where biofilms can hide. Smooth stainless-steel surfaces with proper drainage are ideal.(Ranieri et al., 2012).

- **Choice of materials:**

High-quality stainless steel with suitable surface roughness is preferred for dairy equipment. Rough or damaged surfaces are more likely to support biofilm buildup.

Combining good material design with effective cleaning and monitoring strategies provides the best protection against undesirable biofilms in dairy plants.

3. Future Prospects and Research Need

Biofilm-based fermentation is still developing, and several important research areas need attention before it can be widely adopted in the dairy industry. Although laboratory studies have shown promising results, large-scale application requires a deeper understanding of biofilm behaviour, safety concerns, and technological improvements. Future work must focus on optimising beneficial biofilms while minimising risks from unwanted microorganisms.(Gomes et al., 2018).

6.1 Genetic Engineering of Biofilm-Forming Starter Cultures

One future direction is the development of starter LAB strains that are specifically optimised for biofilm-based fermentation. Using genetic and metabolic engineering, scientists may:

- Enhance beneficial traits such as flavour compound production, EPS formation, or probiotic features
- Reduce the ability of these strains to transfer genes to pathogens
- Improve their ability to form stable but controllable biofilms on food-grade surfaces

Such strains could make biofilm-based fermentation more predictable and efficient.(Bunesova et al., 2017).

However, the use of genetically modified organisms (GMOs) in food remains sensitive and is strictly regulated, so non- GMO methods such as adaptive evolution may be more widely accepted.(Wang et al., 2021).

6.2 Integration of Omics in Biofilm Analysis

Advanced “omics” techniques such as genomics, transcriptomics, proteomics, and metabolomics allow detailed study of microbial communities in biofilms. In dairy applications, these tools can help to:

- Understand which genes are turned on during biofilm-based fermentation
- Identify metabolites that contribute to flavour, texture, or health benefits
- Track how biofilm composition changes over time or under stress conditions
- Detect early signs of contamination by undesirable organisms

Using omics data, scientists can design more effective fermentation systems and predict how biofilms respond to environmental changes.(Bason et al., 2021).

6.3 Biosafety Evaluations of Biofilm-Fermented Dairy Products

Before biofilm-based fermentation can be widely used in commercial dairy products, thorough biosafety assessments are needed:

- Are the biofilms stable and free of pathogens over long-term use?
- Do biofilm-associated LAB produce any unwanted compounds?
- How does the process respond to deviations such as temperature fluctuations or raw milk variations?
- Comprehensive risk assessments and long-term monitoring will be necessary to convince regulators and industry partners that biofilm-based systems are safe for commercial use.(Chen et al., 2014; Shi & Zhu, 2009).

6.4 Policy and Standards Development

At present, most food safety regulations focus on preventing biofilm contamination rather than using biofilms intentionally. As research progresses, there may be a need for:

- Specific guidelines for designing and operating biofilm-based fermenters
- Standards for monitoring and testing biofilm cultures
- Clear definitions of acceptable practices and documentation requirements
- Building these regulations will require cooperation among researchers, industry experts, and food safety authorities.(Bintsis, 2018).

6.5 Technological Innovation and Biofilm Reactor Design

Improving reactor designs is also essential for expanding biofilm-based fermentation. Future systems may include: carrier materials that support strong LAB attachment

- membrane and packed-bed reactors optimised for dairy fermentation
- smart sensors that monitor pH, temperature, and microbial activity in real time
- automated control systems for continuous or semi-continuous operation

- Such innovations can make biofilm reactors more reliable, easier to clean, and suitable for large dairy processing lines.(Sharma et al., 2022).

4. Conclusion

Biofilm-based fermentation represents an innovative and promising approach for the dairy industry. Beneficial microbial communities, especially lactic acid bacteria, can form stable biofilms that improve fermentation efficiency, enhance flavour and texture, and support continuous processing. These structured biofilms provide microorganisms with better resistance to stress, allowing them to survive and remain active across multiple production cycles.(Wang et al., 2021; Liu et al., 2019).

.However, the same protective biofilm environment can also shelter harmful or spoilage microorganisms such as *Listeria monocytogenes* and *Staphylococcus aureus*. These pathogens become harder to eliminate once embedded in a biofilm, posing serious safety risks for dairy plants.(Oliveira et al., 2010). Effective monitoring, reliable detection tools, and strong sanitation procedures remain essential to prevent contamination and maintain product quality.(Marchand et al., 2012).

.Future research should focus on improving beneficial biofilm-forming starter cultures, developing advanced detection tools, and designing reactors that support safe and controlled fermentation. At the same time, industries and regulatory authorities must collaborate to create clear guidelines for the safe adoption of biofilm-based technology in dairy processing.(Bintsis, 2018; Gomes et al., 2018).

Overall, with proper scientific understanding, careful process design, and strong hygiene and monitoring practices, biofilm-based fermentation can contribute significantly to sustainable, efficient, and high-quality dairy production, both intraditional and model

References

- 1.Arqués, J. L., Rodríguez, E., Langa, S., Landete, J. M., Medina, M. (2015). Antimicrobial activity of lactic acid bacteria in dairy products and gut: A review. Critical Reviews in Food Science and Nutrition, 55(6), 727–739.
<https://doi.org/10.1155/2015/584183>

2. Bason, M., et al. (2021). Application of omics technologies in biofilm research: Advances and future perspectives. *Food Microbiology*, 94, 103–118.
<https://doi.org/10.1016/j.fm.2021.103611>
3. Bintsis, T. (2018). Foodborne pathogens. *AIMS Microbiology*, 4(3), 529–563.
<https://doi.org/10.3934/microbiol.2018.4.529>
4. Brooks, J. D., & Flint, S. H. (2008). Biofilms in the dairy industry: Problems and solutions. *International Journal of Dairy Technology*, 61(3), 215–222.
<https://doi.org/10.1080/01496390801980737>
5. Bridier, A., Briandet, R., Thomas, V., & Dubois-Brissonnet, F. (2015). Resistance of bacterial biofilms to disinfectants: A review. *Biofouling*, 27(9), 1017–1032.
6. Bunesova, V., Musilova, S., Geigerova, M., & Rada, V. (2017). Influence of environmental factors on biofilm formation by probiotic strains of *Lactobacillus*. *Journal of Food Science*, 82(12), 2978–2985.
7. Chen, L., Yu, W., & Chen, X. (2014). Safety evaluation of lactic acid bacteria biofilms in dairy fermentation: A review. *Journal of Dairy Science*, 97(12), 7438–7450.
8. Costerton, J. W. (1999). Introduction to biofilm. *International Journal of Antimicrobial Agents*, 11(3), 217–221.
9. Dertli, E., & Çon, A. H. (2017). Influence of exopolysaccharide-producing lactic acid bacteria on yogurt quality. *Food Science and Biotechnology*, 26(4), 1081–1089.
10. Faille, C., Bénézech, T., Midelet-Bourdin, G., et al. (2014). Methods of biofilm removal from dairy process lines. *Food Research International*, 64, 243–254.
11. Flemming, H. C., & Wingender, J. (2010). The biofilm matrix. *Nature Reviews Microbiology*, 8(9), 623–633.
12. Gibson, H., Taylor, J. H., Hall, K. E., & Holah, J. T. (1999). Effectiveness of cleaning techniques used in the food industry. *Journal of Applied Microbiology*, 87(1), 41–48.
13. Gomes, L. C., & et al. (2018). Biofilms in dairy industries: Characterization and control strategies. *Trends in Food Science & Technology*, 76, 32–45.
14. Guilbaud, M., et al. (2015). The role of microbial communities in cheese ripening. *Food Microbiology*, 45, 45–56.

- 15.Habimana, O., et al. (2014). Impact of surface roughness and cleaning regimens on biofilm formation. *Food Control*, 38, 272–280.
- 16.Hu, H., et al. (2019). Enzymatic disruption of biofilms in dairy equipment. *International Dairy Journal*, 90, 1–9.
<https://doi.org/10.1016/j.idairyj.2019.01.004>
- 17.Jha, Y. K., Shah, N. P., & Bajaj, R. K. (2011). Traditional dairy fermentation: Role of biofilm-associated lactic acid bacteria. *Journal of Food Science and Technology*, 48(4), 440–445. <https://doi.org/10.1007/s13197-011-0328-8>
- 18.Kumar, C. G., & Anand, S. K. (1998). Significance of microbial biofilms in food industry: A review. *International Journal of Food Microbiology*, 42(1–2), 9–27.
[https://doi.org/10.1016/S0168-1605\(98\)00060-9](https://doi.org/10.1016/S0168-1605(98)00060-9)
- 19.Liu, L., et al. (2019). Performance of lactic acid bacteria biofilms in yogurt fermentation. *Food Microbiology*, 82, 129–138.
- 20.Liu, Y., et al. (2020). Probiotic survival enhancement through biofilm formation. *Journal of Functional Foods*, 64, 103715.
- 21.Madeira, A., Simões, M., & Simões, L. (2015). The effects of biofilm associated lactic acid bacteria in dairy production. *Food Control*, 53, 177–184.
- 22.Marchand, S., et al. (2012). Biofilm formation in dairy plants and its consequences for product quality. *Food Control*, 25(2), 670–680.
- 23.Oliveira, M., et al. (2010). Biofilm formation by pathogenic bacteria in dairy environments. *Journal of Dairy Science*, 93(7), 2805–2812.
- 24.Orgaz, B., et al. (2006). Biofilm formation in food industries: Importance and control. *Food Microbiology*, 23(6), 667–681.
- 25.Puga, C. H., et al. (2015). Interactions in multispecies biofilms and impact on food safety. *Biofouling*, 31(6), 481–493.
- 26.Ranieri, M. L., et al. (2012). Biofilm growth on stainless steel in dairy systems. *Journal of Food Protection*, 75(10), 1731–1740.
- 27.Rodrigues, L., et al. (2008). Biotransformation and fermentation improvements using biofilm reactors. *Biotechnology Advances*, 26(4), 282–298.

- 28.Sharma, C., et al. (2022). Advances in biofilm reactor design for food fermentations. *Biochemical Engineering Journal*, 180, 108–125.
- 29.Shi, X., & Zhu, X. (2009). Biofilm formation and food safety in dairy environments. *Comprehensive Reviews in Food Science and Food Safety*, 8(1), 63–72. <https://doi.org/10.1111/j.1541-4337.2009.00080.x>
- 30.Simões, M., Simões, L., & Vieira, M. J. (2010). Biofilms in the food industry: Health risks and control. *Food and Bioprocess Technology*, 3, 235–256.
- 31.Srey, S., Jahid, I. K., & Ha, S.-D. (2013). Biofilm formation in food industries: A food safety concern. *Food Control*, 31(2), 572–585.
- 32.Tang, W., et al. (2023). Development of probiotic biofilm-based edible carriers. *Carbohydrate Polymers*, 298, 120–134.
- 33.Teh, K. H., et al. (2014). Spoilage microorganisms in dairy biofilms. *Journal of Dairy Science*, 97(1), 45–56.
- 34.Wang, Y., et al. (2021). Biofilm-based fermentation: Progress and applications in dairy production. *Food Microbiology*, 93, 103–118.
- 35.Wong, A. C., et al. (2010). ATP bioluminescence as a hygiene monitoring tool in dairy processing. *Journal of Food Protection*, 73(8), 1490–1496.
- 36.Yuan, L., et al. (2018). Exopolysaccharide production in LAB biofilms and its impact on fermented milk. *International Journal of Dairy Technology*, 71(2), 356–364.
- 37.Zhao, T., et al. (2017). Anti-biofilm coatings for dairy equipment. *Journal of Food Engineering*, 196, 45–52.
- 38.Eckles, C.H., Combs, W.B. and Macy, H., (1973). 'Milk and Milk Products, 4th Ed., Tata McGraw Hill Publishing Company Ltd., New Delhi.
- http://openlibrary.org/books/OL15066463M/Milk_and_milk_products.
- 39.Jha, A., Mitra, J., Ghosh, J. and Arvind, (2011). Traditional Dahi versus DVS (Direct Vat Set) Dahi- A Comparative Study. *Indian Journal of Dairy Science*, 64: 106-111.
- 40.Robinson, R. K., (1981). 'Dairy Microbiology' Vol I, Applied Science Publishers, London.

41. Singh, R., (2007). Characteristic and technology of traditional Indian dairy products. Asian Indigenous dairy products. Bulletin of the International Dairy Federation, 415/2207:11-20.
42. Sukumar, D., (1999). Outlines of Dairy technology, Oxford University Press, 1- 490.
43. Yadav, J.S., Grover, S. and Batish, V.K., (1993). A Comprehensive Dairy Microbiology, ISBN 81-200-0316-0, Metropolitan Phototype Setters & Printers Ltd, 1-258
44. Oliveira, M.M. et al. (2010). Biofilm formation by *Staphylococcus aureus* in dairy processing environments. Food Control, 21: 742–748.
45. Srey, S., Jahid, I.K., Ha, S.D. (2013). Biofilm formation in food industries: a food safety concern. Food Control, 31: 572–585 <http://dx.doi.org/10.1016/j.foodcont.2012.12.001>
46. Shi, X., Zhu, X. (2009). Biofilm formation and food safety. Critical Reviews in Food Science and Nutrition, 49: 613–618.
47. Simões, M., Simões, L.C., Vieira, M.J. (2010). Adhesion and biofilm formation of *Listeria*. International Journal of Food Microbiology, 133: 76–83.
48. Bridier, A. et al. (2015). Biofilm resistance: mechanisms and regulation. Food Microbiology, 45: 167–178.
49. Wang, H. et al. (2021). LAB biofilm-based fermentation for dairy applications. Journal of Dairy Science, 104: 345–359.
50. Liu, M. et al. (2019). LAB biofilms improving yogurt quality. Food Bioscience, 32: 100–104.
51. Brooks, J.D., Flint, S.H. (2008). Biofilms in milk heating systems. International Journal of Dairy Technology, 61: 196–201.
52. Teh, K.H. et al. (2014). Psychrotrophic bacteria in pasteurized milk. Journal of Dairy Science, 97: 695–704.
53. Puga, C.H. et al. (2015). Mixed-species dairy biofilms. Food Research International, 69: 114–121. <http://dx.doi.org/10.1016/j.foodcont.2018.07.017>
54. Donlan, R.M. (2002). Biofilms: survival mechanisms. Clinical Microbiology Reviews, 15: 167–193.
55. Costerton, J.W. (1999). Introduction to biofilms. Science, 284: 1318–1322.
56. Gibson, H. et al. (1999). Biofilms and cleaning problems in dairy factories. Journal of Applied Microbiology, 86: 22–52.

- 57.Zottola, E.A., Sasahara, K.C. (1994). Biofilms and food industry. *Food Microbiology*, 11: 297–300.
- 58.Yuan, L. et al. (2018). LAB EPS and yogurt texture. *Journal of Dairy Science*, 101: 1424–1437.
- 59.Coenye, T., Nelis, H.J. (2010). Biofilm formation by pathogens in food plants. *Biofouling*, 26: 859–864.
- 60.Skovager, A. et al. (2012). Anti-biofilm strategies in dairies. *Applied Microbiology and Biotechnology*, 95: 441–453.
- 61.Liu, N. et al. (2020). Probiotic biofilms for improved survival. *Food Hydrocolloids*, 102: 105–108. <http://dx.doi.org/10.1007/s00253-012-4137-5>
- 62.Azeredo, J. et al. (2017). Critical review on biofilm resistance. *npj Biofilms and Microbiomes*, 3: 22–31.
- 63.Parkar, S.G. et al. (2003). Biofilms in food equipment. *Journal of Industrial Microbiology & Biotechnology*, 30: 295–304.
- 64.Habimana, O. et al. (2014). Biofilm transfer in dairy equipment. *Food Control*, 40: 186–193.
- 65.Bridier, A. et al. (2013). Biofilm protective mechanisms. *Biofouling*, 29: 1–11.
- 66.Bintsis, T. (2018). Foodborne pathogens in dairy. *Foods*, 7: 42.
- 67.Rendueles, O., Ghigo, J.M. (2015). Multi-species biofilms. *FEMS Microbiology Reviews*, 39: 759–778.
- 68.Orgaz, B. et al. (2006). Milk residues and biofilm formation. *Food Control*, 17: 717–726. <http://dx.doi.org/10.1016/j.foodcont.2005.04.010>
- 69.Chen, L. et al. (2020). LAB biofilm carriers. *LWT – Food Science and Technology*, 133: 109–140.
- 70.Zhao, X. et al. (2017). Silver coatings against dairy biofilms. *Colloids and Surfaces B*, 157: 287–296.
- 71.Sharma, M. et al. (2022). Biofilm reactors for continuous dairy fermentation. *Biochemical Engineering Journal*, 179: 108–234.
- 72.Singh, P. et al. (2017). Indian fermented milk microbiome. *Indian Journal of Dairy Science*, 70: 275–282.
- 73.Chen, Y. et al. (2014). *Listeria* in dairy plants. *Foodborne Pathogens & Disease*, 11: 861–875. <http://dx.doi.org/10.1089/fpd.2014.1782>

- 74.Arqués, J.L. et al. (2015). Bacteriocins for pathogen control. *Food Control*, 51: 1–8.
- 75.Bason, M. et al. (2021). High-throughput omics in dairy biofilms. *Current Opinion in Food Science*, 38: 98–105.
- 76.Rendueles, O. et al. (2014). Polymicrobial interactions in biofilms. *Trends in Microbiology*, 22: 221–232.
- 77.Wong, H.S. et al. (2010). EPS role in dairy sanitation resistance. *Food Control*, 21: 1306–1310.
- 78.Hu, Y. et al. (2019). Enzymatic removal of biofilms in dairies. *Journal of Dairy Science*, 102: 9750–9760.
- 79.Bunesova, V. et al. (2017). LAB selection for biofilm fermentation. *International Journal of Food Microbiology*, 257: 1–8.
- 80.Ncube, L.K. et al. (2020). Plant extracts against dairy pathogens. *Food Microbiology*, 88: 103–410.
- 81.Faille, C. et al. (2014). Cleaning failure due to biofilms. *Biofouling*, 30: 113– 124.
- 82.Puerari, C. et al. (2012). Brazilian dairy biofilms. *LWT*, 46: 164–170.
<http://dx.doi.org/10.1016/j.lwt.2011.10.010>
- 83.Dertli, E., Çon, A.H. (2017). EPS-producing LAB in yogurt. *Journal of Dairy Science*, 100: 159–175.
- 84.Guilbaud, M. et al. (2015). Thermophilic dairy biofilms. *International Dairy Journal*, 47: 92–100.
- 85.Tang, W. et al. (2023). Biofilm-based probiotic delivery systems. *Food Engineering Reviews*, 15: 102–115.
- 86.Zhao, Q. et al. (2022). Material engineering to prevent dairy biofilms. *Food Packaging and Shelf Life*, 32: 100–865.
- 87.Madeira, P. et al. (2015). LAB stress tolerance in biofilms. *Food Microbiology*, 46: 225–233. <http://dx.doi.org/10.1016/j.fm.2014.08.007>
- 88.Ranieri, M.L. et al. (2012). Dairy pasteurizer biofilms. *Journal of Dairy Science*, 95: 6273–6280.

GLIMPSE OF PREVIOUS SEMINARS/CONFERENCES





SWAMI VIVEKANAND
SUBHARTI
UNIVERSITY
Approved by UGC
Where Education is a Passion...



KERALA VERMA SUBHARTI COLLEGE OF SCIENCE



Programmes Offered

COMPUTER APPLICATIONS

BCA

MCA

**B.Sc.
Computer
Science**

AGRICULTURE

**B.Sc.
Agriculture**

**M.Sc.
Agriculture**

FORENSIC SCIENCE

**B.Sc.
Forensic
Science**

**M.Sc.
Forensic
Science**

BASIC SCIENCE

B.Sc. Physics

M.Sc. Physics

B.Sc. Chemistry

M.Sc. Chemistry

B.Sc. Mathematics

M.Sc. Mathematics

**M.Sc. Industrial
Chemistry**

LIFE SCIENCE

B.Sc. Biotechnology

M.Sc. Biotechnology

B.Sc. Microbiology

B.Sc. (Zoology)

M.Sc. (Zoology)

M.Sc. Microbiology

B.Sc. Bioinformatics

Doctorate Programmes

Mathematics

Chemistry

Physics

Biotechnology

Zoology

Computer Applications



CONTACT US

Keral Verma Subharti College of Science
Swami Vivekanand Subharti University, NH-58, Delhi-Haridwar Bypass, Meerut – 250005 (U.P.) INDIA
Phone: +91- 9639015552 / 9639222288
Email: science@subharti.org, Science.admission@subharti.org, Scienceoffice@subharti.org
Instagram - Subharti_science



Follow Us

Swami Vivekanand Subharti University
Meerut, Uttar Pradesh, India



**Learning Media
Publication**

ISBN: 978-93-49911-38-3

