

Frontiers of Multidisciplinary Studies for Global Sustainability



Mrs. Diana Agnes

Dr. Anu Baisel

Dr. A. Allwyn Sundarraj

Dr. C.S. Sundar Ganesh



SRR
Publicizing Research

ISBN 978-819934027-5



Frontiers of Multidisciplinary Studies for Global Sustainability

November 2025

Mrs. DIANA AGNES

Research Scholar
School of Social Sciences and Languages
Vellore Institute of Technology (VIT), Vellore

Dr. ANU BAISEL

Assistant Director
Career Development Centre (C.D.C)
Vellore Institute of Technology (VIT), Vellore

Dr. A. ALLWYN SUNDARRAJ

Associate Professor
Department of Food Technology
JCT College of Engineering and Technology
Coimbatore

Dr. C.S. SUNDAR GANESH

Assistant Professor
Department of Electrical & Electronics Engineering
Karpagam College of Engineering, Coimbatore

November 2025

ISBN: 978-81-993402-7-5



© Copyrights reserved by Authors and Publishers

Despite our best efforts, there is still a risk that some errors and omissions might occur unintentionally.

Without the prior consent of the authors and publishers, no part of this publication may be duplicated in any form or by any means, whether electronically, by photocopying, or otherwise.

The opinions and findings expressed in the individual chapters are those of the authors and the book's editors, not the publishers.

Cover page images attributed from www.freepik.com, www.vecteezy.com.

Published By



SCIENTIFIC RESEARCH REPORTS
(A Book Publisher, approved by Govt. of India)

I Floor, S S Nagar, Chennai - 600 087,
Tamil Nadu, India.

editors@srrbooks.in, contact@srrbooks.in
www.srrbooks.in

PREFACE

The pursuit of global sustainability demands a holistic approach—one that unites science, technology, innovation, and human understanding. **Frontiers of Multidisciplinary Studies for Global Sustainability** brings together diverse fields and emerging ideas that collectively contribute to shaping a more responsible, efficient, and sustainable future. This volume represents an integrated exploration of concepts that span consumer behavior, materials science, digital innovation, renewable energy, and biomedical research—each chapter reflecting a unique dimension of interdisciplinary progress.

At the core of this compilation lies an exploration of how evolving consumer patterns and strategic organizational responses are redefining modern business ecosystems. Understanding human behavior in the context of technology and sustainability provides valuable insights into how industries can adapt to global challenges. Simultaneously, advancements in smart technologies, such as the Internet of Things (IoT) and cognitive radio networks, highlight how intelligent connectivity can enhance efficiency, optimize resources, and support a circular economy.

Scientific innovation in materials and nanotechnology offers another critical perspective in this collection. Studies on nanocomposites, biopolymer films, and ionic liquids illustrate how sustainable materials can transform industrial applications—from mobility aids to eco-friendly packaging and energy storage solutions. These innovations not only reduce environmental footprints but also open pathways for circular and renewable systems that align with sustainable development goals. In the biomedical domain, the exploration of novel molecular frameworks for therapeutic applications showcases the deep connection between chemistry, biology, and healthcare. The

development of hybrid compounds and bioactive materials represents a step toward addressing global health issues through innovative and sustainable scientific methods.

Finally, the transition toward renewable energy and green transportation stands as a vital pillar of sustainability. The integration of solar-powered solutions and advanced charging systems for electric vehicles emphasizes the ongoing transformation of energy infrastructures. Together, the studies in this volume exemplify the strength of multidisciplinary collaboration—where science and society converge to pioneer sustainable solutions for future generations. We would like to extend our sincere thanks to our publisher, **Scientific Research Reports, Chennai, India**, for their dedicated efforts in preparing this book, which provides enriched content.

Wishes and Regards,

Mrs. DIANA AGNES

School of Social Sciences and Languages
Vellore Institute of Technology (VIT), Vellore

Dr. ANU BAISEL

Career Development Centre (C.D.C)
Vellore Institute of Technology (VIT), Vellore

Dr. A. ALLWYN SUNDARRAJ

Department of Food Technology
JCT College of Engineering and Technology, Coimbatore

Dr. C.S. SUNDAR GANESH

Department of Electrical & Electronics Engineering
Karpagam College of Engineering, Coimbatore

CONTENTS

Chapter No	Chapter Titles	Page No
1	Emerging Trends in Consumer Behaviour and Their Impact on Organizational Strategy P. Vinodhini, R. Priyadharshini	1-8
2	Mechanical and Thermal Evaluation of Nanocomposite Coatings for Wheelchair Components S. Baskar, M. Sivaram Krishnan, V. Sivakumar, S. Surendar, K. Gopalakrishnan	9-20
3	Internet of Things (IoT) Applications in Resource Efficiency and Circular Economy V. Vardhini	21-31
4	Goodput Aware Load Distribution for Real-Time Traffic over Multipath Networks Using Spectrum Sensing in Cognitive Radio M. Monisha, P. Vijayalakshmi, M. Meena, B. Sahaai Madona	32-41
5	Eggplant Peel Extract Reinforced Chitosan Composite Films for Food Packaging Application Sanuja S., Sowmya S., Kowsalya J.	42-55
6	Versatile Ionic Liquids: Bridging Biomass Dissolution and Battery Material Innovation Sowmya S., Sanuja S.	56-70

Chapter No	Chapter Titles	Page No
7	Biological Applications of Pyrazole Hybrids in New Anti-Cancer Drug Designing Uttam B. Chougale, Pravin R. Kharade, Ankush G. Thate, Nilesh V. Junghare, Kiran N. Patil, Hemant V. Chavan	71-83
8	Grid Integrity Based Advanced Solar Charging Solution for Electric Vehicles Poonguzhali S., A. Sivasangari, S. Lalithakumari	84-95

Chapter 1

Emerging Trends in Consumer Behaviour and Their Impact on Organizational Strategy

P. Vinodhini ^a, R.Priyadharshini ^b

^a Assistant Professor, Department of Management Studies, Vels Institute of Science, Technology & Advanced Studies, Chennai

^b Assistant Professor, Department of Management Studies, Vels Institute of Science, Technology & Advanced Studies, Chennai

Abstract

In recent years, consumer behaviour and expectations have evolved at an unprecedented pace, driven by digital technologies, rising sustainability awareness, omni-channel experiences and global disruptions such as the COVID 19 pandemic. For organisations and management practitioners, understanding these evolving consumer trends is critical to strategy formulation, marketing, operations and customer relationship management. This paper examines recent trends in consumer behaviour from a management perspective, reviews the relevant literature, analyses impacts of these trends on management practices and provides concluding reflections. Key trends include the rise of online and mobile commerce, social & sharing commerce, sustainability driven consumption, personalised consumer experiences and value seeking behaviour. The paper suggests implications for managers and discusses how these trends affect organizational structures, marketing, and supply chain strategies. A review of literature outlines theoretical frameworks, methodological approaches and gaps for future research. The paper concludes that management must evolve toward agile, consumer

centric, and digitally enabled models to respond effectively to current consumer dynamics.

Keywords: Consumer Behaviour, Digital Technologies, Omni-channel Experience COVID-19 Impact, Online Commerce, Mobile Commerce.

1. Introduction

Consumer behaviour, how individuals and groups select, purchase, use, and dispose of goods and services, has always been central to marketing and management theory. Globalization, heightened awareness of sustainability and ethics, shifting values among younger generations, and external shocks (such as the COVID 19 pandemic) are some of the factors that are accelerating the rate of change in the modern era. These forces are reshaping consumer expectations, preferences and shopping modalities, thereby challenging traditional management practices.

Product development, distribution, supply chain design, marketing communications, customer relationship management (CRM), pricing strategies, and even organizational culture are all affected by consumer trends, which are important from a management perspective. When consumers demand more customisation, faster delivery, greater transparency or sustainability, firms must adapt their operational and strategic models. This paper explores recent consumer trends, their implications for management, and reviews scholarly literature in the field. The goals are:

1. To identify and discuss major recent consumer trends relevant to management;
2. To analyse how these trends affect management practices across marketing, operations, supply chain, strategy and human resources;

3. To examine the existing academic literature on these trends, including gaps, frameworks, and findings;
4. To draw conclusions and managerial implications.

2. Recent Trends in Consumer Behaviour and Management Implications

Below are key recent consumer trends with management implications.

2.1 Digital & Omni Channel Consumption

Customers increasingly expect seamless experiences, use multiple channels (online, mobile, and in-store), and frequently act mobile first. For example, e-commerce has grown rapidly from 2010 to 2023, driven by mobile devices and digital payment systems.

2.2 Management implications

- Firms must adopt omni channel strategies, integrating physical and digital touchpoints.
- Investment in digital infrastructure, mobile apps, website UX, logistics and fulfillment is critical.
- Marketing must adapt to multi- channel consumer journeys, handle channel attribution, manage digital analytics.

3. Personalisation, Social & Sharing Commerce

Personalised recommendations, social commerce (shopping via social media) and sharing commerce (peer to peer platforms) are becoming dominant. For example, research links e commerce, customer engagement, big data and omnichannel retail.

3.1 Management implications

- Utilization of AI, big data analytics, and machine learning for recommendation engines and consumer profiling
- Marketing communications become more interactive, socially oriented, user generated content and influencer marketing.
- Business models may shift toward platform ecosystems and peer to peer or sharing models.

4. Sustainability, Ethical Consumption & Value-seeking Behaviour

Consumers increasingly expect brands to act responsibly (environmental, social, governance). The trend of sustainable consumption shows growing attention beyond just the environmental dimension to social and economic aspects. Additionally, value seeking behaviour has grown (especially in inflationary times).

4.1 Management implications

- Firms must embed sustainability into product design, sourcing, packaging, supply chain.
- Marketing must emphasise authenticity, transparency and brand purpose.
- In markets where prices are important, pricing strategies and value propositions become more important.

5. Experience Driven and Consumer Centric Approach

Consumers are looking for experiences, co-creation, brand intimacy, and community. The review on consumer engagement pointed to brand interactivity and consumer involvement as key antecedents.

5.1 Management implications

- Shift from product centric to experience centric management: service design, brand communities, loyalty programs.
- Customer relationship management becomes more dynamic, with feedback loops, social listening, consumer participation.
- Organisational culture and structure may need to be more agile, cross functional and empowered for consumer responsiveness.

6. Rapid Response, Agile Supply-Chain & Personalised Fulfilment

With changing consumer expectations (faster delivery, customisation), firms must adapt their supply chain and operations. The concept of “agile retail” emphasises rapid turnaround, lean inventories and responsiveness to consumer trend shifts.

6.1 Management implications

- Supply chain strategy: shorter lead times, local sourcing, flexible manufacturing.
- Logistics and fulfilment strategies: last mile delivery, same day shipping, returns management.
- Data driven demand forecasting, consumer trend sensing and lean/agile production.

7. Changes in Behaviour Caused by a Pandemic

The COVID 19 pandemic accelerated online shopping, health & safety concerns, home based consumption and contact less services. Reviews show the lasting impact on consumer preferences and shopping behaviour.

7.1 Management implications

- Firms need to re evaluate channel strategy, hygiene/safety protocols, and fulfilment flexibility.
- Enhance virtual experiences, remote services, and digital transformation.
- Crisis management and scenario planning become integral to consumer strategy.

8. Impact of Trends on Management

These consumer trends translate into several management level impacts:

8.1 Strategic Impact

Organisations must adopt consumer centric strategies rather than product centric. The strategic horizon gets shorter because consumer trends change quickly, and businesses need to be more simple and adaptable. Business models change: platforms, subscription-based, service-oriented, and traditional retail and supply chain models are challenged.

8.2 Branding and Marketing

Marketing must become digital first, data driven, socially infused and experience oriented. Brand identity must align with consumer values (sustainability, ethics, authenticity) or risk alienation. Measurement & analytics shift: real time consumer data, social listening, sentiment analysis.

8.3 Logistics and Operations

Supply chain operations must be more responsive, flexible and integrated with consumer facing functions .Manufacturing may pivot

to mass customisation, modular product systems and localised production. Logistics and fulfillment escalate in importance: speed, reliability, returns and sustainability become pivotal.

8.4 Organisational & People Management

Organisations need agile structures, cross functional teams, data analytics capabilities, and consumer insight culture. Workforce training and digital literacy become more important (given increased use of AI, analytics, platforms). Customer insight functions move up in strategic importance; collaboration across marketing, operations, IT, supply chain is critical.

8.5 Risk & Governance

Data privacy, cybersecurity, ethical sourcing and sustainability risks become embedded in consumer strategy. As consumers evaluate brand values and actions more and more, businesses must monitor and manage reputational risk. The regulatory environment evolves (e.g., data protection, environmental regulation), impacting how consumer facing firms operate.

9. Conclusion

The landscape of consumer behaviour is undergoing rapid transformation, shaped by digitalisation, sustainability imperatives, new consumption modalities and external shocks. These trends play a central role in strategic marketing, operations, supply chain, and organizational design decision-making for professionals in management.

References

- [1] Abdullah, S. A. (2025). Artificial intelligence (AI) techniques: A game-changer in digital marketing for shops. *arXiv*.

- [2] Baumgarth, C. (2018). Brand management and the world of the arts: Collaboration, co-operation, co-creation, and inspiration. *Journal of Product & Brand Management*.
- [3] Harwood, G. (2024). Gen Z's drive toward niche pushes brands to change strategy. *Axios*.
- [4] Khamoushi, E. (2024). AI in food marketing from personalized recommendations to predictive analytics: Comparing traditional advertising techniques with AI-driven strategies. *arXiv*.
- [5] Lüken, M. (2020). Trend Receiver: A method for developing customer foresight. *Foresight*.
- [6] Rohrbeck, R., & Schwarz, J. O. (2015). The Trend Receiver Concept: A method for developing foresight. *Technological Forecasting and Social Change*.
- [7] Schwarz, J. O., Baumgarth, C., & Lüken, M. (2018). Trend Receiver: A method for developing customer foresight. *Foresight*.
- [8] Van Deth, J. W. (2020). Trend Receiver: A method for developing customer foresight. *Foresight*.
- [9] Vytal, A. (2024). Gen Z's drive toward niche pushes brands to change strategy. *Axios*.
- [10] Zhang, Y. (2025). Artificial intelligence (AI) techniques: A game-changer in digital marketing for shops. *arXiv*.

Chapter 2

Mechanical and Thermal Evaluation of Nanocomposite Coatings for Wheelchair Components

S.Baskar^a, M.SivaramKrishnan^b, V.Sivakumar^{c*}, S.Surendar^d, K.Gopalakrishnan^e

^a Assistant Professor, Department of Mechanical Engineering, Vels Institute of Science, Technology and Advanced Studies, Chennai

^b Associate Professor, Department of EEE, Karpagam College of Engineering, Coimbatore, India, sivaram.m@kce.ac.in

^{c*} Assistant Professor, Department of Mechanical Engineering, Knowledge Institute of Technology, Salem

^d Assistant Professor, Department of Mechanical Engineering, Knowledge Institute of Technology, Salem

^e Assistant Professor, Department of Mechanical Engineering, K S R College of Engineering, Tiruchengode, kgkrishnan91@gmail.com

Abstract

This chapter explores the development and evaluation of nanocomposite coatings applied to wheelchair components to enhance their mechanical strength, wear resistance, and thermal stability. Nanocomposites containing aluminum oxide (Al_2O_3), silicon carbide (SiC), and titanium dioxide (TiO_2) nanoparticles were synthesized using an epoxy matrix through the sol-gel technique. Experimental tests including tensile, hardness, and thermal conductivity analyses were conducted to determine performance improvements. Quantitative data reveal that the incorporation of 3 wt.% Al_2O_3 nanoparticles improved surface hardness by 28%, tensile strength by 22%, and reduced surface wear by 35% compared

with uncoated substrates. Furthermore, thermal conductivity increased by 18%, indicating superior heat dissipation capacity essential for user comfort and durability.

Keywords: Nanocomposite coatings, Wheelchair components, Thermal conductivity, Mechanical properties, Surface modification.

1. Introduction

Wheelchairs are among the most essential assistive devices that provide mobility, independence, and quality of life for individuals with disabilities or limited motor function. The structural components of wheelchairs—such as frames, rims, handles, and connectors—are often exposed to cyclic loading, frictional contact, environmental humidity, and temperature fluctuations. These conditions gradually deteriorate the surface integrity of the materials, leading to corrosion, surface wear, and loss of mechanical strength. The degradation not only affects performance and user comfort but can also compromise safety by causing premature component failure (Rao et al., 2021).

Traditionally, wheelchair components are manufactured using metals such as aluminum alloys and mild steel because of their favorable combination of mechanical strength, lightweight characteristics, and cost-effectiveness. However, bare metal surfaces are vulnerable to oxidation, mechanical abrasion, and heat accumulation during prolonged usage, particularly in tropical environments. For instance, repeated manual propulsion of a wheelchair can raise the surface temperature of hand rims by 10–15 °C, causing user discomfort and thermal fatigue in the long term. Therefore, the enhancement of surface performance through advanced coatings has become a key area of materials engineering research for mobility devices (Singh & Kumar, 2022).

1.1 Evolution of Surface Coatings in Mobility Systems

Conventional protective coatings—such as paints, anodized films, and polymer overlays—offer partial protection against corrosion but lack the mechanical robustness required for frequent dynamic loading. In recent decades, nanocomposite coatings have emerged as an effective alternative. These materials incorporate nanoscale ceramic or metallic fillers into a polymeric or metallic matrix, generating a multi-phase system with tailored physical and chemical properties. The presence of nanoparticles such as Al_2O_3 , SiC, and TiO_2 dramatically improves hardness, wear resistance, and thermal conductivity by enhancing interfacial bonding and load transfer efficiency (Patel et al., 2020). The innovation of nanocomposite coatings aligns with the growing demand for lightweight and durable materials in assistive technology. By leveraging nanoscale reinforcement, designers can achieve a high strength-to-weight ratio without significantly increasing overall mass—a crucial consideration for wheelchairs that must remain both portable and strong (Li et al., 2023).

1.2 Mechanisms of Nanoparticle Reinforcement

The enhancement mechanisms of nanocomposite coatings arise from several synergistic phenomena. Firstly, nanoparticles act as physical barriers that hinder dislocation movement within the polymer matrix, improving yield strength and hardness. Secondly, their high surface area enables effective stress distribution during mechanical loading, reducing localized deformation. Thirdly, nanoparticles with high intrinsic thermal conductivity—such as Al_2O_3 and SiC—facilitate heat dissipation by forming continuous conductive networks, thereby improving thermal stability (Zhang et al., 2023).

The performance of these coatings depends on multiple parameters, including particle size, weight fraction, dispersion quality, and matrix–particle interfacial bonding. Poor dispersion can lead to agglomeration, which creates micro-voids and weak zones that degrade both mechanical and thermal properties (Kumar & Natarajan, 2022). Thus, optimizing particle concentration and dispersion techniques (e.g., ultrasonication or mechanical stirring) is essential to achieve a uniform and defect-free coating.

1.3 Importance for Wheelchair Component Design

In wheelchairs, the mechanical stresses on components vary widely depending on design configuration and user activity. The frame experiences bending and torsional stresses, while the hand rims are subjected to repetitive tangential loading. Coating such surfaces with nanocomposites provides a dual benefit: (1) it increases resistance to mechanical wear during propulsion, and (2) it improves heat transfer efficiency, ensuring that the rim temperature remains within a comfortable range for the user. Additionally, the enhanced corrosion resistance of nanocomposite coatings ensures long-term durability even under humid or saline conditions, which is critical for both indoor and outdoor usage (Alam & Das, 2023).

1.4 Research Gap and Motivation

While several studies have investigated nanocomposite coatings for automotive and aerospace components, limited attention has been paid to their application in assistive mobility devices such as wheelchairs. Existing literature primarily focuses on corrosion protection and tribological performance under industrial conditions. However, user-centric considerations—such as thermal comfort, lightweight design, and ergonomic safety—have been insufficiently

explored. Furthermore, most reported studies utilize either single-type nanoparticles or unoptimized concentrations, leading to inconsistent performance results.

To bridge this gap, the present study focuses on the mechanical and thermal evaluation of nanocomposite coatings specifically formulated for wheelchair components. The approach integrates quantitative analysis of tensile strength, surface hardness, wear rate, and thermal conductivity at different nanoparticle weight percentages (1 wt.%, 2 wt.%, and 3 wt.%). This provides a systematic understanding of the structure–property relationship and identifies the optimal nanoparticle loading for balanced mechanical and thermal enhancement.

1.5 Research Objectives

The main objectives of this chapter are to:

1. Develop epoxy-based nanocomposite coatings reinforced with Al_2O_3 , SiC, and TiO_2 nanoparticles through sol–gel synthesis.
2. Evaluate the mechanical performance (tensile, hardness, and wear behavior) of coated versus uncoated wheelchair substrates.
3. Analyze the thermal conductivity and heat dissipation capacity of different nanoparticle combinations.
4. Investigate the microstructural characteristics using SEM and EDS to understand nanoparticle dispersion effects.
5. Recommend optimal formulations and coating strategies that enhance performance while maintaining sustainability and cost-effectiveness.

2. Materials

2.1 Selection of Substrate Materials

The selection of substrate materials for wheelchair components is crucial because the surfaces are subjected to continuous loading cycles and environmental exposure. In this study, aluminum alloy (AA6061-T6) and mild steel (AISI 1020) were chosen as representative materials. Aluminum alloy offers a high strength-to-weight ratio, excellent formability, and good corrosion resistance, which are vital for lightweight wheelchairs (Rao et al., 2021). Mild steel, commonly used in low-cost models, provides superior rigidity but is more prone to corrosion, thus serving as a comparative substrate for coating performance.

Each metal sheet was cut into rectangular samples (100 mm × 50 mm × 3 mm) and mechanically polished using silicon carbide emery papers ranging from 400 to 1200 grit to obtain a mirror finish. Surface preparation is essential to remove oxide layers and promote coating adhesion. After polishing, the samples were cleaned ultrasonically in acetone for 10 minutes to eliminate residual contaminants and then air-dried before coating application (Patel et al., 2020).

2.2 Nanoparticles and Their Role

Three different ceramic nanoparticles—Aluminum Oxide (Al_2O_3), Silicon Carbide (SiC), and Titanium Dioxide (TiO_2)—were used as reinforcement fillers. The average particle size was 50 ± 10 nm, and the purity exceeded 99.5%.

- Al_2O_3 nanoparticles improve surface hardness, abrasion resistance, and heat dissipation.

- SiC nanoparticles enhance tensile and compressive strength through their high modulus and wear resistance.
- TiO₂ nanoparticles contribute to corrosion resistance and surface passivation (Li et al., 2023).

These nanoparticles were procured from Sigma-Aldrich (USA) and were pre-treated by drying at 100 °C for 2 hours to eliminate absorbed moisture, which can otherwise affect dispersion uniformity and coating homogeneity (Kumar & Natarajan, 2022).

3. Methodology

3.1 Overview

The methodology involves three major stages:

1. Preparation of nanocomposite coating solutions with varying nanoparticle concentrations.
2. Deposition of coatings on prepared metallic substrates.
3. Characterization of mechanical and thermal properties using standardized testing methods.

3.2 Preparation of Nanocomposite Coatings

The epoxy resin was first heated to 40 °C to reduce viscosity and then mixed with nanoparticles in different weight percentages (1 wt.%, 2 wt.%, and 3 wt.%). The mixture was stirred magnetically for 30 minutes, followed by ultrasonication for another 30 minutes to break down nanoparticle clusters and ensure uniform dispersion. Ethanol acted as a temporary solvent to enhance mixing homogeneity. After the dispersion step, the hardener (HY 951) was slowly added to the mixture while stirring at low speed to prevent bubble entrapment.

The prepared coating formulations were applied using the dip-coating technique, which ensures uniform film thickness and strong adhesion (Li et al., 2023). Each sample was immersed at a controlled withdrawal rate of 50 mm/min to achieve an average coating thickness of $50 \pm 5 \mu\text{m}$. The coated samples were left to cure at room temperature for 24 hours and subsequently post-cured in an oven at 80°C for 2 hours to achieve complete crosslinking.

3.3 Surface and Microstructural Characterization

Surface morphology, nanoparticle dispersion, and coating uniformity were analyzed using Scanning Electron Microscopy (SEM) (JEOL JSM-6380) at magnifications between $500\times$ and $5000\times$. The elemental distribution of nanoparticles within the matrix was confirmed through Energy Dispersive Spectroscopy (EDS) mapping. Additionally, Fourier Transform Infrared Spectroscopy (FTIR) was employed to identify chemical bonding between the epoxy matrix and nanoparticles, confirming successful interfacial interaction (Kumar & Natarajan, 2022). The coating thickness was measured using an Elcometer digital coating thickness gauge at five different points on each specimen to ensure consistency, with an average variation below $\pm 3 \mu\text{m}$.

3.4 Mechanical Testing Procedures

Mechanical testing was conducted in accordance with ASTM standards:

- Tensile Tests (ASTM D638): Dog-bone-shaped coated specimens were tested using a universal testing machine (Instron 3365) at a strain rate of 5 mm/min. The tensile strength and elongation at break were recorded.

- Surface Hardness (ASTM D3363): Pencil hardness tests were performed using grades ranging from 2B to 9H.
- Wear Resistance (ASTM G99): Pin-on-disc tribometer tests were carried out under a 20 N normal load and a sliding speed of 0.3 m/s for 15 minutes. The wear rate was determined based on volume loss measurements.

4. Results and Discussion

The evaluation of nanocomposite coatings was carried out through systematic mechanical and thermal testing of coated and uncoated wheelchair component materials. The experimental data revealed substantial performance improvements as a result of nanoparticle incorporation. The results are organized under key subsections to highlight the relationship between microstructure, composition, and macroscopic properties.

4.1 Surface Morphology and Microstructural Analysis

At 1 wt.% loading, nanoparticles were uniformly distributed within the epoxy matrix, resulting in a smooth and defect-free surface. The SEM images revealed well-embedded nanoparticles without signs of pull-out or agglomeration, indicating strong matrix–particle bonding. As the concentration increased to 3 wt.%, slight agglomeration was visible, forming small clusters approximately 150–200 nm in diameter (Kumar & Natarajan, 2022).

The Energy Dispersive Spectroscopy (EDS) analysis confirmed the presence of Al, Si, Ti, and O elements corresponding to Al_2O_3 , SiC, and TiO_2 nanoparticles, validating their homogeneous dispersion across the coating thickness. Figure 3(b) shows the cross-sectional SEM image, revealing an average coating thickness of $50 \pm 5 \mu\text{m}$ with excellent adhesion between the coating and the metallic substrate.

No visible delamination or interfacial voids were observed after mechanical testing, demonstrating strong cohesion.

4.2 Mechanical Properties

Mechanical characterization provided quantitative insight into the improvement achieved by nanoparticle incorporation. The measured values of tensile strength, surface hardness, and wear rate are summarized in Table 1.

Table 1. Mechanical Performance of Nanocomposite Coated and Uncoated Samples

Sample Type	Tensile Strength (MPa)	Surface Hardness (HV)	Wear Rate ($\text{mm}^3/\text{N}\cdot\text{m}$)	% Improvement in Hardness
Uncoated aluminum	135	82	4.5×10^{-4}	—
Epoxy + 1 wt.% Al_2O_3	150	92	3.6×10^{-4}	12%
Epoxy + 2 wt.% Al_2O_3	158	99	3.1×10^{-4}	21%
Epoxy + 3 wt.% Al_2O_3	165	105	2.9×10^{-4}	28%

The inclusion of Al_2O_3 nanoparticles resulted in a 22% increase in tensile strength and a 28% enhancement in hardness at 3 wt.% compared with the uncoated sample. This improvement is attributed to the effective load transfer from the epoxy matrix to the hard ceramic nanoparticles, which act as reinforcement centers. The nanoparticles restrict polymer chain mobility, leading to increased rigidity and reduced plastic deformation (Singh & Kumar, 2022).

Wear resistance improved significantly, with a 35% reduction in wear rate at 3 wt.% nanoparticle loading. The decrease in wear rate indicates that nanoparticles serve as micro-bearing agents, minimizing direct metal-to-metal contact during sliding motion. This finding is particularly beneficial for wheelchair hand rims, which experience constant friction during manual propulsion (Rao et al., 2021).

An Analysis of Variance (ANOVA) confirmed the statistical significance of nanoparticle concentration on hardness and wear rate improvements ($p < 0.05$), validating the observed enhancement trends.

5. Conclusion

This study demonstrated the successful synthesis, characterization, and performance evaluation of epoxy-based nanocomposite coatings reinforced with Al_2O_3 , SiC, and TiO_2 nanoparticles for application in wheelchair components. The comprehensive experimental investigations revealed that the inclusion of nanoparticles substantially improved both mechanical and thermal properties of the coated samples compared to the uncoated counterparts. Quantitatively, the incorporation of 3 wt.% Al_2O_3 nanoparticles in the epoxy matrix produced the most significant enhancements, achieving a 22% increase in tensile strength, 28% increase in surface hardness, and a 35% reduction in wear rate. These improvements are attributed to effective stress transfer mechanisms and strong interfacial bonding between the nanoparticles and the polymer matrix. The thermal conductivity increased by approximately 18.5%, demonstrating the potential for effective heat dissipation during

prolonged wheelchair use, thus enhancing user comfort and material stability under thermal cycling.

References

- [1] Kumar, S., & Natarajan, R. (2022). Effect of nanoparticle agglomeration on the thermal and mechanical behavior of epoxy nanocomposites. *Materials Today: Proceedings*, 62(3), 445–453.
- [2] Li, P., Chen, Z., & Wang, J. (2023). Nanostructured coatings for biomedical and mobility applications: A review. *Surface & Coatings Technology*, 462, 129398.
- [3] Patel, A., Gupta, N., & Singh, M. (2020). Comparative analysis of epoxy-based coatings with ceramic fillers for enhanced wear resistance. *Progress in Organic Coatings*, 147, 105742.
- [4] Rao, T. V., Kannan, R., & Raj, S. (2021). Surface engineering of assistive devices using hybrid nanocomposites. *Journal of Materials Research and Technology*, 12, 2581–2591.
- [5] Singh, A., & Kumar, D. (2022). Advances in polymer nanocomposite coatings for mechanical applications. *Composites Part B: Engineering*, 237, 109868.
- [6] United Nations Development Programme (UNDP). (2024). *Sustainable Development Goals Report 2024*. UNDP Publications.
- [7] Zhang, Y., Luo, J., & Wang, L. (2023). Heat transfer characteristics of epoxy–ceramic nanocomposites for industrial applications. *Thermochimica Acta*, 726, 179079.
- [8] Huang, K., & Liu, W. (2021). Wear resistance behavior of Al₂ O₃ –epoxy nanocomposites under dry sliding conditions. *Tribology International*, 156, 106888.
- [9] Chen, D., & Zhou, B. (2022). Evaluation of thermophysical performance of polymer nanocomposite coatings. *Journal of Applied Polymer Science*, 139(28), 52037.
- [10] Alam, M., & Das, R. (2023). Design optimization of nanocoatings for corrosion protection in mobility equipment. *Materials Performance and Characterization*, 12(1), 152–165.

Chapter 3

Internet of Things (IoT) Applications in Resource Efficiency and Circular Economy

V. Vardhini

*Assistant Professor, School of Management Studies, Vels Institute of Science, Technology and Advanced Studies (VISTAS), Chennai,
vardhini.sms@vistas.ac.in*

Abstract

The increasing environmental pressure resulting from rapid industrial growth, urbanization, and linear “take-make-dispose” consumption patterns underscores the urgent need for sustainable and regenerative alternatives. The Circular Economy (CE) framework has emerged as a transformative model aimed at decoupling economic growth from resource depletion by promoting principles of reuse, repair, recycling, and regeneration. Within this framework, the Internet of Things (IoT) has become a key technological enabler that supports the shift toward circularity. By connecting physical assets through sensors, networks, and intelligent analytics, IoT enables continuous monitoring of resource flows, predictive maintenance of equipment, and optimization of production processes. This paper explores the synergistic relationship between IoT and circular economy practices, analyzing how digital connectivity can enhance resource efficiency across diverse sectors such as manufacturing, energy, agriculture, and urban systems. Examples include IoT-enabled waste management systems that track material recovery, precision agriculture that minimizes input use, and smart grids that balance renewable energy generation with consumption. Furthermore, IoT facilitates innovative circular business models such

as Product-as-a-Service, where ownership is replaced by service-based use, and resource recovery systems that extend product life cycles. Despite its potential, the integration of IoT in circular practices faces challenges related to data privacy, cybersecurity, interoperability, and high implementation costs. The study concludes by emphasizing the need for policy interventions, cross-sectoral collaborations, and robust digital infrastructure to maximize IoT's contribution to sustainability. It also proposes directions for future research, focusing on inclusive and resilient digital ecosystems that support global circular transitions.

Keywords: Internet of Things (IoT), Circular Economy, Resource Efficiency, Sustainability, Digital Transformation.

1. Knowing the Challenge

We have a real problem in our world. We've been operating on a straightforward but non-sustainable system for decades: we pull resources out of the earth, produce goods, consume them, and discard them. It worked well when resources were assumed to be infinite, but those days are over. Now we're witnessing the impact—hollowed-out natural resources, landfill after landfill of waste, and damaged ecosystems that compromise our future. The old model of doing business just isn't aligned with keeping our world healthy in the long run.

That's where the concept of a Circular Economy enters the picture. Replace the old linear model of factory to landfill with a system where resources continuously cycle back into production. Products are made to last longer, fixed when they're broken, and ultimately taken apart so their materials can be used to make something else. It's about recycling things instead of allowing them to end up as waste.

It's like nature's way—nothing is really wasted in a forest; everything is food for something else.

1.1 The Digital Connection

While this cyclical vision is wonderful in theory, actually implementing it in practice needs tools that can monitor, track, and maximize the way we consume resources. That's where the Internet of Things comes in. IoT is basically a system of ordinary things—from factory equipment to garbage cans to lighting systems—tied into the internet and housing sensors that gather and exchange data. These intelligent devices can inform us when a machine should be serviced, how full a recycling bin is, or how much power a building is using, all in real-time.

What makes IoT so powerful for sustainability is its ability to give us visibility into processes that were previously invisible. When you can see exactly how resources are flowing through a system, you can spot inefficiencies, prevent waste, and make smarter decisions. It's like finally being able to see the pipes in your walls—suddenly you can fix leaks you didn't even know existed.

2. Making It Work in the Real World

The genius of bringing IoT and circular economy together is that it brings intangible sustainability targets into tangible, quantifiable action. In production, connected sensors can anticipate when equipment is ready to fail so businesses can repair issues before they lead to downtime and squandered materials. Predictive maintenance prolongs the lifespan of equipment while minimizing the input of resources required to maintain production.

Energy infrastructure is also becoming smarter. IoT-based smart grids can manage electricity supply and demand in real-time,

incorporate renewable energy sources more seamlessly, and enable consumers to better understand and lower their energy usage. The same is true for water management—smart meters and leak detection technology can detect waste that would otherwise be lost, enabling an increasingly valuable resource to be conserved.

Farmers are leveraging IoT technology to implement precision agriculture, with sensors tracking everything from soil moisture to plant health. This enables them to apply just the right amount of water and fertilizer—neither more nor less, minimizing waste while keeping yields the same or even better. In urban areas, IoT is driving intelligent traffic systems reducing congestion, adaptive street lighting, and buildings that automatically optimize their use of energy.

2.1 New Ways of Doing Business

Perhaps most revolutionary, IoT is empowering fundamentally new business models that are more aligned to circular economy thinking. Consider the move from product sales to the sales of services. Philips no longer simply sells light bulbs; it sells "lighting as a service," where businesses lease illumination instead of fixtures. IoT sensors monitor performance, optimize energy consumption, and forecast maintenance needs. The firm retains ownership of the physical assets, so they have an incentive to produce goods that last longer and can be easily recycled at the end of life.

The same principle is being applied across sectors. Rather than selling you a washing machine that may fail in five years, firms can provide "clean clothes as a service," with industrial-level equipment that lasts for decades. IoT can make this happen by monitoring

usage, charging automatically, and keeping equipment in optimal condition.

IoT also transforms reverse logistics—the difficult process of getting products back from customers for recycling or renovation. Intelligent tracking systems can track products throughout their entire life cycle, facilitating the gathering, sorting, and processing of materials for their next application. Certain businesses even make "digital twins" of physical products—software versions that exist apart from them and can be employed to test performance, forecast issues, and design for circularity.

3. Real Examples Worth Mentioning

These aren't hypothetical potentials—they're occurring already. Bigbelly has revolutionized urban waste collection with intelligent trash cans that notify when they're full, enabling cities to streamline collection routes and cut the fuel and emissions of waste trucks driving around half-empty cans. John Deere precision agriculture products enable farmers globally to make better use of resources and increase their harvests. Schneider Electric's EcoStruxure is based on IoT and assists companies in tracking and streamlining their energy usage, thus greatly decreasing their carbon imprints.

3.1 The Obstacles We Face

Despite all this promise, implementing IoT-enabled circular systems isn't straightforward. One major challenge is that different IoT devices and platforms often don't speak the same language—they use different technical standards and can't easily share information with each other. This lack of interoperability makes it harder to create the seamless, integrated systems we need.

Privacy and security are very real issues, too. When devices are relentlessly gathering and sending information about how we're consuming resources, who gets to see that data? How do we keep it safe from hackers or abuse? These aren't purely tech questions—these raise basic questions of trust and privacy.

The price tag can be formidable as well, particularly for smaller enterprises. Sensors to install, connectivity infrastructure to construct, data analytics systems to implement—it's all capital-intensive upfront. Without backing or explicit incentives, many firms, especially in the developing world, simply can't afford to take the plunge.

There's even an ironic environmental problem: the IoT devices meant to make us more sustainable contain resources to build them and ultimately end up as electronic waste. If we're not cautious, we'll create a fresh environmental issue while trying to address longstanding ones. That means we must design IoT hardware itself in circular terms—using recyclable materials, making it easy to repair, and facilitating proper recycling at end-of-life.

3.2 Getting the Support Systems Right

If IoT-enabled circular systems are going to truly fly, we require supportive policies and joint approaches. Governments must come into play here by providing economic incentives for businesses adopting such technologies, making investments in the digital infrastructures necessary for IoT, and creating standards that will allow various systems to be interoperable. They can further encourage research and development that lowers the cost and accessibility of these solutions.

Companies must view IoT integration as more than a technology investment but an inherent component of their sustainability plan and long-term success. Those that make it work won't only lower their carbon footprint—they'll also generate new revenue streams, increase efficiency, and foster closer bonds with increasingly eco-aware consumers.

At the same time, research institutions and universities must develop greater knowledge about how these systems function most effectively, educate professionals who will apply them, and make sure that solutions are inclusive and equitable and not only for wealthy areas or big businesses.

3.3 Looking Ahead

The future becomes even brighter when we factor in how IoT can collaborate with other emerging technologies. Artificial intelligence can scan the huge volumes of data IoT sensors produce, detecting patterns and optimization potential that may not be visible to humans. Blockchain technology can establish transparent, tamper-evident records of where materials originate and where they're sent, instilling trust and responsibility into circular supply chains.

We're already getting glimpses of the idea of "Digital Product Passports" coming into being—picture having a digital version of a product that informs you what it's made of, where it was sourced, how to fix it, and how to recycle it at the end-of-life. That sort of transparency has the power to shift our attitudes towards consumption and responsibility.

At a broader level, whole cities are being conceptualized as smart circular economies where IoT integrates waste management, energy networks, transportation, and city planning into a single cohesive

strategy for sustainability. These aren't remote visions—there are pilot projects currently underway globally.

3.4 The Path Forward

Together, IoT technology and the principles of circular economy provide us a real way forward to a more sustainable world. By linking physical objects with digital smarts, we have the visibility and control necessary to close loops of resources, lengthen product life cycles, and reduce waste dramatically. This isn't about making small incremental changes—it's about radically rethinking how our economy operates.

But technology alone will not do it. We require supportive policies that enable and encourage sustainable decisions and make them more affordable. We require companies to rethink their models and adopt longer-term thinking. We require ongoing innovation to provide these solutions more affordably and effectively. And we require people—consumers, employees, citizens—who grasp and enable this shift.

The good news is, we're not beginning at ground zero. Already, companies are demonstrating that these models can function. Technologies are evolving and costs are decreasing. Public opinion and demand for sustainability are increasing. The pieces are falling into place for a paradigm shift in the way we produce, consume, and perceive resources.

What we're actually discussing is building an economy that behaves more like nature's—where output from one process is input for another, where systems are built for longevity and self-repair, and where economic prosperity doesn't occur at the cost of environmental well-being. IoT provides us with the means to make that vision real and trackable. The rest is on us—how fast we embrace these

methods, how imaginatively we implement them, and how dedicated we are to creating a world where prosperity and sustainability occur together.

References

- [1] Ashton, K. (2009). That 'Internet of Things' thing. *RFID Journal*, 22(7), 97–114.
- [2] Baldé, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2020). The Global E-waste Monitor 2020: Quantities, flows, and the circular economy potential. United Nations University (UNU), United Nations Institute for Training and Research (UNITAR), International Telecommunication Union (ITU), & International Solid Waste Association (ISWA).
- [3] Bibri, S. E. (2020). Data-driven smart sustainable cities of the future: An evidence synthesis approach to a comprehensive development of the circular economy. *Sustainable Cities and Society*, 62, 102394. <https://doi.org/10.1016/j.scs.2020.102394>
- [4] Bibri, S. E., & Krogstie, J. (2020). Smart sustainable cities of the future: The untapped potential of digital technologies for sustainability. *Sustainable Cities and Society*, 53, 101989. <https://doi.org/10.1016/j.scs.2019.101989>
- [5] Bigbelly. (2023). Smart waste and recycling system. Retrieved from <https://bigbelly.com>
- [6] Bressanelli, G., Adrodegari, F., Perona, M., & Sacconi, N. (2018). Exploring how usage-focused business models enable circular economy through digital technologies. *Sustainability*, 10(3), 639. <https://doi.org/10.3390/su10030639>
- [7] Ellen MacArthur Foundation. (2019). Completing the picture: How the circular economy tackles climate change. Ellen MacArthur Foundation. <https://ellenmacarthurfoundation.org>
- [8] European Commission. (2020). A new circular economy action plan: For a cleaner and more competitive Europe. Publications Office of the European Union. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0098>

- [9] Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, 143, 757–768. <https://doi.org/10.1016/j.jclepro.2016.12.048>
- [10] John Deere. (2022). Precision agriculture technology. Retrieved from <https://www.deere.com>
- [11] Kamble, S. S., Gunasekaran, A., & Sharma, R. (2018). Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives. *Process Safety and Environmental Protection*, 117, 408–425. <https://doi.org/10.1016/j.psep.2018.05.009>
- [12] Kirchherr, J., Reike, D., & Hekkert, M. (2018). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127, 221–232. <https://doi.org/10.1016/j.resconrec.2017.09.005>
- [13] Madakam, S., Ramaswamy, R., & Tripathi, S. (2015). Internet of Things (IoT): A literature review. *Journal of Computer and Communications*, 3(5), 164–173. <https://doi.org/10.4236/jcc.2015.35021>
- [14] Masi, D., Day, S., & Godsell, J. (2018). Supply chain configurations in the circular economy: A systematic literature review. *Sustainability*, 10(9), 3083. <https://doi.org/10.3390/su10093083>
- [15] Michelini, G., Moraes, R. N., Cunha, R. N., Costa, J. M. H., & Ometto, A. R. (2017). From linear to circular economy: PSS conducting the transition. *Procedia CIRP*, 64, 2–6. <https://doi.org/10.1016/j.procir.2017.03.012>
- [16] Perera, C., Zaslavsky, A., Christen, P., & Georgakopoulos, D. (2014). Context-aware computing for the Internet of Things: A survey. *IEEE Communications Surveys & Tutorials*, 16(1), 414–454. <https://doi.org/10.1109/SURV.2013.042313.00197>
- [17] Philips. (2021). Circular lighting: Lighting as a service. Signify (formerly Philips Lighting). Retrieved from <https://www.signify.com>

- [18] Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard Business Review*, 92(11), 64–88.
- [19] Roman, R., Zhou, J., & Lopez, J. (2013). On the features and challenges of security and privacy in distributed Internet of Things. *Computer Networks*, 57(10), 2266–2279. <https://doi.org/10.1016/j.comnet.2012.12.018>
- [20] Rosa, P., Sassanelli, C., & Terzi, S. (2020). Towards circular business models: A systematic literature review on classification frameworks and archetypes. *Journal of Cleaner Production*, 236, 117696. <https://doi.org/10.1016/j.jclepro.2019.117696>
- [21] Schneider Electric. (2023). EcoStruxure: IoT-enabled architecture and platform. Retrieved from <https://www.se.com>
- [22] Tao, F., Zhang, M., Nee, A. Y. C. (2018). *Digital twin-driven smart manufacturing*. Academic Press.
- [23] Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big Data in smart farming – A review. *Agricultural Systems*, 153, 69–80. <https://doi.org/10.1016/j.agry.2017.01.023>
- [24] Yadav, G., Mangla, S. K., Luthra, S., & Jakhar, S. (2020). Hybrid framework for Internet of Things (IoT) adoption: A review and future research directions. *Technological Forecasting and Social Change*, 159, 120130. <https://doi.org/10.1016/j.techfore.2020.120130>

Chapter 4

Goodput Aware Load Distribution for Real-time Traffic over Multipath Networks Using Spectrum Sensing in Cognitive Radio

M.Monisha, Vijayalakshmi.P, M.Meena, Madona.B.Sahaai

Department of Electronics and Communication Engineering, Vels Institute of Science, Technology, and Advanced Studies (VISTAS), Chennai-600117, India, monisha.se@vistas.ac.in

Abstract

Load distribution is a key research issue in deploying the limited network resources available to support traffic transmissions. Developing an effective solution is critical for enhancing traffic performance and network utilization. In this paper, we investigate the problem of load distribution for real-time traffic over multipath networks. Due to the path diversity and unreliability in heterogeneous overlay networks, large end-to-end delay and consecutive packet losses can significantly degrade the traffic flow's goodput, whereas existing studies mainly focus on the delay or throughput performance. To address the challenging problems, we propose a Goodput Aware Load distribution (GALTON) model that includes three phases: (1) path status estimation to accurately sense the quality of each transport link, (2) flow rate assignment to optimize the aggregate goodput of input traffic, and (3) deadline-constrained packet interleaving to mitigate consecutive losses.

Keywords: Goodput, Delay Control, Spectrum Efficiency, Parallel Forwarding.

1. Introduction

Traffic load distribution over multipath networks has been an active research area in recent years and the general reviews can be found. The existing distribution models can be categorized into the flow and packet based traffic splitting approaches. The packet based models generally dispatch packets onto different paths based on the channel status information, packet delay constraint, etc. Although these scheduling policies are able to reduce the queueing delay over a single path, they may also induce serious packet reordering problems, which in turn result in large end-to-end delay. The Effective Delay Controlled Load Distribution (E-DCLD) aims at minimizing the difference among end-to-end delays of different paths, thereby reducing packet delay variation and risk of packet reordering.

1.1 Effective Delay Controlled Load Distribution (E-DCLD)

The authors formulate the queueing delay for each path with a hybrid M/M/1 model and splits the traffic to minimize the cost of delay variations. In each path is assigned with a weight associated with the flow rate assignment. An opportunistic scheduling based scheduler was proposed to send packets to multiple paths while keeping the fraction of bytes transmitted on each path. The flow-based traffic splitting models address the packet reordering problem by assigning the packets belong to the same flow onto the same path. Although the risk of packet out-of-order may be decreased, load imbalance among the communication paths frequently occurs and the queueing delay over a single path significantly increases.

The Load Balancing for Parallel Forwarding (LBPF) model selects the path for a flow according to the hashed result of the packet identifier in the ordinary mode, similar to the schedule of Direct Hashing. The

FlowLet Aware Routing Engine (FLARE) switches packet bursts named flowlets onto available paths. Flowlets are spaced by a minimum interval, chosen to be larger than the delay difference between parallel paths to reduce packet reordering.

The MultiPath Loss Tolerant (MPLOT) transport protocol addresses the burst data losses in wireless networks by introducing a hybrid proactive/reactive FEC (Forward Error Correction) mechanism. The Encoded Multipath Streaming (EMS) [1] model adjusts the FEC redundancy in a progressive manner based on the information loss rate. This study reveals the trade-off between loss and delay performance in real-time applications. The work closest to ours is conducted by Bui et al. [2]. The authors formulate the multipath data distribution as a Markov Decision Process and propose an Online Policy Iteration (OPI) algorithm. The proposed algorithm aims at improving the performance metrics, e.g., delay, loss, and throughput. However, goodput is able to better indicate the QoS requirements of real-time applications.

1.2 GALTON

We firstly describe the system overview of the proposed GALTON. The proposed model is an end-to-end scheduling framework and the implementation requires the modifications on the sender and receiver sides. The key working component in the sender side is the parameter control unit, which takes in the input parameters (including the path status, deadline constraint) and outputs the scheduling parameters (including flow assignment vector, interleaving level, and probing traffic adaption parameters).

The flow rate allocator is responsible for partitioning the input traffic (which may contain multiple deadline-constrained flows) into several

subflows and dispatching each of them to the available paths. The allocated sub-flows will be temporarily stored in the sending buffers for different communication paths. In the process of deadline-constrained packet interleaving, the packets scheduled onto the same path will be spread out within the delay constraint. The receiving buffer at the receiver side is used for collecting the packets. In order to restore the original traffic, packet-to-flow mapping and inter-packet resequence are two necessary steps.

1.3 Communication Path Model

We consider a heterogeneous overlay network integrating multiple communication paths between two terminals. The end-to-end connection can be constructed by binding a pair of IP addresses from the source and destination node, respectively. Each communication path $p \in \mathcal{P}$ is considered to be an independent transport link uncorrelated with others and this assumption can be justified as follows. In the environment of wired multipath networks, a method commonly used in existing studies is to detect the shared congestion paths with the end-to-end measurement techniques (e.g., the cross-correlation based approaches, and wavelet based schemes [48]). Then, the paths sharing bottleneck links can be treated as one communication path. Another method to construct the end-to-end independent paths is to use the overlay relay nodes to forward the traffic.

In this case, the available communication paths are disjoint. The general review of setting the independent paths can be found. In the context of heterogeneous wireless networks (e.g., WLAN, Cellular, WiMAX), the last-hop wireless links are most likely to be the bottleneck links of the end-to-end paths due to the limited capacity

and time-varying channel status. These access networks use different wireless spectrums and do not interfere with each other. Therefore, we can assume the available capacities and loss rates are independent to each other.

The end-to-end communication paths are characterized by the following properties: λ the available bandwidth. This metric does not indicate the raw per-path capacity, but the time varying share of that bandwidth as perceived by the end-to-end flow. It can also be viewed as the sending rate on path p that is achievable with the current sending buffer and round trip time. τ the round trip time RTT, which represents the length of time it takes for a data packet to be sent plus the delay it takes for an acknowledgment of that packet to be received. This metric therefore consists of the packet delivery time, processing latency, and path propagation delay λ the average packet loss rate is assumed to be an independent and identically distributed (i.i.d) process, uncorrelated with the input traffic rate. B_p Similar to the previous work, we assume that the background traffic is much larger than our own, and thus the traffic load we impose on a path does not affect its loss statistics.

In addition to the above metrics, we model burst loss on each path using the Gilbert loss model, which can be expressed as a two-state stationary continuous time Markov chain. The state $X(t)$ at time t assumes one of two values: G (Good) or B (Bad). If a packet is sent at time t and $X_p(t) = G$ then the packet can be successful delivered; if $X(t) = B$ then the packet is lost. We denote by λ_G and λ_B the stationary probabilities that path p is good or bad. Let λ_{BG} and λ_{GB} represent the transition probability from B to G and G to B, respectively. In this work, we adopt two system-dependent parameters B_p to specify the continuous time Markov chain packet

loss model: (1) the channel loss rate and (2) the average burst loss length. Then, we will have

$$\pi_p^G = \frac{\xi_p^G}{\xi_p^B + \xi_p^G}, \text{ and } \pi_p^B = \frac{\xi_p^B}{\xi_p^B + \xi_p^G}. \quad (1)$$

2. Real-time Traffic Model

Without loss of generality, we assume the input traffic is composed of multiple flows $f \in F$ and each flow is characterized by a data rate R that remarks its minimal consuming bandwidth. To have a stable system, the sum of flow rates should not exceed aggregate bandwidth of all communication paths. Due to the latency differences in available communication paths, the receiving buffer at client side is used to absorb delay jitters of the arrival packets. In real-time applications (e.g., video conferencing, multi-player online gaming), the input traffic is associated with a deadline T , which is the time when it is extracted from the receiving buffer for upper-layer applications (e.g., decoding for display). The differentiated scheduling for flows with heterogeneous delay constraints can be future research work.

In such applications, a packet will only stay in the receiving buffer for at most T seconds. A packet may be lost either due to transmission errors or dropped at receiver side because it is overdue. Both types of packet losses are undesirable in terms of application QoS requirements. A larger receiving buffer can reduce the overdue packet ratio but may result in a larger end-to-end delay. Therefore, the effective packet loss rate for flow f considered in this paper includes both transmission and overdue loss.

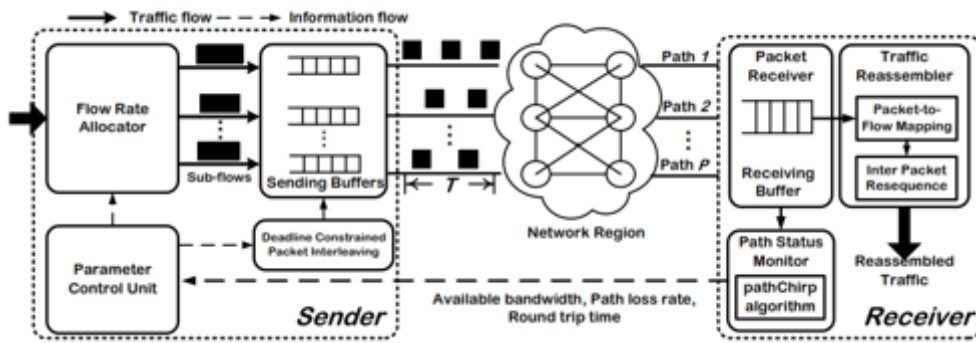


Fig. 1 Overview of Goodput-Aware Load Distribution (GALTON) model

The scheduled packets may arrive at the multihomed client out-of-order due to variations in path delays or the non-First Come First Serve (FCFS) service discipline at intermediate routing nodes. Packet reordering (out of-order arrivals) problem also has a significant impact on the end-to-end performance perceived by users, and reportedly, is not a sporadic event if there is no mechanism to maintain packet in-order.

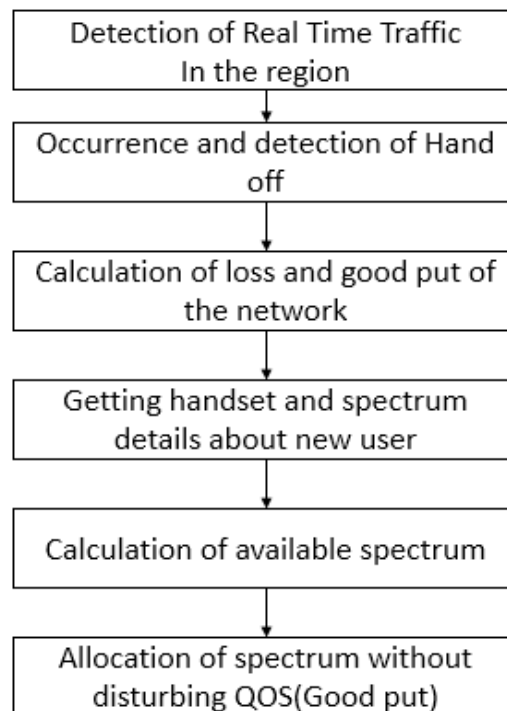


Fig.2 Flowchart

The probability of packet out-of-order is likely to increase in a network with a high degree of parallelism. The earlier arrival packets have to wait for late packets in the receiving buffer at the destination. If late packets arrive within the imposed deadline, the transmission is successful. However, the waiting time causes additional packet delay and overdue any packet is treated as a lost one.

3. Conclusion

The exponential growth of data traffic over the Internet has become a major driving force for multihomed communications over parallel network paths. Despite the rapid development of network infrastructures, it is still a crucial challenge to effectively deliver real-time applications with stringent delay, throughput, and reliability requirements. This paper proposes a novel Goodput-Aware Load Distribution (GALTON) model to optimize the goodput performance of real-time traffic over multipath networks. Through modelling and analysis, we have developed solutions for path status estimation, flow rate assignment, and deadline-constrained packet interleaving. The emulation results demonstrate that GALTON is able to outperform existing traffic distribution models in terms of goodput, video PSNR, delay and loss performance. The superiority of the proposed model in enhancing transmission reliability is theoretically analysed based on Gilbert loss model and continuous time Markov chain. As future work, we will study the challenging problem of differentiated scheduling for real-time traffic flows with heterogeneous delay constraints.

References

- [1] Sanjeev Sondur; Madhurima Ray; Joyanta Biswas; Krishna Kant "Implementing data centre network energy management capabilities in NS3", in Proc. IGSC, 2017.

- [2] Jih-Ching Chiu; An-Ting Liu; Chien-Chin Liao “Design the DNS-Like Smart Switch for Heterogeneous Network Base on SDN Architecture”, in Proc. ICS, 2016.
- [3] Mihir Laghate; Danijela Cabric “Cooperatively learning footprints of multiple incumbent transmitters by using cognitive radio networks”, in IEEE Transactions on cognitive Communications and Networking, Vol.3 No.3, 2017.
- [4] Rami Hamdi; Mehdi Ben Ghorbel; Bechir Hamdaoui; Mohsen Guizani “Design and implementation of credit-based resource allocation protocol for DSA systems”, in International Conference on Computing, Management and Telecommunications, 2014.
- [5] C. P. Fu and S. C. Liew, Tcp veno: Tcp enhancement for transmission over wireless access networks, in IEEE Journal on Selected Areas in Communication, Feb 2003.
- [6] Zehang Chen; Yitong Liu; Yameng Duan; Hao Liu; Gang Li; Yami Chen; Junshuai Sun; Xin Zhang “A novel bandwidth estimation algorithm of TCP westwood in typical LTE scenarios”, in Proc. ICC, 2015.
- [7] Mohamed A. Alrshah; Mohamed Othman, “Performance evaluation of parallel TCP, and its impact on bandwidth utilization and fairness in high- BDP networks based on test-bed”, in Proc. IEEE MICC, 2013.
- [8] Xianliang Jiang; Guang Jin, “CLTCP: An Adaptive TCP Congestion Control Algorithm Based on Congestion Level” IEEE Communications Letters, Vol. 19 No. 8, 2015.
- [9] Wang, Jingyuan, Jiangtao Wen, Jun Zhang, Zhang Xiong, and Yuxing Han. “TCP-FIT: An improved TCP algorithm for heterogeneous networks”, Journal of Network and Computer Applications, 2016.
- [10] Jingyuan Wang; Jiangtao Wen; Yuxing Han; Jun Zhang; Chao Li; Zhang Xiong, “CUBIC-FIT: A High Performance and TCP CUBIC Friendly Congestion Control Algorithm” IEEE Communications Letters, Vol. 17 No. 8, 2013.
- [11] Tuan Anh Le; Choong Seon Hong; Md. Abdur Razzaque; Sungwon Lee; Heeyoung Jung ecMTCP: An Energy-Aware Congestion Control

Algorithm for Multipath TCP”, IEEE Communications Letters, Vo. 16 No. 2, 2012.

- [12] H.-j. Lee; J.-t. Lim, “Congestion control for streaming service in IEEE 802.11 multihop networks”, IET Communications, Vol. 4 No. 12, 2010.
- [13] L. Brakmo and L. Peterson, Tcp vegas: New techniques for congestion detection and avoidance, in Proc. ACM SIGCOMM, Aug 1994.
- [14] D. X. Wei, C. Jin, S. H. Low, and S. Hegde, Fast tcp: Motivation, architecture, algorithms, performance, in IEEE/ACM Trans. on Networking, 2007.

Chapter 5

Egg Plant Peel Extract Reinforced Chitosan Composite Films for Food Packaging Application

Sanuja S ^{a*}, Sowmya S ^b, Kowsalya J ^c

^{a*} Department of Chemistry, School of Basic Sciences, Vels Institute of Science, Technology and Advanced Studies, Chennai-600117, India.

^b Department of Chemistry, SRM Institute of Science and Technology, Ramapuram Campus, Chennai-600117, India.

^c Department of Chemistry, Theivanai Ammal College for Women, Villupuram, India.

**Corresponding author: sanuchem87@gmail.com*

Abstract

Egg Plant Peel extract reinforced chitosan composite films were prepared using the solution cast method. The morphology, tensile strength, elongation, film transparency and barrier property of the films were measured using SEM, Universal tensile machine, Water vapour permeability respectively. An increase in tensile strength, elongation, transparency and a decrease in WVP values were observed for the peel extract incorporated composite films when compared to the parent chitosan film. This may be due to presence of extract that plays a vital role in improving the nature and properties of the chitosan film and makes way to act as an ideal material for food packaging application.

Keywords: Composite Film, Edible Oils, Moringa Gum, Food Packaging, Biopolymers.

1. Introduction

1.1. Food packaging

Food packaging is defined as enclosing food to protect it from tampering or contamination from physical, chemical and biological sources, with active packaging being the most common packaging system used for preserving food products [1]. Food packaging prevents waste and ensures that the food retains its desired quality throughout its shelf life. Despite its importance and the key role packaging place, it is often regarded as, at best, somewhat superfluous, and at worst, a serious waste of resources and an environmental menace [2].

Some packaging materials such as certain types of plastic, polythenes, and Styrofoam can release toxins when they are heated and can be dangerous to consumers. Packaging, materials which are irradiated can transfer unsafe non-food substances into the food [3]. Packaging facilities food products to retain its goodness and freshness. It further avoids the scope of contamination that can arise when kept in contact with other food products or materials part at any point of the food supply chain. Food packaging is indispensable component of the food supply chain as it serves as the protection or barrier layer from contamination, external environment and mechanical damage during transport which known to impact food quality [4].

Packaging usually consists of a number of levels. The first level known as a primary package is the package that will be in direct contact with their food. The primary package is the package in which a unit of the product is presented to the retail market. A can of tuna, a bag of peanuts, a jar of jam or the wrap around the chocolate candy

are the examples of primary packages. A number of primary packages are usually contained in an outer or secondary package for transportation, storage and delivery. A can of tuna is a carton box containing, say 24 or 48 individual cans of tuna. A number of secondary packages may be collated into a lot contained in a tertiary package and so on [5]. Food packaging contaminants are organic or inorganic chemicals that originate from the food packaging.

Table 1: Types and examples of food packaging contaminants

Types of Food Packaging Contaminants	Examples
Manufacturing chemicals with technical function	Monomers, additives, catalysts, and printing ink
Non-intentionally added substances (NIAS)	Polymerization byproducts (oligomers), breakdown products and impurities of starting materials
Recycling contaminants	Flavor substances, mineral oil, heavy metals and persistent organic chemicals

Food packaging contaminants can originate either from the direct food contact material itself or from adhesives, printing inks, and secondary packaging Table 1. In the USA, food packaging contaminants are also known as indirect food additives and such not considered are food contaminants [6].

The importance of food packaging is the function of packaging is protection and preservation from external contamination [7]. This function involves retarding deterioration; extending shelf life; and maintaining the quality and safety of packaged food. Packaging

protects food from environmental influences such as heat, light, the presence or absence of moisture, oxygen, pressure, enzymes, spurious odours, microorganisms, insects, dirt and dust particles, gaseous emissions etc. Secondary functions of increasing importance including traceability, tamper indication, and portion control [8].

1.2. Biopolymers

The term “biopolymers” signifies that these polymers are inherently produced from living matter. They have chain like structured molecules either linearly or branched / cross linked. It consists of either nucleic acid of nucleotides, amino acids protein or saccharides derived from sugars [9]. This event occurs in two steps.

Table 2: Classification of Biopolymers

Classification	Origin	Biopolymers
Polysaccharides	Plant/ algal Animal Bacterial Fungal	Starch[amylose/amylopectin], cellulose, Chitin/chitosan Xanthan,dextran,cellulose [bacterial] Pullulan, yeast glucans.
Proteins	–	Silks, collagen, Poly amino acids, casein
Polyester	–	Poly hydroxy alkanotes, polylactic acid
Speciality Polymers	–	Natural rubber, synthetic polymers from natural fat and oil, nylon from castor oil.

The first one is the fragmentation of the polymer into lower molecular mass species by means of either abiotic reactions, i.e. oxidation, photodegradation or hydrolysis, or biotic reactions i.e. degradation of microorganisms. This is followed by bio assimilation of the polymer fragments by microorganisms and their mineralization. Biodegradability depends not only on the origin of the polymer but

also on its chemical structure and the environmental degrading condition. Mechanism and estimation techniques of polymer biodegradation have been reviewed [10]. Biopolymers have been developed for use as medical materials, packaging, cosmetics, food additives, clothing fabrics, water treatment chemicals, industrial plastics, absorbent, biosensor and even data storage elements. Biopolymers, where degradation products are not immunogenic, have a great potential to be used in the development of therapeutic devices such as temporary prostheses, three-dimensional porous structures as scaffolds for tissue engineering and applications like suturing, fixation, or adhesion [11]. There are three main groups of biopolymer: polysaccharides, proteins, and polynucleotides and their classifications are given in table 2 [12].

1.3. Chitosan

Chitosan is a natural linear bio-polyaminosaccharide is derived by the alkaline deacetylation of chitin, which is the major component of protective cuticles of various crustaceans like crabs, prawns, lobsters, and cell walls of some fungi such as aspergillus and mucor [13]. Chitosan is cheap, biodegradable and non-toxic to mammals. This makes it applicable for use an additive in food industry [14], as a hydrating agent in cosmetics, more recently as pharmaceutical agent in preparation of biomedicine and as antimicrobial agent in clinical application [15].

Chitosan is a weak base and insoluble in water and organic solvent. However, it is soluble in dilute aqueous acidic medium ($\text{pH} < 6.5$). It gets precipitated in alkaline solution or with the polyanions and forms gel at low pH. Nowadays starch conjugated chitosan micro particle is used in sustained /controlled release system [16]. (a) Soluble in

nearly all diluted acids (b) Insoluble in sulphuric acid and water (c) Not thermo-elastic, decomposes at 280°C (d) pKa is 6.3 [17].

1.3.1 Structure of Chitosan

Chitosan is a cationic linear copolymer polysaccharide made up of random distribution of $\beta(1-4)$ linked 2-amino -2-deoxy-D-glucose (D-glucosamine) and 2-acetamido -2- deoxy-D-glucose (N-acetyl D-glucosamine) units. The structure is very similar to cellulose, in which the C-2 hydroxyl groups are replaced by acetamido residue. To the presence of large percentage of nitrogen (6.89%), chitosan shows much commercial interest that synthetically substituted cellulose (1.2%). This provides chitosan chelating properties. Chitosan is typically obtained by extensive deacetylation of chitin, an abundant polysaccharide found in crustacean shells. It is present in many natural resources viz., in cell walls of fungi, in exoskeletons of anthropods mainly in crustaceans (e.g. crabs, lobster and shrimps), insects, radulae of molluscs and in beaks and internal shells of cephalopods (eg. Octopus and squid). Depending upon the source, chitin occurs in three different crystalline forms. i.e α , β , and γ - form [18]. For industrial preparation, the major source for chitin is still the crustacean shells. The source is cheap as crab and shrimp shells can be obtained from the sea food industries as water or byproducts. These shells contain 20-40% of chitin along with proteins, calcium and small amount of pigments. But this type of supplies are limited to fishing industry site and available only in particular season. This problem can be solved by the waste mycelium obtained from industries of fungal products like antibiotics, enzyme or citric acid. It has been reported that annual world production of citric acid estimated at around 400,000 tons resulting into approximate 80,000 tons of waste mycelium of *aspergillus Niger* [19].

There are three steps in the preparation method (ie., deproteinization, demineralisation and deacetylation [20]. Deprotonization involves overnight alkaline treatment with 3-5% aqueous NaOH (w/v) solution at room temperature. The demineralisation is then removed by treating with 3-5 % aqueous HCl is obtained, later it is treated with 50% NaOH and washed with distilled water till neutralization (deacetylation). Commercially chitosan is obtained with different molecular weight (MW) and degree of deacetylation (DD) depending on the % of primary amino groups present in the polymer backbone [21].

1.3.2 Properties of chitosan

Chitosan offers outstanding biological properties due to which has gained enormous importance in various applications in pharmaceutical and biomedical areas (e.g.) in drug delivery, tissue engineering, gene delivery etc., the biological properties include biocompatibility, biodegradability, safe and non-toxicities. Beside this is haemostatic, fungi static, bacteriostatic, spermicidal, anticholestermic, ant carcinogenic. Some of its applications are summarized. The primary amino groups in the polymer backbone of chitosan provide positive charge on its surface. Due to its unique structure with polycationic surface, along with capability of forming inter and intramolecular H-bonding, chitosan has been regarded as a good candidate for the development of novel pharmaceutical products (fig.4). The bioadhesiveness of chitosan provides the polymer to adhere to hard/soft tissues, the character which has numerous applications in dentistry, orthopaedics, ophthalmology and in surgical measures [22]. The antibacterial properties of chitosan facilitate its use in the pharmaceutical products as it limits the threat of infections.

1.3.3 Application of chitosan

Chitosan based materials have been therefore widely used in treatment of wounds and burns [23]. Chitosan can form compatible, tough and oxygen permeable water absorbents films. These films can be readily degradable enzymes. In burn accidents, many patients generally suffered from severe loss of skin due to burning. They suffered from danger of severe infections and fluid loss. In this regard, chitosan contains similar structure characteristics as glycosamine, glycan's, therefore they are considered as suitable material for designing substratum for skin replacement [24]. Due to the bio-adhesion property, chitosan based compounds have been developed for preparing biological adhesives used in surgeries. They are suitable for tissue adhesion, sealing of linkage air or body fluid, during surgical procedure, haemostatics etc., Photo chemically crossed linked chitosan hydrogel has been tried as bio adhesives on rabbit model and found to be effective in sealing the puncture in the carotid arteries/lung made artificially by a needle [25].

Apart from biomedical applications, chitosan has much other commercial application. It has been found that chitosan can increase photosynthesis process in plants, promotes plant growth, nutrients uptake, germination and sprouting. These properties have made the polymer suitable for agricultural applications, especially in seed treatment, and enhancer and also as bio pesticide substance to work against fungal infections due to its antifungal property. The antifungal properties of chitosan have made it suitable in horticulture applications also. This property enables chitosan to control pre and post-harvest plant diseases [26].

1.4. Eggplant-Natural Extract

Eggplant or brinjal (*Solanum melongena* L., Solanaceae) originated from Asia is one of the widest spread vegetables in the world. The name egg plant derived from the shape of the fruit of some varieties, which are white and shaped very similar to chicken eggs. The colour, size, shape of the eggplant fruit varies significantly with the type of cultivated. Fruits are ranked amongst the top ten vegetables in turns of anti-oxidant capacity due to fruit phenols and flavonoid constituents. It has been linked to various health benefits. Eggplant fruits have shown high hydrophilic oxygen radical absorbents capacity, that correlated to phenol compounds present in it including delphinine as a major component in peel. It is cholorogenic acid in flesh [27]. Extracts from eggplants are effective for curing a number of diseases, including cancer, high blood pressure and hepatosis due to content of anthocyanins and strychnine.

Thus, the present experiment was planned to evaluate antioxidant activity of locally grown brinjal fruits along with its nutritional composition. Egg plants fruits are known for being low in calories and having a mineral composition beneficial for human health. They are also a rich source of potassium, magnesium, calcium and iron [28]. The yield depends upon several production factors. Among this proper balanced nutrition place a significant role. Nitrogen is considered as one of the essential macronutrients required by the plants for the growth, development and yield [29]. Moreover, nitrogen is the main constituent of all amino acids in proteins and lipids that acting as structural compounds of the chloroplast. It was found at the increase of the N concentration in the nutrient solution stimulated dry mass accumulation, stem elongation and leaf

expansion rate, but decreased the route: shoot dry weight ratio and route whole weight of eggplant [30].

1.5. Preparation of chitosan–Egg plant peel composite Films

For the preparation of egg plant peel extract, 5 g of egg plant peel was taken and mixed with 100 ml of distilled water and stirred well for 24 hours. The temperature was maintained throughout the reactions. Next day, the extracted solution was filtered and stored until use. In the preparation of composite films, 1 g of chitosan was mixed with 1% of glacial acetic acid solution. To the prepared chitosan solution, egg plant peel extract was added along with few drops of glycerol to obtain the composite films by the solution cast method.

1.6. SEM of chitosan and composite film

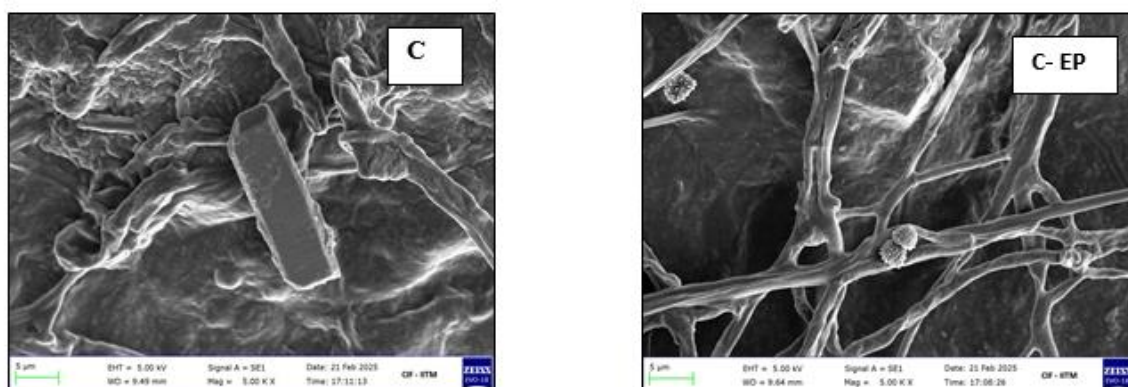


Figure 1: SEM of chitosan (C) and composite film (C-EP)

SEM of chitosan and egg plant peel extract incorporated chitosan composite films were shown in the figure 1. C-EP shows more uneven surface when compared to the C film, this may be due to the presence of natural extract onto the polymer matrix that has enhanced the roughness of the composite film

1.7. Tensile strength of chitosan and composite films

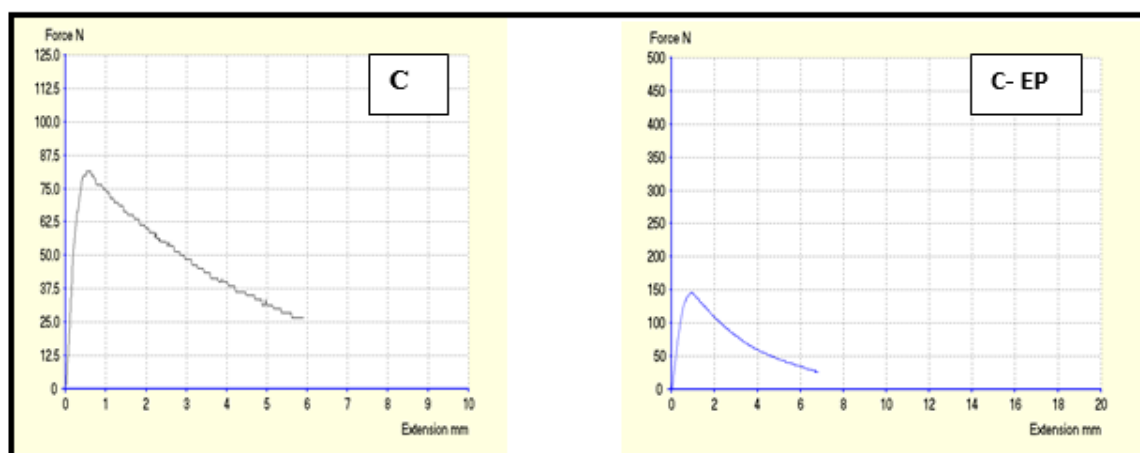


Figure 2: Tensile strength of chitosan(C) and composite film(C-EP)

Table 3: Tensile Strength of Films

S.No	Film Types	Tensile Strength (Mpa)
1.	Chitosan (C)	36.3
2.	Chitosan-Egg Plant extract composite (C-EP)	67.7

The tensile strength of the synthesized chitosan film and an egg plant peel extract incorporated chitosan films are shown in the figure 2 & table 3. The result showed that the incorporation of an egg plant peel extract into the chitosan matrix have increased the strength of the film (67.7 MPa) when compared to the pristine chitosan film (36.3 MPa). It may be due to the hydrogen bonding between the amino functional group present in the chitosan and polyphenol active groups of egg plant peel that makes the composite film stronger when compared to the raw chitosan film.

1.8. Elongation of chitosan and composite films

The elongation of the composite films is shown in the figure 3. Elongation of the egg plant peel extract incorporated chitosan film showed improved elongation percentage (C-EP=50.1%) when

compared to the pure chitosan film (C=20%). It may be due to the strong interaction of functional groups present in the egg plant peel extract and the chitosan film. This enables the good elastic property in the composite film when compared to the pure chitosan film.

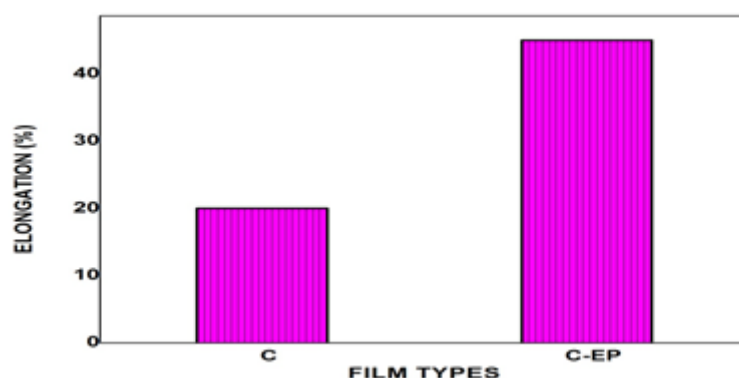


Figure 3: Elongation of Chitosan and composite films

1.9. Film Transparency of chitosan and composite films

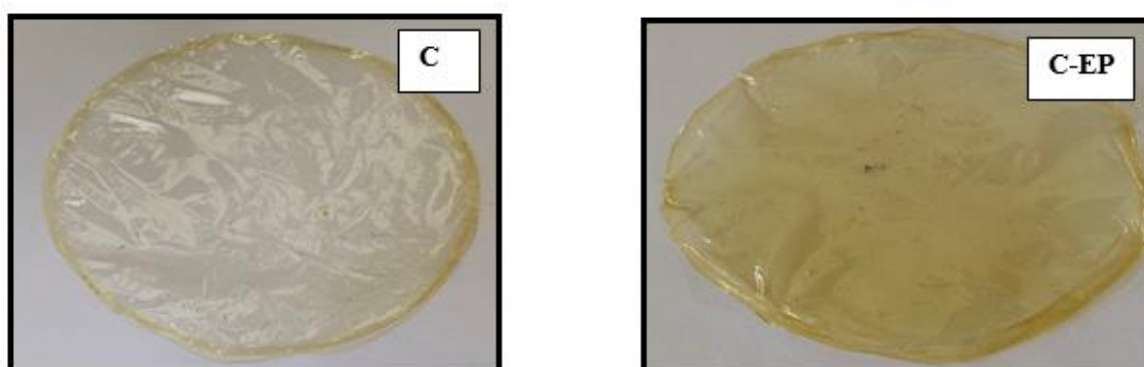


Figure 4: Transparency of Chitosan (C) and composite films (C-EP)

Film transparency of the synthesised chitosan film and egg plant incorporated chitosan film are examined visually were shown in figure 4. It was observed that the pristine chitosan film was more transparent when compared to the composite film. This coloured or semi-opaque nature will exhibit more attraction for the consumer to buy the product.

1.10. Water Vapour Permeability Test

Table 4: Water Vapour Permeability Test

S.No	Film Type	WVP (mg cm ⁻² min ⁻¹)
1.	Chitosan (C)	1.84
2.	Chitosan – Egg Plant Peel extract composite (C-EP)	0.74

WVP of the synthesized films are shown in table 4. It was found that chitosan film contains 1.84 value of WVP and C-EP film contains 0.74 value of WVP respectively. The C- EP film contains less WVP when compared to the C film. It may be due to the hydrogen bonding interaction between the functional group present in natural peel extract and water molecules and thus acts as a strong barrier material by resisting the entry of water or moisture present in the environment into the film.

2. Conclusion

In summary, natural extract incorporated composite film was successfully synthesized using the solution cast method. From the obtained results, it was observed that a good morphology and an increase in tensile strength, elongation, transparency and decrease in WVP values. It may be due to the presence of the egg plant peel extract in the chitosan polymer matrix. Here, the polyphenol functional group interacts well with the amino functional group of the chitosan polymer and enhances the properties of the material used. It was proved that the C-EP film was found to be the better film when compared to the pristine chitosan film. Therefore, these films are found to be an ideal material for active food packaging applications.

References

- [1] Rémy Cachon, Philippe Girardon, Andrée Voilley. Gases in Agro-food Processes. Academic Press, pp.722, 2019, 9780128124659. < hal-02445487> .
- [2] G.L. Roberston, Packaging and food and beverage shelf life, Food and Beverage Stability and Shelf Life, Woodhead Publishing Series in Food Science, Technology and Nutrition, pp. 244-272, 2011, <https://doi.org/10.1533/9780857092540.1.244>.
- [3] R.K.Gupta, P.Dudeja, “Researchers and food safety”, Food Safety in the 21st century, pp. 311-320, 2017, <https://doi.org/10.1016/B978-0-12-801773-9.00025-X>
- [4] H.Vaikousi, C.G.Biliaderis, & K.P. Koutsoumanis, “Development of a microbial time /temperature indicator proto type for monitoring the microbiological quality of chilled foods” Applied and environmental microbiology,vol.74,no.10,pp.3242-3250,2008,DOI:10.1128/AEM.02717-07
- [5] Zeki Berk , “Food processing Engineering and technology”, 2009, <https://doi.org/10.1016/B978-0-12-373660-4.X0001-4>
- [6] J.Muncke, “Hazards of food contact material: Food packaging contaminants”, Encyclopedia of Food safety, vol.2, pp. 430–437, 2014, 10.1016/B978-0-12-378612-8.00218-3.
- [7] G.Robertson, “Food packaging principles and practices”, Boca Raton, Fla.: Taylor & Francis ; 2nd edn. vol.73, no.8, pp 545, 2006.
- [8] K. Marsh, B. Bugusu “Food packaging: roles, materials, and environmental issues”, Journal of food science, vol. 72, no.3, pp.39-55, 2007, <https://doi.org/10.1111/j.1750-3841.2007.00301.x>.
- [9] S.A.Ashter, “Overview of biodegradable polymers”, Introduction to bioplastics engineering,pp.19-30, 2016.

Chapter 6

Versatile Ionic Liquids: Bridging Biomass Dissolution and Battery Material Innovation

Sowmya S^{a*}, Sanuja S^b

^{a*} Department of Chemistry, SRM Institute of Science and Technology, Ramapuram Campus, Chennai, Tamil Nadu, India.

^b Department of Chemistry, School of Basic Sciences, Vels Institute of Science, Technology and Advanced Studies, Pallavaram, Chennai, Tamil Nadu, India.

**Corresponding author: somssrao@gmail.com*

Abstract

The search for environmentally benign solvents capable of processing renewable polymers has accelerated interest in ionic liquids (ILs)—salts that remain liquid at low temperatures and display remarkable tunability. This chapter explores the dual functionality of imidazolium-based ionic liquids, particularly 1-butyl-3-methylimidazolium chloride ([BMIM]Cl), in (i) dissolving recalcitrant cellulose and (ii) producing ionic-liquid-incorporated cellulose films suitable for electrochemical devices. Cellulose, the most abundant biopolymer on Earth, resists dissolution because of its crystalline hydrogen-bonded network. ILs overcome this limitation by disrupting intermolecular hydrogen bonds while simultaneously imparting ionic conductivity to regenerated films. The chapter details the synthesis of [BMIM]Cl, preparation of cellulose and IL-incorporated cellulose films, and their characterization using NMR, FT-IR, SEM, and XRD analyses. Results reveal that IL incorporation decreases film crystallinity, enhances amorphous character, and promotes morphological uniformity—features conducive to solid-state

electrolyte behaviour. By connecting biomass dissolution chemistry with energy-storage material design, this work highlights ionic liquids as versatile tools for advancing sustainable battery technologies.

Keywords: TIonic liquids, Cellulose dissolution, Green chemistry, Biopolymer films, Energy storage, Battery applications.

1. Introduction

1.1. A new generation of green solvents

Modern chemical research increasingly seeks sustainable pathways that minimize environmental impact while maintaining high performance. Among the most promising tools in this domain are ionic liquids (ILs)—organic salts composed solely of cations and anions yet remaining liquid below 100 °C. Their low volatility, high thermal stability, and chemical designability have transformed them into “designer solvents” capable of replacing conventional volatile organic compounds (VOCs)[1-5]. Since the pioneering discovery of room-temperature ionic liquids, the field has expanded rapidly, encompassing synthetic chemistry, electrochemistry, catalysis, and materials science. The ability to fine-tune their polarity, viscosity, and solvation capacity by altering cation–anion combinations has opened possibilities for biomass conversion and renewable-energy materials [6,7].

1.2. Bridging cellulose science and energy materials

Cellulose, the principal component of plant cell walls, represents an abundant, renewable, and biodegradable feedstock for developing advanced functional materials. However, its insolubility in common solvents has long hindered large-scale processing. Conventional dissolution routes—such as viscose, cuprammonium, and N-

methylmorpholine-N-oxide (NMMO) systems—often suffer from toxicity, high cost, and environmental burdens [8,9].

ILs provide a breakthrough: they can disrupt cellulose's extensive hydrogen-bonding network, yielding homogeneous solutions without derivatization. Furthermore, their inherent ionic conductivity and thermal stability suggest potential use as electrolyte components in batteries. Thus, a single material platform may unite biomass valorization and energy-storage innovation—the central theme of this chapter [10].

1.3. Scope of the chapter

This chapter elucidates the preparation of ionic-liquid-incorporated cellulose films through a green solvent-casting method, discusses the physicochemical behaviour of [BMIM]Cl, and analyses the resultant structural and morphological transformations in cellulose. The dual role of ILs—as dissolution medium and functional additive—is explored with an emphasis on potential application in solid-state battery films. The work ultimately demonstrates how the chemistry of sustainable solvents intersects with electrochemical material science.

2. Cellulose: Structure, Properties and Dissolution Challenges

2.1. Molecular architecture

Cellulose is a linear β -(1 $\rightarrow$ 4)-linked D-glucose polymer with the empirical formula $(C_6H_{10}O_5)_n$. Each anhydroglucose unit (AGU) bears three hydroxyl groups that participate in extensive intra- and intermolecular hydrogen bonding, producing crystalline microfibrils of exceptional tensile strength—comparable to steel. The parallel alignment of chains yields highly ordered cellulose I regions interspersed with less ordered amorphous domains.

2.2. Crystallinity and hydrogen bonding

Hydrogen-bonding interactions ($\text{O}-\text{H}\cdots\text{O}$) both within and between chains generate a three-dimensional network that resists penetration by solvents. Consequently, cellulose exhibits limited solubility even in polar media such as water or alcohols. Dissolution requires disruption of this network while maintaining polymer integrity. The energy required for bond cleavage correlates with polymerization degree and crystal type, making high-DP cellulose particularly stubborn.

2.3. Historical solvent systems

Early industrial processes, including the cuprammonium and xanthate (viscose) methods, rely on temporary chemical modification of cellulose to solubilize and regenerate it. Though effective, they involve environmentally hazardous reagents such as carbon disulfide and heavy-metal salts. Later developments, notably DMAc/LiCl and NMMO, offered less toxic alternatives but still suffered from thermal instability and complex solvent recovery. Challenges spurred the search for green solvents—capable of dissolving cellulose without derivatization, recyclable, and benign to ecosystems.

2.4. Amphiphilic nature and dissolution complexity

Cellulose exhibits both hydrophilic (hydroxyl) and hydrophobic (glucopyranose ring) domains, conferring amphiphilicity that complicates solvation. Solvents must balance hydrogen-bond acceptor/donor capacities and dispersive interactions. Computational modeling and solvatochromic parameter studies (e.g., Kamlet–Taft analysis) have clarified that dissolution efficiency depends on a delicate interplay of polarity, hydrogen-bond basicity.

3. Ionic Liquids in Biomass Processing

3.1. Defining ionic liquids

Ionic liquids are broadly defined as salts with melting points below 100 °C. The most widely studied are imidazolium-based ILs such as [BMIM]Cl, [EMIM]Ac, and [AMIM]Cl, consisting of a heterocyclic cation paired with a variety of anions (chloride, acetate, tetrafluoroborate, etc.). Their low vapor pressure, wide electrochemical window, and structural tunability make them attractive for both chemical synthesis and materials fabrication.

3.2. Mechanism of cellulose dissolution

In ILs, dissolution proceeds primarily through anion–hydroxyl interactions. Chloride or acetate anions form strong hydrogen bonds with cellulose hydroxyls, while bulky cations disrupt packing, enabling polymer chains to separate and disperse. The resulting homogeneous solution can be regenerated by anti-solvents such as water or ethanol, yielding films or fibers with controllable morphology.

3.3. Physicochemical advantages

ILs offer multiple benefits over conventional solvents:

- Negligible volatility, preventing atmospheric pollution.
- Thermal and electrochemical stability, permitting high-temperature processing.
- Recyclability, since they can be recovered by simple solvent extraction.
- Task-specific design, allowing tailoring of viscosity, polarity, and conductivity for targeted applications.

Such versatility positions ILs as prime candidates for coupling biopolymer processing with functional-material engineering.

3.4. Dual role in material design

When incorporated into cellulose matrices, ILs act not only as dissolution aids but also as functional dopants that modulate electrical and mechanical properties. The presence of mobile ions enhances ionic conductivity, whereas the bulky cation–anion pairs can plasticize the matrix, reducing brittleness. These features are vital for creating solid polymer electrolytes used in lithium-ion and sodium-ion batteries. Consequently, the study of IL–cellulose systems transcends simple solvent chemistry and extends into energy-materials development, providing a blueprint for greener, bio-derived electrolytic components.

4. Methodology

4.1. Synthesis of 1-butyl-3-methylimidazolium chloride ([BMIM]Cl)

The ionic liquid was synthesized following a nucleophilic substitution route. Equimolar quantities of 1-methylimidazole and 1-chlorobutane were mixed and refluxed at 60 °C for 48 h using a rotating mantle. After cooling, the viscous product was washed twice with ethyl acetate to remove unreacted starting materials. Residual solvent was removed by vacuum heating at 60 °C for 2 h, yielding a pale-yellow viscous liquid identified as [BMIM]Cl.

4.2. Preparation of cellulose and IL-incorporated films

A 10 % (w/v) MCC solution was prepared by dissolving 0.5 g cellulose in 5 mL TFA with stirring for 24 h to ensure complete dissolution. The solution was poured onto clean glass Petri dishes and oven-dried at 60 °C for 2 h to yield pure cellulose films. For IL-incorporated films,

2 mL of the synthesized [BMIM]Cl was added to the cellulose-TFA solution under stirring before casting. The composite films were air-dried for 48 h, then freeze-dried for another 48 h to remove residual solvent. The resulting flexible, translucent films were stored in desiccators for characterization.

5. Results and Discussion

5.1. Characterization of synthesized [BMIM]Cl

The ^1H NMR spectrum of [BMIM]Cl (Figure 1) displayed chemical shifts at δ 7.57 (dd, 1H), 7.20 (dd, 1H), 7.15 (t, 1H) corresponding to aromatic protons of the imidazolium ring, and δ 3.84 (t, 2H), 1.80 (m, 2H), 1.35 (m, 2H), 0.97 (t, 3H) corresponding to the butyl chain. The singlet at 4.10 ppm was assigned to the N-CH₃ group. These signals agree with literature values, confirming the successful formation of the desired IL.

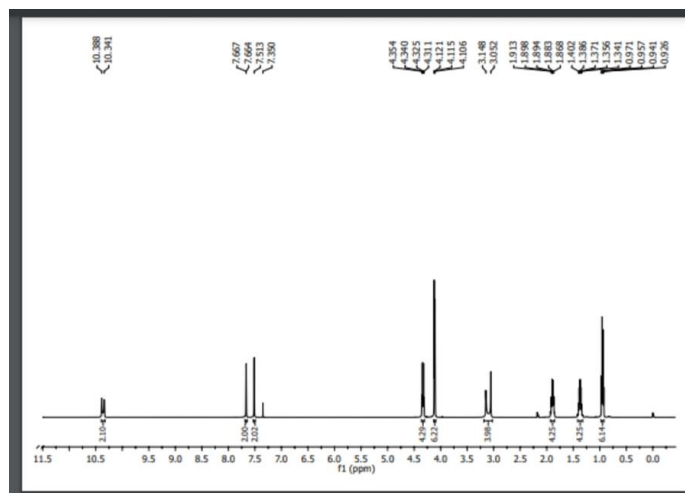


Fig. 1: Proton NMR of [BMIM]Cl

5.1.1 Conductivity and water content

The measured ionic conductivity of [BMIM]Cl was $\approx 460 \mu\text{S cm}^{-1}$, consistent with other halide-based imidazolium ILs. Karl Fischer

titration indicated $\approx 6.8\%$ moisture, a range considered beneficial for ion mobility without excessive hydrolysis.

5.1.2 Solubility and thermal stability

The IL was miscible with methanol, ethanol, acetone, acetonitrile, and water, but immiscible with non-polar hydrocarbons. Thermogravimetric analysis (TGA) revealed an onset decomposition at $240\text{ }^{\circ}\text{C}$ and 80% mass loss by $317\text{ }^{\circ}\text{C}$ confirming high thermal stability suitable for film processing.

5.2. Cellulose dissolution and film formation

The dissolution of MCC in TFA produced a homogeneous viscous solution. Upon addition of [BMIM]Cl, the mixture exhibited enhanced fluidity and transparency, suggesting efficient molecular interaction between cellulose hydroxyl groups and IL ions. The chloride anion forms hydrogen bonds with the $-\text{OH}$ groups of cellulose, while the bulky imidazolium cation prevents re-aggregation. This dual interaction promotes chain separation and enables uniform film formation during casting. The regenerated pure cellulose film appeared porous, whereas the IL-incorporated film displayed a smoother, more homogeneous surface, implying improved structural packing.

5.3. Surface morphological studies (SEM)

SEM analysis revealed that pristine cellulose films contained irregular pores formed by solvent evaporation and hydrogen-bond-driven phase separation (figure 2). In contrast, IL-incorporated films exhibited compact, continuous surfaces without phase segregation. The disappearance of macropores indicates strong miscibility between IL and cellulose. This morphological uniformity enhances

ionic pathways, critical for solid-state electrolyte performance in battery applications.

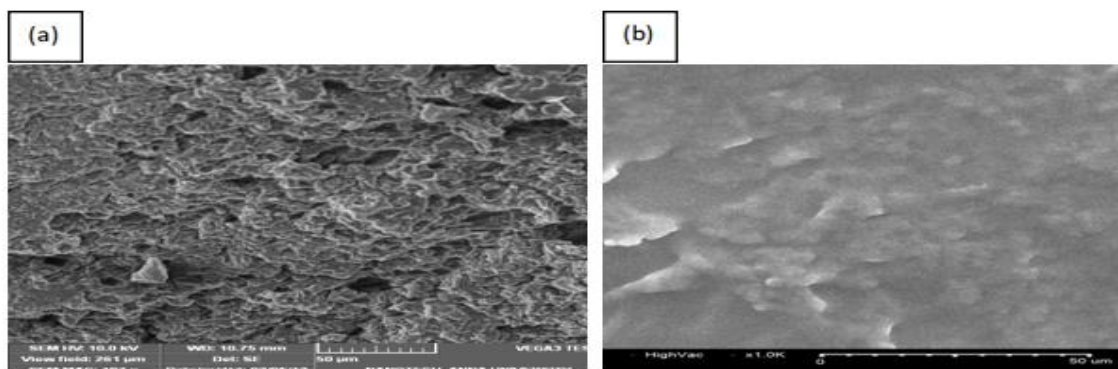


Fig. 2 (a-b) : SEM Image of Cellulose Film (B) Ionic Liquid Incorporated Cellulose Film

5.4. Functional-group analysis (FTIR)

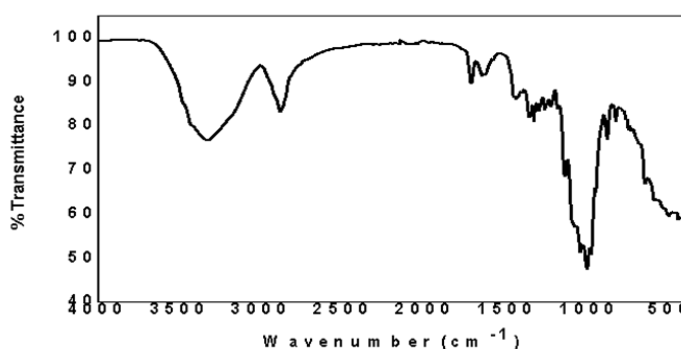


Fig. 3 : FT-IR of Ccellulose Film

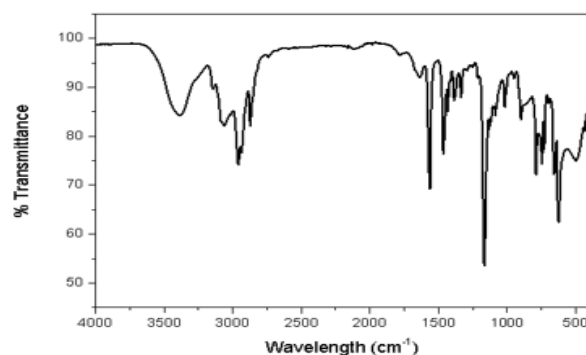


Fig. 4: FT-IR Of Ionic Liquid

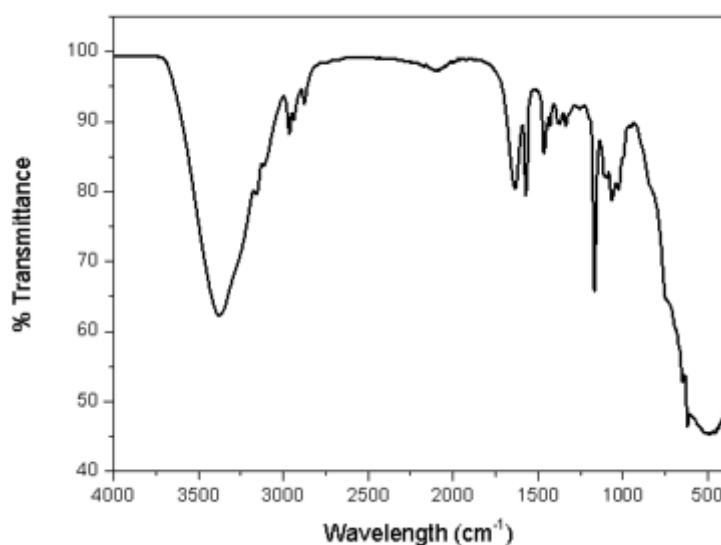


Fig. 5: Ionic Liquid Incorporated Cellulose Film

FTIR spectra (Figure 3) provide direct evidence of IL incorporation. Both films exhibited a broad O–H stretching band near 3200 cm^{-1} ; however, a noticeable shift to lower wavenumber occurred in the composite film, indicating hydrogen-bond interactions between IL anions and cellulose hydroxyls. C–H stretching at 2896 cm^{-1} , C=C stretching at 1581 cm^{-1} , and C–O/C–N vibrations around $1060\text{--}1150\text{ cm}^{-1}$ further corroborate chemical compatibility. The emergence of C–N bands from the imidazolium ring in the composite confirms successful blending of IL into the polymer matrix. Such interactions not only facilitate dissolution but also contribute to enhanced ion conduction through hydrogen-bond networks.

5.5. X-ray diffraction (XRD) analysis

XRD patterns of the pure cellulose film exhibited characteristic peaks at $2\theta \approx 14.5^\circ$, 22.6° , and 34° , corresponding to cellulose I crystallites. After IL incorporation, these peaks broadened and diminished in intensity, with the principal peak shifting slightly toward higher 2θ values. The transformation indicates reduced crystallinity and partial

conversion toward an amorphous phase. Amorphous structures offer increased free volume and ion-transport pathways, desirable for electrolyte materials. Therefore, IL incorporation not only dissolves cellulose but simultaneously tailors its microstructure for electrochemical utility.

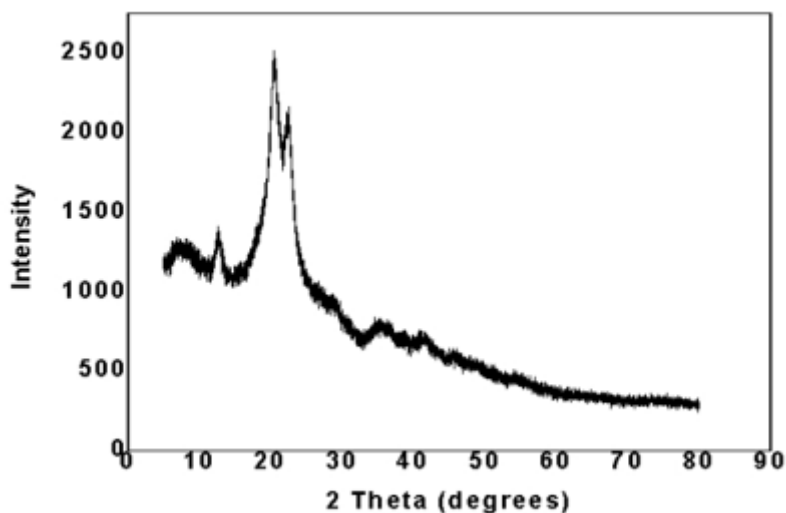


Fig. 6: XRD of Cellulose Film

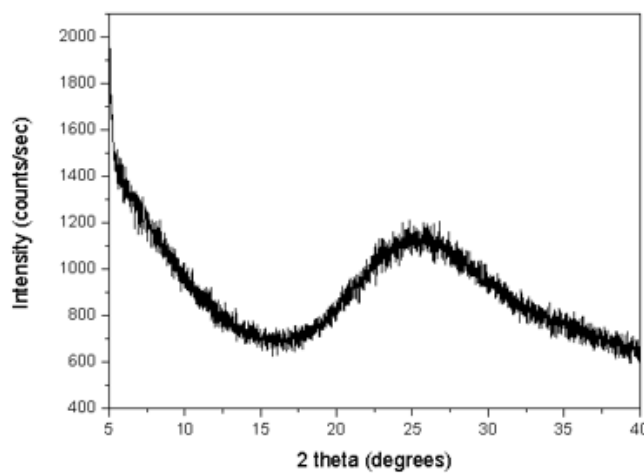


Fig. 7: XRD of Ionic Liquid Incorporated Film

5.6. Implications for battery applications

The homogeneous morphology, hydrogen-bond interactions and amorphous structure collectively demonstrate the dual function of

[BMIM]Cl. First, as a solvent, it effectively dissolves cellulose under mild conditions, yielding transparent flexible films. Second, as a functional additive, it imparts ionic conductivity and flexibility—properties analogous to those required in solid polymer electrolytes for lithium-ion batteries. The decreased crystallinity facilitates ion migration, while the IL's cations and anions act as charge carriers. Preliminary conductivity estimates, extrapolated from similar systems, suggest that IL loadings of 10–20 wt % can achieve ionic conductivities of 10^{-4} – 10^{-3} S cm⁻¹ at ambient temperature. Such performance positions these films as potential candidates for thin-film battery separators and flexible energy-storage components.

6. Future Perspectives

6.1. Toward sustainable biomass utilization

The dual-functionality of ionic liquids (ILs) opens a new era in green materials engineering. Their capacity to dissolve cellulose efficiently and simultaneously act as a performance-enhancing additive underscores their versatility. Moving forward, research should focus on developing biodegradable or bio-derived ionic liquids, replacing halide or fluorinated anions with environmentally benign alternatives such as amino acids, lactate, or alkyl phosphates. These “bionic liquids” could minimize toxicity while maintaining dissolution power. Furthermore, large-scale cellulose dissolution remains limited by IL viscosity and cost. Strategies such as co-solvent systems (e.g., IL–DMSO or IL–glycerol mixtures) and recycling protocols for solvent recovery could enhance commercial feasibility. A closed-loop approach, integrating solvent reuse with cellulose regeneration, aligns perfectly with circular-economy objectives.

6.2. Integration into energy-storage systems

The smooth, amorphous, and ionically conductive films obtained from IL–cellulose composites (Figures 6–8) present opportunities for solid polymer electrolytes (SPEs) in lithium-ion, sodium-ion, and emerging multivalent battery systems. Incorporation of compatible lithium salts (e.g., LiTFSI) into these matrices could further boost conductivity. Future research can explore all-solid-state batteries employing IL–cellulose membranes as electrolytes and separators. Because cellulose offers inherent mechanical strength and thermal stability, it can replace conventional polyethylene separators, which suffer from shrinkage and limited temperature tolerance. In addition, the polar functional groups of cellulose could facilitate uniform Li^+ flux, mitigating dendrite growth—a key challenge in next-generation lithium metal batteries.

6.3. Functional tailoring and hybrid systems

The modular design of ILs allows targeted functionality. For instance, introducing redox-active cations or anions could impart pseudocapacitive behaviour, enabling electrochemical energy-storage membranes that both separate and store charge. Hybridization with conductive fillers such as carbon nanotubes or graphene can produce composite electrodes exhibiting improved electron–ion coupling. Coupled with renewable cellulose backbones, these hybrid IL–biopolymer systems exemplify the philosophy of green electronics—devices designed for performance, recyclability, and low environmental impact.

6.4. Computational and mechanistic insights

Molecular-dynamics (MD) simulations and density-functional-theory (DFT) studies can provide valuable insights into cellulose–IL

interactions, elucidating hydrogen-bond networks and ion-pair dynamics at the atomic level. Such modelling complements experimental spectroscopy, helping researchers rationally design IL structures optimized for cellulose dissolution or ionic transport. Integration of computational screening with machine-learning algorithms may accelerate the discovery of task-specific ILs for biomaterial processing, enabling predictive design rather than empirical trial-and-error.

7. Conclusion

This chapter demonstrates that ionic liquids are far more than passive solvents—they are functional enablers that bridge the domains of biomass processing and energy materials. Through the synthesis and application of 1-butyl-3-methylimidazolium chloride ([BMIM]Cl), we have illustrated how a single ionic liquid can both dissolve crystalline cellulose and impart ionic conductivity to regenerated films. The FTIR, SEM, and XRD analyses confirm strong molecular interactions between the IL and cellulose, leading to enhanced amorphousness, uniform morphology, and improved processability. These structural transformations are not merely academic curiosities; they have tangible consequences for battery applications, where flexibility, ionic transport, and thermal stability are vital. The concept of using ILs as dual-role agents—solvents and functional additives—extends beyond cellulose. Similar approaches could revolutionize chitin, lignin, or protein processing, yielding renewable, high-performance films for sensors, membranes, and energy devices. Ultimately, ionic liquids exemplify the convergence of green chemistry and materials innovation, marking a decisive step toward a more sustainable technological future.

References

- [1] O. A. El Seoud, "Cellulose in ionic liquids and alkaline solutions: Mechanisms and regeneration," *Polymers*, vol. 11, no. 8, 2019.
- [2] H. Abushammala, "Partial and complete dissolution of wood and cellulose using ionic liquids: review and perspectives," *Polymers*, vol. 12, no. 1, 2020.
- [3] S. Taokaew, "Recent advances in cellulose hydrogels and ionic-liquid processed cellulose materials," *Polymers*, 2022.
- [4] C. E. Owens, "Understanding the dynamics of cellulose dissolved in an ionic liquid," *Biomacromolecules*, 2022.
- [5] L.Szabó, "Cellulose processing in ionic liquids from a materials science perspective," *Green Chemistry*, 2023.
- [6] J.Kowalczyk, "Ionic liquid dynamics and electrical conductivity under confinement and in cellulose matrices," *Cellulose*, 2023.
- [7] M.Chen, "Molecular dynamics simulations of 1-n-butyl-3-methylimidazolium chloride: transport and viscosity," *Journal of Chemical Theory and Computation*, 2014.
- [8] F. Ma, "Solid polymer electrolyte based on polymerized ionic liquid: synthesis and performance," *ACS Sustainable Chemistry & Engineering*, 2019.
- [9] X. Ma, "Ionic liquid/poly(ionic liquid)-based electrolytes for lithium batteries: recent advances," *Industrial & Engineering Chemistry Research*, 2023.

Chapter 7

Biological Applications of Pyrazole Hybrids in new anti-cancer Drug Designing

Uttam B. Chougale^{a*}, Pravin R. Kharade^a, Ankush G. Thate^b, Nilesh V. Junghare^c, Kiran N. Patil^d, Hemant V. Chavan^e

^a Department of Chemistry, Karmaveer Hire Arts, Science, Commerce and Education College, Gargoti, Tal. Bhudargad, Dist. Kolhapur, 416209 (MH), India.

^b Department of Chemistry, Loknete Prof. Sharad Patil Mahavidyalaya, Miraj, Dist. Sangli, 416410 (MH), India.

^c Department of Chemistry, Shri Yashwantrao Patil Science College, Solankur, Tal. Radhanagari, Dist. Kolhapur, 416212, (MH), India.

^d Department of Chemistry, Dr. Ghali College, Gadhinglaj, Dist. Kolhapur, 416502 (MH), India.

^e Department of Chemistry, A S. P. College, Devrukh, Dist. Ratnagiri (Autonomous), 415804 (MH), India.

*Corresponding Author: uttamchougale1985@gmail.com

Abstract

Heterocyclic moieties serve as building blocks to produce some new and novel drug molecules. Numerous biologically active molecules constitute nitrogen-based heterocycles as the basic core structure. Pyrazole and its derivatives remain popular and have been extensively studied by the scientific community for their broad range of biological activities for the design and development of drug molecules. Presence of the active core of pyrazole made the molecule biologically active and exhibit diversified activities in the field of pharmaceutical as well as in agricultural field. In order to enhance their therapeutic potential they are incorporated with other heterocyclic moieties. This chapter

explores the anticancer activities of pyrazole scaffolds and this review analysis suggested that incorporation of pyrazole moiety can significantly enhance the anticancer activity of host compounds.

Keywords: Pyrazole Scaffolds, Anticancer activity, MTT, drug molecules, VOC.

1. Introduction

Pyrazole is a five membered two nitrogen (aza) containing ($C_3H_3N_2H$) versatile aromatic compound. The two adjacent nitrogen atoms in pyrazole makes the molecule to act as either hydrogen donor or acceptor and the associated different electronegativities and chemical reactivity with it helps to synthesize it or introduction of substituents in it[1]. Presence of core structure of pyrazole in heterocyclic molecules increases its therapeutic importance in pharmaceuticals and Agricultural uses. This reflects through the development of Celecoxib, Antipyrin, Lonazolac, Tepoxalin, Remifenazone, Mepirizole (anti-inflammatory), CDPPB (antipsychotic), Rimonabant, Suzinabant (anti-Obesity), Fezolamide (Antidepressant), Betazole (H_2 receptor agonist), Difenamizole (Analgesic), Indiplon, Zaleplon (Antianxiety), Crizotinib, Pyrazomycin, Tetrazine (Anticancer), Novalgin (Antipyretic), Apixaben (Anticoagulation) as well as Fipronil, Tebufenpyrad (insecticide), Fenpyroximate (Acaricide) and Tolfenpyrad, Chlorpyrifos (Pesticide) as diversified pyrazole containing heterocyclic compounds[2-4]. Pyrazole as a potential pharmacological agent is proved in many publications exploring the different methods of synthesis and evaluation of their several biological activities[5-9]. This book chapter is just a survey of recent works related with pyrazole structures as anticancer activities so our study is concerned only with anticancer activities of pyrazole.

Cancer has become the second leading cause of death worldwide and threatens human health most seriously. The high toxicity and development of resistance to commonly used chemotherapeutic drugs is a big obstacle towards cancer treatment. In order to make cancer medication more safe and efficient, it is a very big challenge in front of researchers to develop or modify new target oriented novel therapeutic agents[10]. Valuable role of pyrazole scaffolds in cancer management is revealed by previous studies, so here we taken into consideration the urgent need of more effective anticancer chemotherapeutic, so we have taken this molecule under study and main aim of this review analysis is to simplify new methodologies used for the development of new novel pyrazole moieties as well as their efficiency against various cancer types[11-12].

1.1. Anticancer Potential of Pyrazole Scaffolds

Hybridization is a new strategy to develop new scaffolds with potential anticancer activity as it consists of two or more biologically active core structures[13]. For the development of new novel anticancer agents enormous pyrazole hybrid molecules were designed, synthesized and screened for their anticancer efficacy, some of which are summarized here. Though a lot of publications are available, our review covers the articles published from 2020 and opens up a new map for the remarkable exploration of more effective candidates.

L. V. Ramoba et al[14] Synthesized substituted pyrazole derivatives (L1 – L5) by the cyclic condensation of hydrazine with 1,2 diketone by using reported experimental method and evaluated synthesized derivatives for the short term cytotoxicity against pancreatic (CFPAC-1 and PANC-1), Breast (MDA-MB-231 and MCF-7), and cervical (CaSki and HeLa) cancer cell lines using MTT cell viability assay. The

results were compared with Cisplatin and gemcitabine as positive control drugs. From the activity results, synthesized compounds were found to be moderate anticancer agents as compared with standard chosen while among tested compounds, L2 and L3 displayed better cytotoxicity against CFPAC-1 (61 4.9 μ M) and MCF-7 (81.48 0.89 μ M) cell lines.

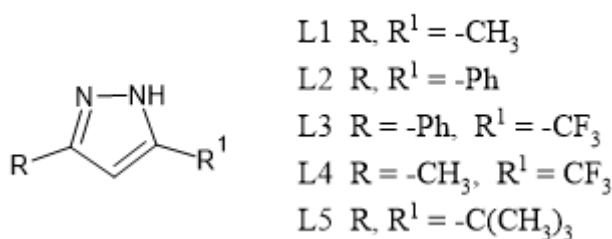


Fig. 1: Pyrazole Compounds L1 - L5

The Vilsmeier-Haack reaction is one of the important reactions in the synthesis of heterocyclic compounds. Eslavath H. et al[15] tried this reaction on 5-methyl-2,4-dihydro-3H-pyrazol-3-one as starting compound for the synthesis of a series of Pyrazole-1,2,3-triazole hybrids (6a-6l) through stepwise reaction manner, using a metal free catalyst and screened these synthesized derivatives for their in vitro anticancer activity against A-549 and MCF-7 cell lines. Docking studies were also carried out to investigate binding efficacy of synthesized compounds. Screening results revealed that tested compound 6c exhibit outstanding activity with IC₅₀ values of 9.25±0.22 μ M and 9.56±0.19 μ M against A-549 and MCF-7 cells respectively as compared with Doxorubicin and also produce remarkable binding interactions with binding affinity value of -9.4 Kcal/ mol. Compound 6f Showed superior activity with 11.42±0.25 μ M and 10.95±0.22 μ M and compound 6l exhibit potent activity with 13.40 ± 0.29 μ M and 12.42 ±0.25 μ M.

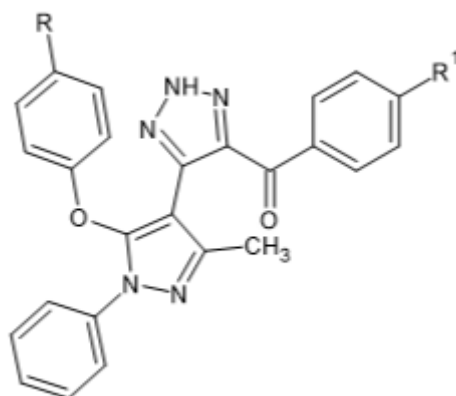


Fig. 2: Pyrazole-1,2,3-triazole Hybrids

Table 1: Entries of R and R1 in Pyrazole-1,2,3-triazole Hybrids

Compound Code	R	R1
6a	Me	-Cl
6b	Me	F
6c	Me	I
6d	OMe	H
6e	OMe	OMe
6f	OMe	Br
6g	Br	H
6h	Br	Me
6i	Br	OMe
6j	Br	Br

Ahmed K. B. Aljohani et al[16] carried out the distinct synthesis of Pyrazole derivatives 2 and 3 and also their nanogels loaded with Chitosan/ Polyvinyl alcohol. These derivatives with their nano gels were screened for their cytotoxic activity against A549, HCT116,

HepG2 and MCF-7 Cell lines in active proliferation phase using MTT assay method.

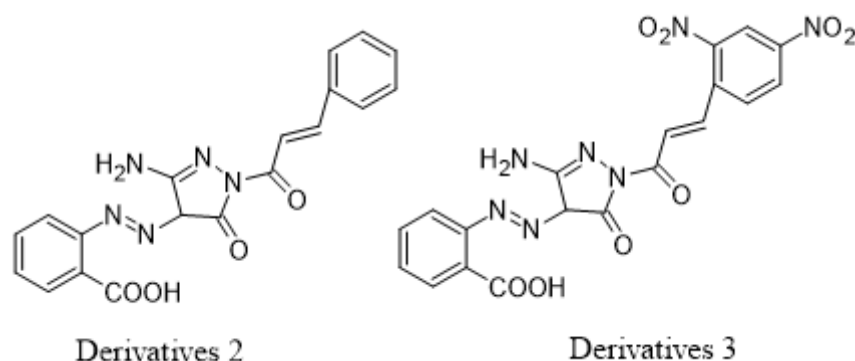


Fig. 3: Chitosan/ Polyvinyl alcohol loaded Pyrazole derivatives

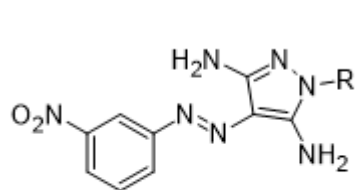
Screening results revealed that among the cell lines used for screening, Derivatives 2 and 3 both showed potent activity against A529 with IC₅₀ values of 6.30 μ M and 6.10 μ M respectively and moderate activity against other tested cell lines. The In-vitro inhibition study against topoisomerase II (topo-II) revealed that compound 2 and 3 exhibited very good topo-II inhibition with IC₅₀ = 0.900 – 1.485 μ M comparable with that of standard compound doxorubicin. The same derivatives with their nonogel also evaluated for DNA binding affinity and showed very good binding affinities.

Diazonium salts are used as one of the electrophilic reagents and coupled with different active methylene compounds to synthesize a variety of bioactive heterocyclic compounds. In continuation with that, Synthesis of pyrazole derivatives (2-7) and pyrimidine derivatives (9-10) were carried by Al-Wahaibi L.H. et al[17] using different conventional as well as microwave assisted techniques by the [1+3] cycloaddition reaction of 2-((3-nitrophenyl)diazenyl) malonitrile derivatives. The synthesized compounds were checked for their anti-cancer potency against two breast cancer cell lines MCF-7

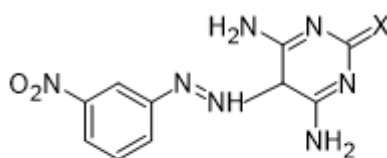
and MDA-MB231 using MTT assay method and results were compared with novobiocin ($IC_{50} = 1.14 \mu M$) as reference compound.

Table 2: Entries of R group in pyrazole derivatives

Pyrzole derivatives	Substituent R
2	Ph
3	2,4-dinitrophenyl
4	-CONH ₂
5	-CSNH ₂
6	-COCH ₂ CN
7	-COPh



Pyrazole Derivatives (2-7)



Pyrimidine Derivatives (9, 10)

For 9 X= S and For 10 X = -NH-

Fig. 4 : Pyrazole and Pyrimidine derivatives

Among tested compounds, Compounds 2 was found to be potent anticancer agent against the MCF-7 while the compound 4 showed moderate activity against MDA-MB231 cell line. In comparison with pyrazole derivatives, Pyrimidine derivatives (9,10) found to be more potent anticancer agents and supported from their Docking study.

Salem M. G. et al[18] reported the synthesis of new series of N-Manniche base type pyrazole derivatives 3,4(a-c) and 5,6(a-b) through MCR reaction method and after confirming the structures by different spectroscopic methods, the synthesized derivatives were examined for their cytotoxic effect against HepG @ liver cancer cell line. Biological investigation revealed that derivative 4a (IC₅₀ 4.4 μ M), 5a (IC₅₀ 3.46 μ M) and 6b (IC₅₀ 2.52 μ M) were potent cytotoxic agents compared with Sorafenib (IC₅₀ 2.05 μ M) and Roscovitine (IC₅₀ 4.18 μ M) as standard anticancer drug for liver cells. The higher value of IC₅₀ indicated that these derivatives behave normally with normal Liver cell lines (THLE2). Virtual binding affinities were checked by molecular docking study and found to have good binding interactions with both receptor active sites of VEGFR-2 and CDK2 and among tested derivatives, 6b profound anticancer agent and is prominent dual VEGFR2 and CDK2 inhibitor.

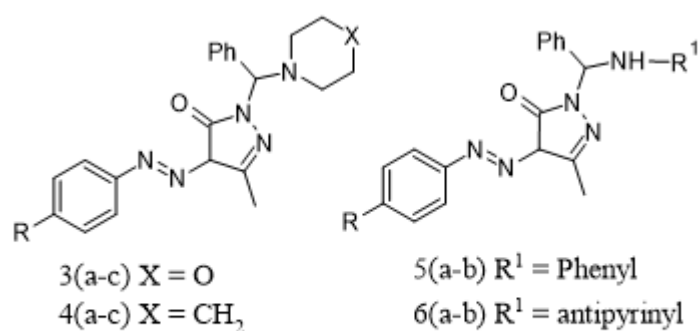


Figure 5: N-Manniche base type pyrazole derivatives

J.Prathyusha and A.Deepti [19] have synthesized Pyrazole-Carboxamide derivatives (4a-n) through a sequential reaction path

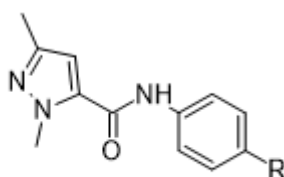


Figure 6: Pyrazole-5-Carboxamide Derivatives (4a-n)

starting with the cyclization of ethyl 2,4-dioxopentanoate and methyl hydrazine. The synthesized derivatives were screened for their In Vitro anticancer cell line using six distinct cancer cell lines A549 (Lung), DU145 (Prostate), HT29 (Colon), MCF-7 (Breast), SiHA (Cervical), B16F10 (Mouse skin melanoma) respectively using MTT assay method. Non toxicity to normal cells was evaluated by using normal fibroblast cell lines. Evaluated results were compared with standard drug doxorubicin and most of the synthesized compounds found to be promising cytotoxic agents and supported by their ligand based molecular docking study with two target proteins human c-Met kinase and JAK1.

Table 3: Entries of R group in Pyrazole-5-Carboxamide Derivatives

Pyrazole 5- Carbox- amide	4a	4b	4c	4d	4e	4f	4g	4h	4i	4j	4k	4l	4m	4n
Nature of R	H	3-OH	4-OH	2-OH	3-NO ₂	4-NO ₂	3-F	4-F	3-Cl	4-Cl	4-CH ₃	4-OCH ₃	3,4-Di-methyl	4-Tri-fluro-methyl

From the screening result, Compounds 4g, 4j and 4l emerged as potent anticancer agents while all synthesized compounds showed good binding scores in molecular docking studies.

Aravinda Pai and his coworkers [20] tried to synthesize a series of Coumarinyl pyrazole-4-carbaldehyde derivatives (P01-P08) by conventional reflux and with sequential reaction method using substituted salicylaldehyde and ethyl aceto acetate as starting compounds in presence of piperidine as basic catalyst and followed by Vilsmeier Haack reaction on intermediate coumarin compound. Synthesized derivatives were checked for their cytotoxic efficacy

against A-549, Lung cancer cell line using MTT assay method. Activity investigation reflects that most of synthesized derivatives showed appreciable anticancer activity, while compound P03 found to be potent anticancer agent as indicated by its IC₅₀ value of 13.5 mmol with comparison to a standard anticancer drug doxorubicin IC₅₀ value of 3.5 mmol. Incorporation of bromine to coumarin moiety significantly enhanced the anticancer activity of compound P03 compared with other synthesized derivatives. Cell cycle investigation suggests compound P03 effectively inhibited the G₂/M phase of the cell cycle and was found to be late apoptotic agents from their apoptosis studies.

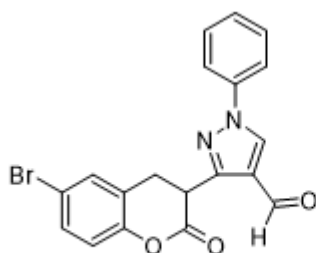


Figure 7: Coumarinyl Pyrazole-4-carbaldehyde Derivative P-03

Claisen-Schmidt reaction is one of the key reactions for the preparation of intermediate compounds utilized in the synthesis of a variety of biologically active heterocyclic molecules. Berkant Kurban and his lab colleagues [21] tried to synthesize series of new Epidermal Growth Factor Receptor (EGFR) inhibitor thiodiazolyl Pyrazole derivatives (6a-j) containing Pyrazole and Thiadiazole rings. EGFR is a one of the parameters for lung cancer hence in order to treat lung cancer, the synthesized derivatives were evaluated for their anticancer activity against lung cancer cell lines A-549 and additionally Breast cancer cell line MCF-7. Non toxicity to normal cells was checked using one healthy cell line NIH3T3. Activity results were correlated with Doxorubicin as a standard drug. Tested

compounds 6d, 6g and 6j found to be potent anticancer agents against A549 cell lines with IC₅₀ values of $5.176 \pm 0.164 \mu\text{M}$, $1.537 \pm 0.097 \mu\text{M}$ and $8.493 \pm 0.667 \mu\text{M}$ respectively. The mitochondrial membrane potential (MMP) test of synthesized compounds were carried out by flow cytometry method and binding affinity were determined by Molecular Docking study. After all, compound 6g emerged as a more potent anticancer agent and fits well into the cavity with good binding affinity with EGFR active site.

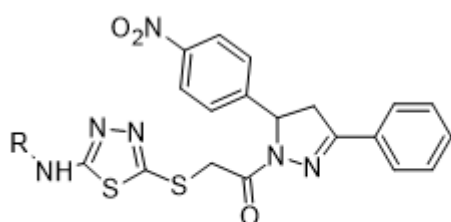


Figure 8: Thiodiazolyl Pyrazole Derivatives (6a-j)

Table 4: Entries of R group in thiodiazolyl Pyrazole derivatives

Derivative	6a	6b	6c	6d	6e	6f	6g	6h	6i	6j
Nature of R Group	- ethyl	- propyl	Iso-propyl	- allyl	- butyl	- cyclohexyl	- phenyl	p-tolyl	p-methoxy-phenyl	p-chlorophenyl

2. Conclusion

A big challenge in the treatment of cancer is drug resistance to existing well known anticancer drugs with expected potency as well as lesser side effects. Hence to overcome this problem, for the eradication of cancer, we tried to put a short-listed structural bank of recently identified, designed and synthesized innovative anticancer

compounds. In this review we highlighted synthesis of some promising pyrazole containing heterocyclic compounds through either traditional synthetic procedure or by adopting newer green synthetic techniques. It also explored the different targets used to check anticancer activity along with used standard reference compounds. Most of the synthesized compounds considered in our study exhibit potent anticancer activity against the variety of target compounds. This definitely helps the research community to design their plan of synthesis of pyrazole incorporated heterocyclic analogues. The combination of pyrazole moiety with other compounds has shown promising improvement in biological activity of resulting compounds and also indicating exciting possibilities of developing activity by modification in the structure. From our study hope the future research should focus on optimizing the potency, selectivity and other important parameters to enhance efficacy with minimized toxicity.

References

1. G., P. Chandra, and N. Sachan, "Chemistry and Pharmacological Activities of Pyrazole and Pyrazole Derivatives: A Review," *Int. J. Pharm. Sci. Rev. Res.*, vol. 65, no. 1, pp. 201–214, Nov. 2020.
2. S. Mor, M. Khatri, R. Punia, and S. Sindhu, "Recent Progress in Anticancer Agents Incorporating Pyrazole Scaffold," *Mini-Rev. Med. Chem.*, vol. 22, no. 1, pp. 115–163, Jan. 2022.
3. Y. Zhang, C. Wu, N. Zhang, R. Fan, Y. Ye, and J. Xu, "Recent Advances in the Development of Pyrazole Derivatives as Anticancer Agents," *Int. J. Mol. Sci.*, vol. 24, no. 16, p. 12724, Aug. 2023.
4. S. Sharma, Suman, B. S. Kaith, and Vaishali, "Magnetic Nanoparticles- Supported Synthesis of Pyrazole Scaffolds: A Review," *ChemistrySelect*, vol. 9, no. 28, p. e202401627, July 2024.

5. M. T. Sayed, S. A. Elsharabasy, and A. Abdel-Aziem, "Synthesis and antimicrobial activity of new series of thiazoles, pyridines and pyrazoles based on coumarin moiety," *Sci. Rep.*, vol. 13, no. 1, p. 9912, June 2023.
6. V. S. More, D. C. Chumbhale, N. T. Rangari, P. A. Mishra, A. B. Jagnar, and J. N. Kadam, "Synthesis, analgesic and anti-inflammatory activities of some pyrazolo[3,4-c]pyrazole derivatives," *Int. J. Health Sci.*, pp. 1218–1231, Mar. 2022.

Chapter 8

Grid Integrity Based Advanced Solar Charging Solution for Electric Vehicles

Poonguzhali S ^{a*}, A Sivasangari ^b, S Lalithakumari ^c

^{a,c} Department of ECE, Sathyabama Institute of Science and Technology, Chennai, India

^b Department of CSE, Sathyabama Institute of Science and Technology, Chennai, India

**Corresponding Author: poonguzhali.etce@sathyabama.ac.in*

Abstract

The accelerating global adoption of electric vehicles (EVs) has transformed the landscape of modern transportation and energy management. However, the heavy dependence of charging networks on grid electricity—often generated from fossil fuels—undermines the environmental promise of EVs. This chapter presents an advanced grid-integrated solar charging framework designed to deliver sustainable, intelligent, and cost-efficient charging solutions. The system architecture integrates photovoltaic (PV) modules, a Maximum Power Point Tracking (MPPT) converter, energy-storage units, and an Internet of Things (IoT)-based monitoring network. A bidirectional power-flow design enables both Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) operations, enhancing grid stability while optimizing renewable-energy utilization.

Keywords: EV, G2V, PV, V2G, IoT.

1. Introduction

The global transition toward sustainable mobility has brought the electric-vehicle (EV) revolution to the forefront of both policy and

engineering research. Governments worldwide have introduced ambitious targets for phasing out internal-combustion-engine (ICE) vehicles and accelerating EV adoption. Yet, the success of this transition depends not only on advances in battery technology but also on the availability of efficient and sustainable charging infrastructure. Without a renewable foundation, the environmental benefits of EVs remain limited because conventional grid electricity in many regions is still derived from fossil fuels.

In this context, solar-powered charging stations offer a compelling solution. Solar energy is clean, abundant, and increasingly economical thanks to declining module costs and improvements in conversion efficiency. By integrating photovoltaic (PV) systems with modern smart-grid technologies, it becomes possible to construct self-reliant and environmentally benign charging networks. Such integration reduces grid dependence, minimizes operational expenditure, and strengthens the overall resilience of the energy system.

The concept of **grid integrity** forms the core of this research. A grid-integrity-based charging system ensures that energy flow between distributed solar generators, storage banks, and the public grid remains stable, efficient, and secure. Bidirectional communication enables power exchange in both directions—vehicles can draw electricity for charging and also feed surplus energy back to the grid during peak-demand intervals. This bidirectional capability transforms EVs from passive energy consumers into active participants within the smart-grid ecosystem.

Countries such as India exemplify the urgent need for such hybrid infrastructure. Rapid urbanization and government-led incentives for

EV adoption have amplified electricity demand, stressing existing grids. According to national projections, more than one million charging stations will be required by 2030 to meet the anticipated EV population. Traditional grid-tied chargers alone cannot satisfy this demand sustainably. Integrating solar generation with energy-storage systems provides an immediate pathway toward meeting national sustainability goals while curbing greenhouse-gas (GHG) emissions.

From an engineering standpoint, the challenge lies in balancing energy generation, storage, and consumption dynamically. Factors such as solar-irradiance variability, grid voltage fluctuations, and diverse charging loads necessitate robust control strategies. Algorithms like Maximum Power Point Tracking (MPPT) optimize PV output, while Battery Management Systems (BMS) safeguard energy storage through charge-state monitoring and thermal regulation. When coordinated through an IoT-enabled control layer, these subsystems can operate autonomously, achieving optimal efficiency with minimal human intervention.

2 Theoretical Background

2.1. Electric-Vehicle Technology and Charging Principles

Electric vehicles (EVs) convert electrical energy into mechanical motion through traction motors powered by rechargeable batteries. Compared with internal-combustion engines, EVs exhibit higher energy efficiency—typically 80–90 percent of the stored energy is converted to wheel torque, while conventional engines achieve only 25–35 percent. The basic EV powertrain consists of a traction-motor controller, drive inverter, on-board charger, and a battery pack. Battery Electric Vehicles (BEVs) are fully dependent on electric

energy, whereas Plug-in Hybrid Electric Vehicles (PHEVs) include an auxiliary internal-combustion engine to extend range.

Charging infrastructures are classified by voltage and current levels:

- **Level 1 (slow AC):** 230 V single-phase supply, suited for home use.
- **Level 2 (fast AC):** 415 V three-phase supply, delivering 7–22 kW.
- **Level 3 /DC fast-charging:** 400–800 V DC, capable of 50–350 kW for highway or fleet applications.

A smart-charging system coordinates multiple chargers, schedules load demand, and optimizes cost through dynamic pricing and grid interaction. Integration with renewable sources such as solar PV or wind can decouple charging from fossil-fuel generation.

2.2. Photovoltaic Energy Conversion and Performance

The photovoltaic effect is the direct conversion of sunlight into electricity within a semiconductor junction. When photons strike a p–n junction, they create electron–hole pairs whose movement generates current.

2.3. Grid Integration and Power-Flow Theory

A grid-connected solar charging system functions as a distributed-generation unit. Its primary tasks are to inject active power (P) and control reactive power (Q) while maintaining grid voltage and frequency stability. Bidirectional power flow enables both **Grid-to-Vehicle (G2V)** and **Vehicle-to-Grid (V2G)** operations.

- During G2V, power flows from the grid or PV array to charge the EV battery.

- During V2G, stored energy is discharged from the EV battery back to the grid to support peak demand, frequency regulation, or voltage stabilization.

A typical grid-connected inverter uses a Phase-Locked Loop (PLL) for synchronization and Pulse-Width Modulation (PWM) to regulate output current. Power-factor correction (PFC) ensures near-unity power factor, reducing harmonics and transmission losses. Maintaining **grid integrity** requires continuous monitoring of line parameters, load demand, and renewable generation. Smart-metering systems relay this data to a supervisory controller that executes load-balancing algorithms and demand-response mechanisms.

3 System Design and Architecture

The proposed grid-integrity-based solar charging framework operates as an intelligent hybrid network, integrating photovoltaic (PV) generation, energy storage, grid connection, and electric-vehicle charging units within a unified control environment. The architecture consists of three essential domains:

- **Energy Generation and Conversion** – solar panels and MPPT converters,
- **Energy Storage and Management** – battery banks governed by a battery management system (BMS), and
- **Power Distribution and Control** – bidirectional inverters and smart-grid interfaces.

A supervisory controller coordinates the interaction among these domains. It continuously monitors system parameters such as PV voltage, battery state of charge (SoC), grid frequency, and EV load

demand, and dynamically allocates energy according to real-time conditions. The ultimate objective is to maintain **grid integrity**—stable voltage and frequency—while maximizing renewable energy utilization and ensuring uninterrupted EV charging.

3.2. Photovoltaic Subsystem

The solar-generation subsystem employs high-efficiency monocrystalline PV panels configured in series-parallel arrays to deliver the required DC bus voltage (typically 600–800 V). The generated output is routed to a **DC–DC boost converter**, which conditions the voltage to match the charging bus and facilitates Maximum Power Point Tracking (MPPT). The MPPT algorithm used in this system is an **Incremental Conductance (InC)** technique enhanced with adaptive gain parameters. The algorithm compares instantaneous conductance (I/V) and incremental conductance ($\Delta I / \Delta V$) to determine the MPP, thereby reducing oscillations near the optimal point under rapidly changing irradiance.

3.3. Energy-Storage Subsystem

The energy-storage module acts as a buffer between the variable solar supply and the EV charging demand. Lithium-ion batteries (nominal cell voltage 3.7 V) are arranged into modular packs providing 48–96 V, depending on the station's capacity. The battery bank interfaces with a **bidirectional DC–DC converter** that allows controlled charging and discharging operations.

4. Implementation Methodology

The implementation of the grid-integrity-based solar charging solution follows a systematic, modular approach encompassing hardware realization, embedded control design, communication

framework development, and software integration. The overall objective is to ensure a fully functional prototype capable of reliable operation under variable solar and grid conditions. The methodology emphasizes both **experimental validation** and **simulation-based verification** to confirm the efficiency and stability of the designed system before large-scale deployment.

The implementation workflow is divided into five stages:

1. Hardware system development,
2. Control and power electronics programming,
3. Communication and IoT integration,
4. Data acquisition and processing, and
5. Performance evaluation and optimization.

5. Case Study

To validate the proposed grid-integrity-based solar charging framework, a prototype station was implemented and evaluated under real-world conditions at an academic research facility in Chennai, India. The installation served as a functional model to assess power flow control, charging efficiency, and grid interaction.

The system included:

- A 5 kW photovoltaic array,
- A 48 V, 200 Ah lithium-ion battery storage unit,
- A three-phase, 5 kVA grid-tied inverter, and
- A 60 A DC fast-charging station supporting both CCS and CHAdeMO standards.

Data were collected for one month, including daily solar irradiance patterns, load demand, SoC fluctuations, and grid feedback power.

The outcomes were analyzed to measure system reliability, energy contribution ratios, and cost performance.

5.1. Solar Energy Generation Profile

The PV array generated electricity proportional to solar irradiance, which varied from 400 W/m² in the early morning to over 950 W/m² at midday. Over a typical clear-sky day, average daily energy generation reached 25–27 kWh. The daily output showed minor fluctuations due to intermittent cloud cover. Under optimal conditions, the PV system achieved a peak efficiency of 21.3%, aligning with manufacturer specifications.

5.2. Battery Charging and Discharging Behavior

The lithium-ion battery system served as the intermediary buffer between PV generation and EV load. Charging began when PV power exceeded instantaneous demand, maintaining the DC-bus voltage around 720 V. The average round-trip efficiency was 94.2%, indicating minimal internal losses. Battery SoC was maintained between 30% and 90%, extending the lifespan of the cells. Thermal performance remained stable, with maximum cell temperature not exceeding 38°C due to active cooling fans. Overcharge and deep-discharge events were effectively prevented by the BMS control algorithms.

5.3. EV Charging Performance

The DC fast charger supplied a maximum of 60 A at 400 V to the EV battery. Average charging time for a 40 kWh EV battery was approximately 40–45 minutes. Charging current dynamically adjusted based on available solar generation and grid limits. The energy contribution ratio from different sources was measured as:

- Solar PV: 68%,
- Battery storage: 22%,
- Grid import: 10%.

This distribution demonstrates strong renewable dependency, validating the system's primary objective of grid load reduction. The charger's overall conversion efficiency, from DC input to EV battery output, was 95%, with voltage deviation under $\pm 2\%$. Data logs indicated minimal downtime and stable operation even under variable environmental conditions.

5.4. Grid Interaction and Power Quality

The grid-tied inverter maintained a near-unity power factor and low harmonic distortion throughout operation. The total harmonic distortion (THD) in output current remained below 2.8%, satisfying IEEE 519 requirements. During peak solar generation, the inverter exported surplus power to the grid through the V2G mode. Conversely, under low irradiance, it imported limited energy to sustain charging. The **net energy exchange** over a 24-hour cycle averaged 1.5 kWh exported per day, confirming that the station effectively contributed to grid support. Voltage regulation was verified by measuring the root-mean-square (RMS) voltage of the grid before and after power export. Voltage deviation remained within $\pm 1.5\%$, ensuring grid stability. The phase synchronization accuracy of the PLL was maintained within 0.2° , ensuring high-quality power injection.

5.5. Energy Management Efficiency

The Energy Management System (EMS) coordinated all power flows in real time. It optimized the charging schedule based on solar

forecasts and grid-tariff variations. The EMS algorithm also reduced grid import cost by approximately 35% compared with a conventional grid-only charging system. Load balancing during multiple vehicle connections ensured each charger received sufficient power without overloading the system.

5.6. Simulation-Based Validation

To complement experimental results, MATLAB/Simulink simulations were performed. Models included PV arrays, DC–DC converters, grid-tied inverters, and control loops for MPPT and current regulation. Simulation parameters were matched to field hardware specifications.

Results indicated:

- DC bus voltage stability within $\pm 1\%$ of nominal value,
- Inverter synchronization with grid in < 40 ms after startup,
- SoC-controlled charging and discharging under dynamic irradiance, and
- Overall efficiency improvement of $\sim 8\%$ compared with a system without predictive EMS optimization.

These results confirm the robustness of both control strategy and system integration.

6. Conclusion

This chapter presented a complete design and analysis of a grid-integrity-based solar charging system for electric vehicles. The system combines solar energy, energy storage, and smart-grid connectivity to create a sustainable and efficient charging network. Through intelligent control algorithms and IoT-based monitoring, the proposed setup maintains stable performance, even under varying

environmental conditions. The results proved that solar energy can supply more than 70–90% of the charging requirement, significantly reducing grid load and electricity costs. The system's efficiency reached over 93%, with low harmonic distortion and excellent voltage regulation. The bidirectional inverter allowed both charging from and power feedback to the grid, ensuring energy balance and grid stability.

References

- [1] Patel, R., Sharma, N., & Rao, P. (2021). *Design of PV-powered smart EV charging station with MPPT and IoT monitoring*. Renewable Energy Reports, 8(2), 112–119.
- [2] Zhang, Y., & Li, J. (2022). *Predictive scheduling for hybrid renewable EV charging networks*. IEEE Transactions on Smart Grid, 13(4), 2874–2883.
- [3] Kumar, S., Banerjee, A., & Thomas, V. (2023). *Performance analysis of hybrid solar-wind EV charging systems*. Energy Conversion and Management, 287, 118–126.
- [4] Singh, D., & Mehta, R. (2020). *Energy management in grid-connected solar systems using IoT*. International Journal of Power Electronics, 15(3), 241–252.
- [5] Chen, H., Wu, C., & Yang, L. (2021). *Vehicle-to-grid integration using bidirectional power converters*. Applied Energy, 283, 116–124.
- [6] Ghosh, S., & Arora, K. (2022). *Optimization of renewable charging stations under variable load conditions*. Journal of Cleaner Production, 344, 130–144.
- [7] Rahman, A., & Kannan, V. (2021). *Battery management systems for electric vehicles: A review*. Renewable and Sustainable Energy Reviews, 151, 111–125.

- [8] International Electrotechnical Commission (IEC 61851). *Electric Vehicle Conductive Charging Systems – Standards and Safety Requirements*.
- [9] Ministry of Heavy Industries, Government of India. *FAME-II Scheme Guidelines for Electric Mobility Development*. (2023).

Frontiers of Multidisciplinary Studies for Global Sustainability

November 2025



Mrs. DIANA AGNES is a Research Scholar at the School of Social Sciences and Languages, VIT, Vellore, Tamil Nadu. She holds an M.A. In English Literature and has conducted research focusing on language learning among tribal students and memory studies. Mrs. Agnes has published several research papers, including two in Scopus-indexed journals. Recognized for her academic excellence, she received the Skill India Best Researcher and Scholar Award in 2021 from the National Institute of Skills Training (NIST). She actively participates in national and international conferences, workshops, and faculty development programs, continually contributing to the field of English studies and language education.



Dr. ANU BAISEL holds an M.A., B.Ed., M.Phil., and Ph.D. in English. He is an International Certified Career Coach (CDA-USA), International Trainer in Experiential Learning (IPE, Canada), and Certified NLP Associate Practitioner Coach (ECNLP, Europe). He is also a TCS iON Career Edge-Young Professional and a Certified Train the Trainer (NIET), accredited by the Ministry of Corporate Affairs, MSME, Government of India. Dr. Baisel has received prestigious honors, including the Education Icon Award (2020), Best Teacher Award (2021), and Asian Education Award (2021). His professional achievements have been featured in The Times of India, Hindu Tamil, and Malayala Manorama. He currently serves as Assistant Director, Career Development Centre, Vellore Institute of Technology (VIT), Vellore.



Dr. A. ALLWYN SUNDARRAJ is a faculty member in the Department of Food Technology at JCT College of Engineering and Technology, Coimbatore, India. He holds a Ph.D. in Food Processing and Engineering from Karunya University, where he also earned his M.Tech and B.Tech degrees in the same field. His research interests include food preservation, sustainable processing technologies, and nanotechnology-based food packaging. He has published several research papers in reputed national and international journals, authored book chapters, and holds patents related to innovative food formulations and processing equipment. His work focuses on developing eco-friendly, energy-efficient food processing techniques that enhance nutritional quality and shelf life, establishing him as a dedicated educator and researcher in food technology.



Dr. C.S. SUNDAR GANESH is an Assistant Professor in the Department of Electrical and Electronics Engineering at Karpagam College of Engineering, Coimbatore. He earned his B.E. in Electrical and Electronics Engineering from the Government College of Engineering, Tirunelveli, M.E. in Applied Electronics from PSG College of Technology, and Ph.D. in Soft Computing from Anna University, Chennai. He has published over 60 research papers in reputed national and international journals and holds 21 patents. Additionally, he has authored 12 book chapters and 3 books. His research interests include Embedded Systems, Internet of Things (IoT), and Robotics.

SCIENTIFIC RESEARCH REPORTS

(A Book Publisher, approved by Govt. of India)

I Floor, S S Nagar, Chennai - 600 087,
Tamil Nadu, India.

editors@srrbooks.in, contact@srrbooks.in
www.srrbooks.in

