IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.301
Volume 3, Issue 1, March 2023

Advancements in Biodegradable Polymers for Sustainable Packaging

Golekar Sham Machchhindra
Associate Professor
Jamkhed Mahavidyala, Jamkhed

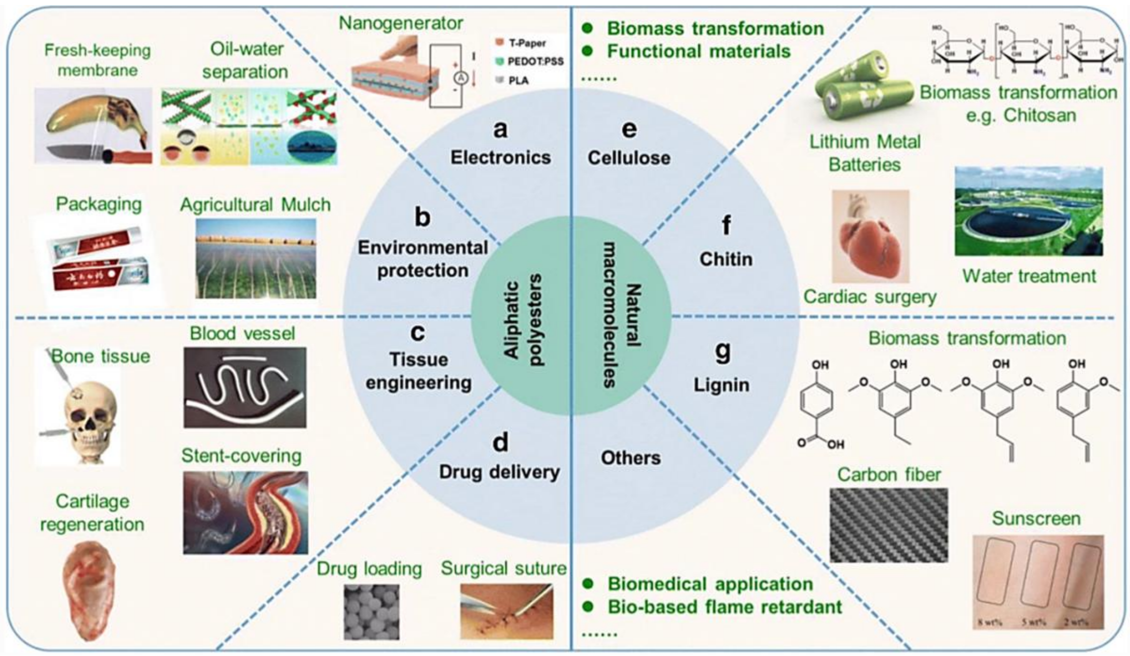
Abstract: *The global surge in plastic pollution has intensified the demand for sustainable packaging solutions, positioning biodegradable polymers as a critical alternative to conventional plastics. This study presents a comprehensive review of recent advancements in biodegradable polymers, focusing on their sources, classification, biodegradation mechanisms, and industrial applications in packaging. Key materials such as polylactic acid (PLA), polyhydroxyalkanoates (PHAs), starch-based polymers, and cellulose derivatives are examined for their improved mechanical and environmental performance. Despite significant progress, challenges including high production costs, variable degradation rates, and limited waste management infrastructure remain obstacles to widespread adoption. The study highlights the role of regulatory frameworks and consumer awareness in promoting biodegradable packaging and outlines future research directions to enhance material properties and sustainability. Overall, biodegradable polymers offer promising pathways toward reducing plastic waste and advancing a circular economy in packaging industries.*

Keywords: Biodegradable Polymers, Sustainable Packaging, Polylactic Acid (PLA), Polyhydroxyalkanoates (PHAs), Biodegradation Mechanisms, Compostable Packaging, Plastic Pollution

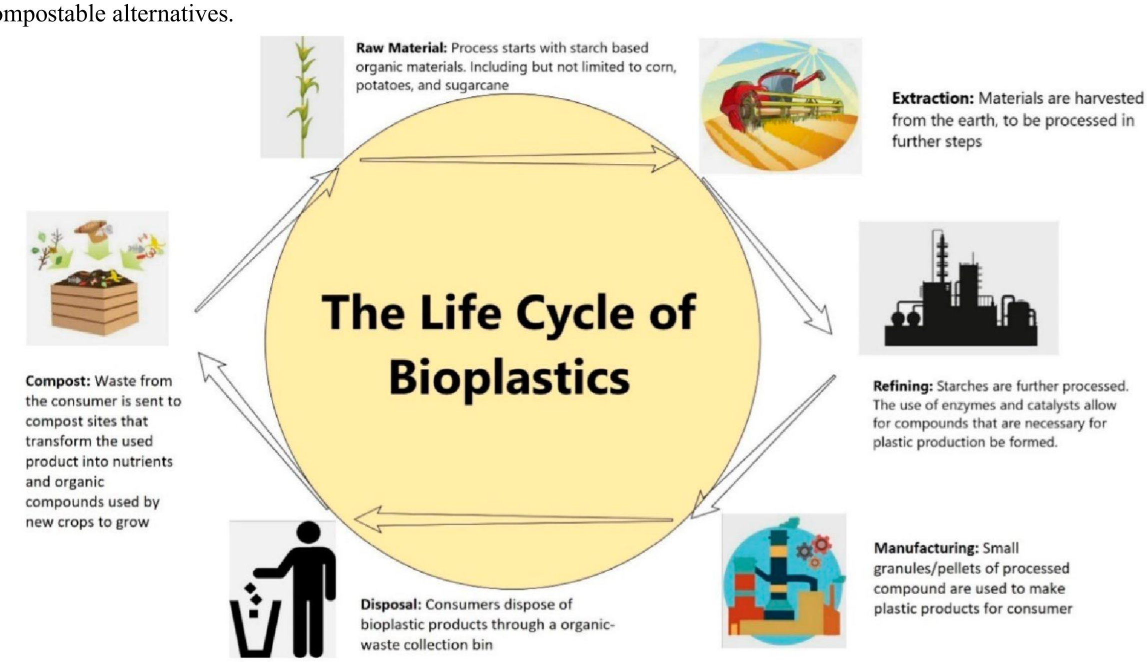
I. INTRODUCTION

The escalating environmental crisis caused by plastic pollution has intensified the global demand for sustainable packaging alternatives. Traditional petroleum-based plastics, while cost-effective and versatile, pose severe ecological risks due to their resistance to degradation and accumulation in landfills and oceans. In response, biodegradable polymers have emerged as a promising solution, offering the potential to reduce environmental impact without compromising on performance and functionality. Biodegradable polymers are materials capable of breaking down into natural byproducts through microbial action, making them a crucial component of eco-friendly packaging systems (Wu et al. 2021). Over the past decade, significant advancements in polymer science, material engineering, and biotechnology have led to the development of new biodegradable materials with enhanced mechanical properties, processability, and biodegradation rates. These innovations are not only transforming packaging design but also aligning with global sustainability goals and circular economy principles. This paper explores the latest developments in biodegradable polymers for sustainable packaging, examining key materials such as polylactic acid (PLA), polyhydroxyalkanoates (PHA), starch-based polymers, and cellulose derivatives. It also delves into current challenges, industrial applications, and future prospects, aiming to provide a comprehensive overview of how biodegradable polymers are reshaping the future of sustainable packaging.

The widespread use of conventional plastic packaging has led to significant environmental concerns due to its non-biodegradable nature and the persistence of plastic waste in terrestrial and marine ecosystems. With global plastic production exceeding 400 million tonnes annually, of which a substantial portion is used for single-use packaging, the urgency to find sustainable alternatives has never been more critical. Biodegradable polymers, which can decompose naturally by the action of microorganisms into water, carbon dioxide, and biomass, are increasingly being recognized as viable substitutes for traditional plastics in packaging applications (Samir et al. 2022).



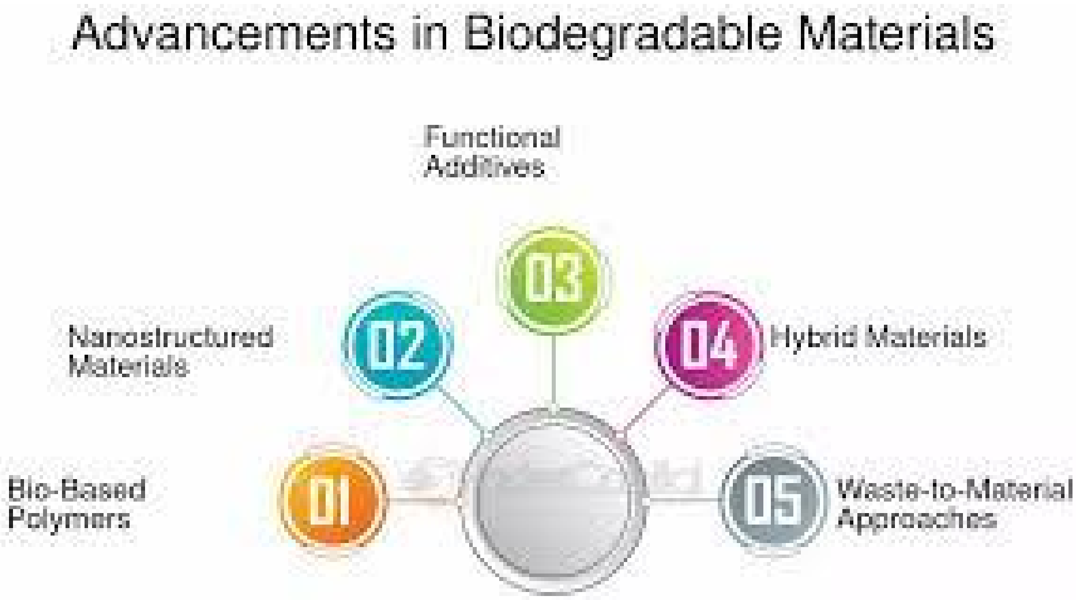
Biodegradable polymers are derived from renewable resources such as starch, cellulose, and polylactic acid (PLA), or synthesized through microbial fermentation processes to form polyhydroxyalkanoates (PHAs). These materials are designed to meet the functional demands of modern packaging—such as barrier properties, flexibility, durability, and transparency—while significantly reducing the environmental footprint. In recent years, technological advancements have led to improvements in the mechanical strength, shelf life, processability, and cost-efficiency of biodegradable polymers, making them more competitive with petroleum-based plastics (Wu et al. 2021). The development of sustainable packaging solutions is not only driven by environmental awareness but also by increasing regulatory pressure, consumer demand for green products, and corporate responsibility initiatives. Countries around the world are introducing bans and restrictions on single-use plastics, incentivizing research and investment into biodegradable and compostable alternatives.



Furthermore, industries such as food and beverage, cosmetics, pharmaceuticals, and e-commerce are actively exploring biodegradable packaging as part of their sustainability commitments. This study aims to provide a comprehensive overview of recent advancements in biodegradable polymers for sustainable packaging. It explores the scientific basis of biodegradability, the synthesis and properties of key biodegradable polymers, and the current industrial and commercial applications (Singh et al. 2021). Additionally, it evaluates the challenges associated with scalability, cost, performance limitations, and composting infrastructure, while also discussing emerging trends and future directions in the field. By addressing both the opportunities and obstacles, this paper contributes to a deeper understanding of how biodegradable polymers can play a transformative role in achieving a sustainable packaging ecosystem.

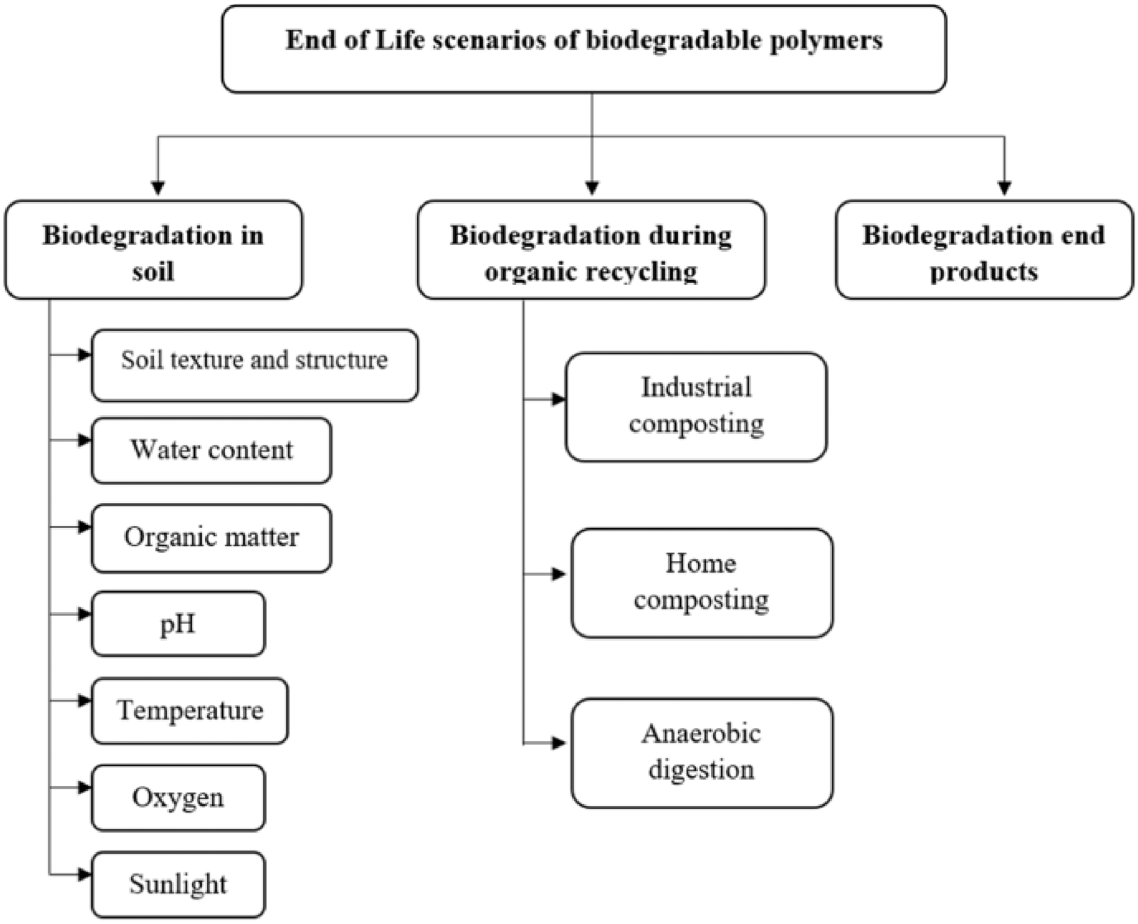
IMPORTANCE OF THE STUDY

The growing environmental impact of plastic waste, particularly from single-use packaging materials, has become a pressing global concern. Non-biodegradable plastics contribute to land and marine pollution, endanger wildlife, and disrupt natural ecosystems, creating long-term challenges for sustainability. In this context, the exploration and advancement of biodegradable polymers offer a viable and urgent solution. This study is important because it addresses a critical intersection of environmental science, material innovation, and industrial application.



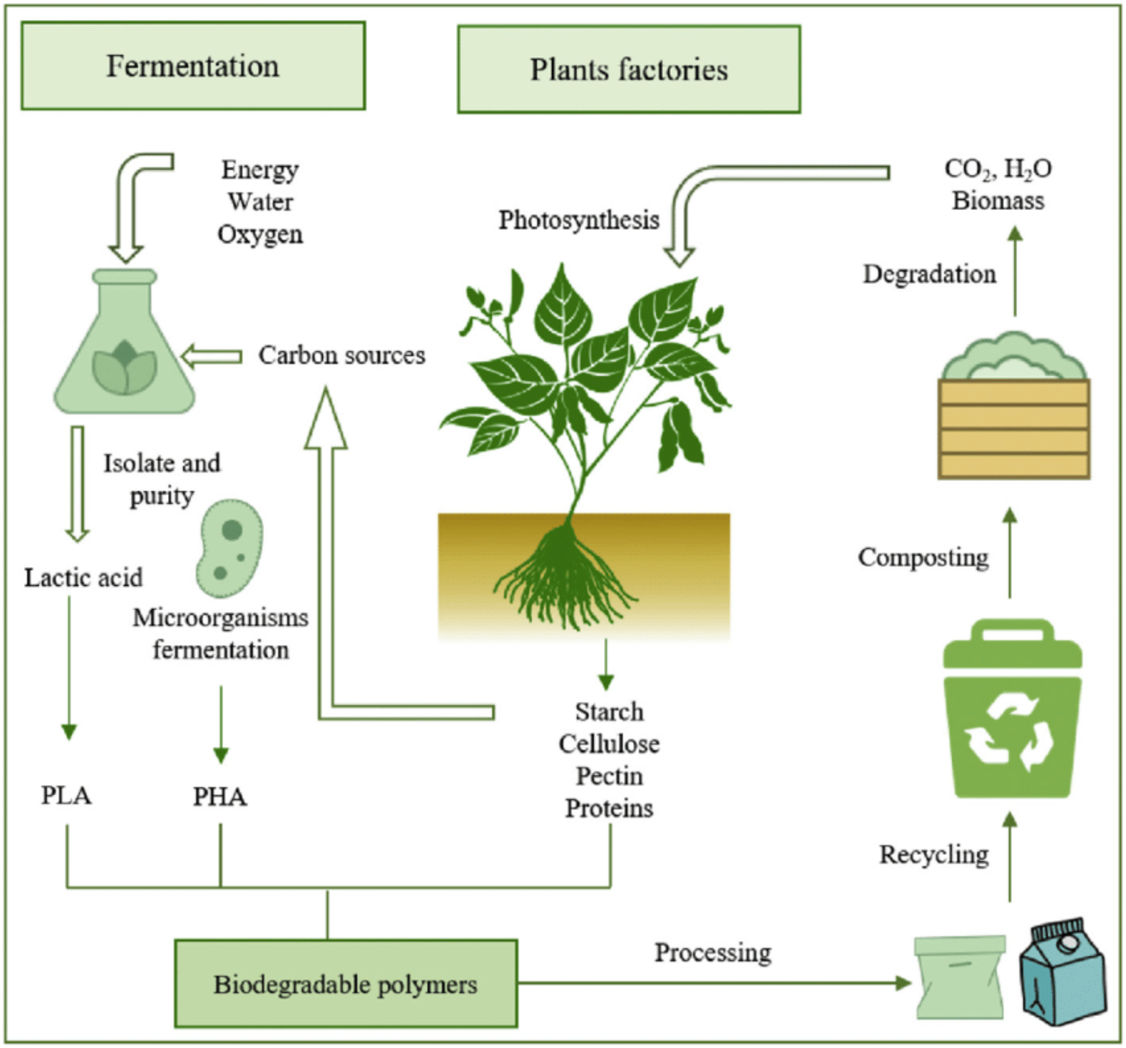
Understanding the advancements in biodegradable polymers is essential for multiple reasons. Firstly, it promotes the development and adoption of environmentally friendly packaging materials that can significantly reduce dependence on fossil fuels and mitigate plastic pollution. Secondly, it contributes to the global shift toward a circular economy by encouraging the use of renewable resources and enhancing the compostability of post-consumer waste (Wróblewska-Krepsztul et al. 2018). Thirdly, the study helps identify the gaps in current technologies, policies, and infrastructure that hinder the large-scale adoption of biodegradable alternatives. Moreover, this research is highly relevant to policymakers, industry leaders, environmentalists, and scientists working toward sustainable development goals (SDGs), particularly those focused on responsible consumption and production (SDG 12), climate action (SDG 13), and life below water (SDG 14). By analyzing the progress, limitations, and potential of biodegradable polymers, the study provides valuable insights for decision-making in packaging design, waste management strategies, and environmental regulations. In essence, the study is crucial for shaping a more sustainable future—one where packaging solutions are both functional and environmentally responsible. It supports innovation in material science, encourages responsible consumer behavior, and contributes to the global movement toward reducing the ecological footprint of human activities.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.301
Volume 3, Issue 1, March 2023



The study of advancements in biodegradable polymers for sustainable packaging holds significant relevance in today's environmental, economic, and industrial landscape. With global concern over climate change, resource depletion, and waste accumulation growing rapidly, there is a crucial need for innovative materials that can replace conventional plastic packaging without compromising performance or safety. Biodegradable polymers have emerged as a key solution, and understanding their development is central to achieving long-term sustainability goals. One of the primary reasons for the importance of this study is the escalating environmental crisis caused by plastic waste. Traditional petroleum-based plastics take hundreds of years to degrade and are a major contributor to soil and marine pollution (Hussain et al. 2021). Biodegradable polymers offer a way to reduce this impact by decomposing naturally under specific environmental conditions, thus lowering the burden on landfills and decreasing the release of toxic substances into ecosystems. Secondly, the study addresses the demand for renewable and eco-friendly materials. As global industries and consumers alike move toward more sustainable products, biodegradable packaging provides a path forward that aligns with environmental regulations and consumer expectations. The insights gained from this study can help industries such as food packaging, pharmaceuticals, retail, and cosmetics to transition from harmful materials to more sustainable packaging solutions.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.301
Volume 3, Issue 1, March 2023



Furthermore, this study plays a critical role in advancing material science and innovation. The development of biodegradable polymers involves complex research in chemistry, biotechnology, and polymer engineering. This study reviews these technological advancements and highlights the latest progress in enhancing biodegradability, mechanical strength, barrier properties, and thermal stability of bio-based polymers—factors that directly affect their industrial viability. In addition, this research is vital from a policy and regulatory standpoint. Governments across the world are implementing bans on single-use plastics and offering incentives for the development of biodegradable alternatives (Singh et al. 2021). A comprehensive understanding of the current state of biodegradable polymer technology will support effective policymaking and help bridge the gap between innovation and implementation. Economically, the study also sheds light on the potential for market expansion and job creation in green industries. As demand for biodegradable packaging grows, it opens up opportunities for new businesses, startups, and sustainable supply chains, contributing to economic development with a reduced ecological footprint.

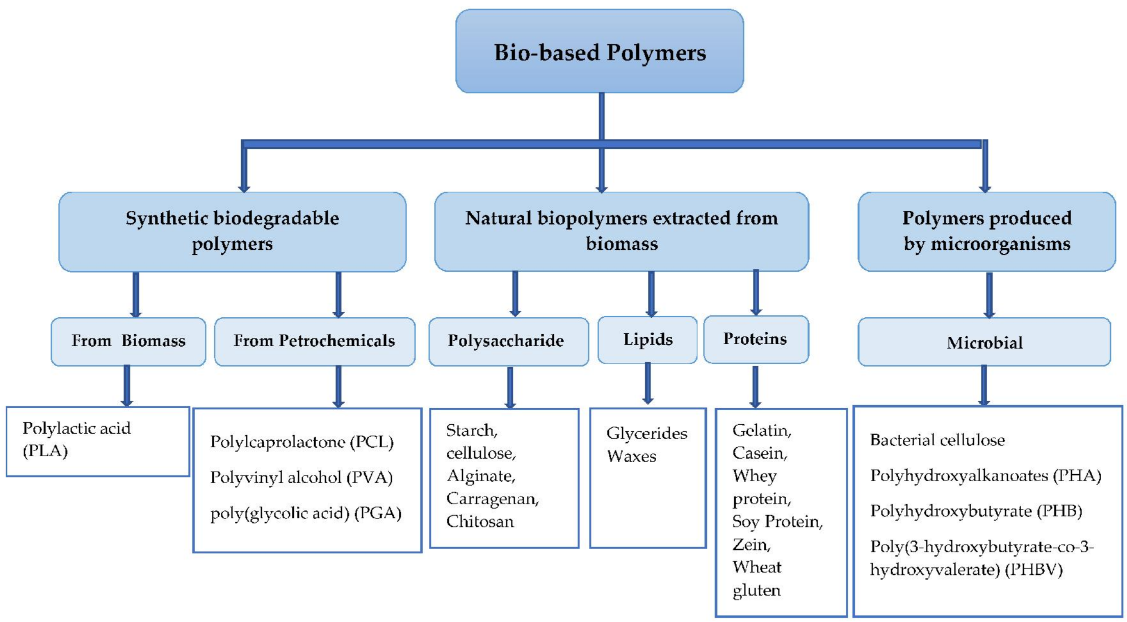
JUSTIFICATION OF THE STUDY

The justification for conducting a detailed study on advancements in biodegradable polymers for sustainable packaging stems from the urgent need to address the global environmental crisis posed by plastic pollution. Conventional plastics, although cost-effective and widely used, are non-biodegradable and contribute significantly to land, air, and marine pollution. These plastics often persist in the environment for centuries, causing harm to wildlife, entering the food

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.301
Volume 3, Issue 1, March 2023

chain, and contributing to greenhouse gas emissions through their life cycle. Therefore, identifying and advancing viable, eco-friendly alternatives such as biodegradable polymers is both a scientific and societal imperative (Wróblewska-Krepsztul et al. 2018). Biodegradable polymers, derived from renewable resources or developed through microbial processes, represent a transformative shift in packaging technology. However, despite their promise, these materials still face critical challenges in terms of scalability, cost competitiveness, functional performance, and end-of-life disposal systems. A focused study is justified to evaluate the recent innovations that aim to overcome these limitations and improve the real-world applicability of such materials.

This study is also justified by the rising global emphasis on sustainability across all sectors. Governments, industries, and consumers are increasingly demanding packaging solutions that reduce carbon footprint, support waste reduction, and align with the principles of a circular economy. Many nations are introducing bans on single-use plastics, mandating biodegradable alternatives, and offering incentives for research in green technologies. In this context, the study provides timely insights into how biodegradable polymers can help stakeholders meet regulatory standards and sustainability targets (Hussain et al. 2021). Moreover, there exists a research gap in the integration of scientific advancements with commercial implementation. While academic studies on biodegradable materials are plentiful, there is a need for comprehensive analyses that bridge the gap between laboratory-scale innovations and industrial-scale applications. This study seeks to provide that link by reviewing both the material science aspect and the packaging industry's readiness to adopt biodegradable polymers.



Another critical justification lies in the potential economic and social benefits. Advancing the use of biodegradable packaging not only addresses environmental concerns but also opens new avenues for green businesses, job creation in sustainable industries, and innovation in material development. By focusing on this topic, the study supports broader economic growth rooted in sustainability (Samir et al. 2022). Lastly, the study is academically justified because it contributes to the ongoing scholarly discourse on sustainable materials, environmental preservation, and polymer science. It provides a structured analysis of the current landscape, identifies existing bottlenecks, and highlights future directions for research and development in the field.

II. LITERATURE REVIEW

EVOLUTION OF BIODEGRADABLE PACKAGING MATERIALS

The evolution of biodegradable packaging materials is a response to the growing environmental concerns associated with conventional plastic packaging. Initially, plastic materials were praised for their durability, lightweight nature, and versatility, leading to their widespread adoption across industries since the mid-20th century. However, their resistance to degradation soon became a major environmental issue, with plastic waste accumulating in landfills and oceans, taking centuries to decompose (Verma et al. 2021). The search for alternatives began in the 1970s and 1980s with the rising awareness of pollution and environmental sustainability. Early biodegradable materials were often derived from natural polymers such as starch, cellulose, and proteins, but their functional limitations—such as poor water resistance and weak mechanical strength—hindered widespread adoption.

In the 1990s, research intensified on biopolymers derived from renewable sources, such as polylactic acid (PLA) obtained from corn starch, and polyhydroxyalkanoates (PHA), produced through microbial fermentation. These materials demonstrated better performance and biodegradability under industrial composting conditions, marking a significant step toward practical alternatives to petroleum-based plastics. The 2000s and 2010s saw further technological advancements, including the development of polymer blends, bio-nanocomposites, and additive-enhanced materials that improved flexibility, barrier properties, and shelf life. At the same time, there was a noticeable shift in consumer attitudes, government policies, and corporate responsibility, all favoring sustainable packaging solutions (Lindström and Österberg, 2020).

More recently, innovations have focused on second-generation biodegradable materials that are designed for specific disposal conditions—such as home compostability or marine biodegradability. Additionally, the integration of smart packaging elements (e.g., indicators for freshness or degradation) with biodegradable substrates has pushed the boundaries of eco-friendly packaging. Today, biodegradable packaging materials represent a convergence of environmental necessity, scientific innovation, and regulatory pressure. Their evolution reflects not just a technological journey but also a broader cultural shift toward sustainability, where packaging is designed with its entire life cycle in mind.

CLASSIFICATION AND SOURCES OF BIODEGRADABLE POLYMERS

Biodegradable polymers are materials that undergo degradation through the action of microorganisms such as bacteria, fungi, and algae, ultimately breaking down into carbon dioxide, water, and biomass under suitable environmental conditions. These polymers can be broadly classified based on their origin and method of production into three main categories: naturally occurring polymers, synthetic biodegradable polymers, and microbially derived polymers. Each category possesses unique properties and limitations that influence their suitability for various packaging applications (Verma et al. 2021).

Natural biopolymers are directly obtained from renewable biological sources such as plants, animals, and marine organisms. Common examples include starch, cellulose, chitosan, and various proteins. Starch, extracted from crops like corn, potatoes, or cassava, is frequently modified into thermoplastic starch (TPS) and used in the production of biodegradable films and bags. Cellulose, derived from plant fibers, is another widely used natural polymer, often modified into cellulose acetate or other derivatives to improve its film-forming and barrier properties (Doppalapudi et al. 2014). Chitosan, obtained from crustacean shells, offers excellent biodegradability and antimicrobial characteristics, making it particularly suitable for food packaging. Proteins such as gelatin, casein, and soy protein also exhibit good film-forming abilities and are being explored for biodegradable packaging applications, including edible films and coatings.

Synthetic biodegradable polymers, though chemically produced, are often derived from renewable resources and designed to degrade under specific environmental conditions. Polylactic acid (PLA), for example, is produced from the fermentation of plant sugars such as those found in corn or sugarcane. PLA is one of the most commercially successful biodegradable plastics, widely used in containers, cutlery, and wraps. Other synthetic biodegradable polymers include polycaprolactone (PCL), which is known for its compatibility in polymer blends, and polybutylene succinate (PBS) and polybutylene adipate terephthalate (PBAT), both of which offer enhanced flexibility and processability, making them suitable for compostable films and bags.

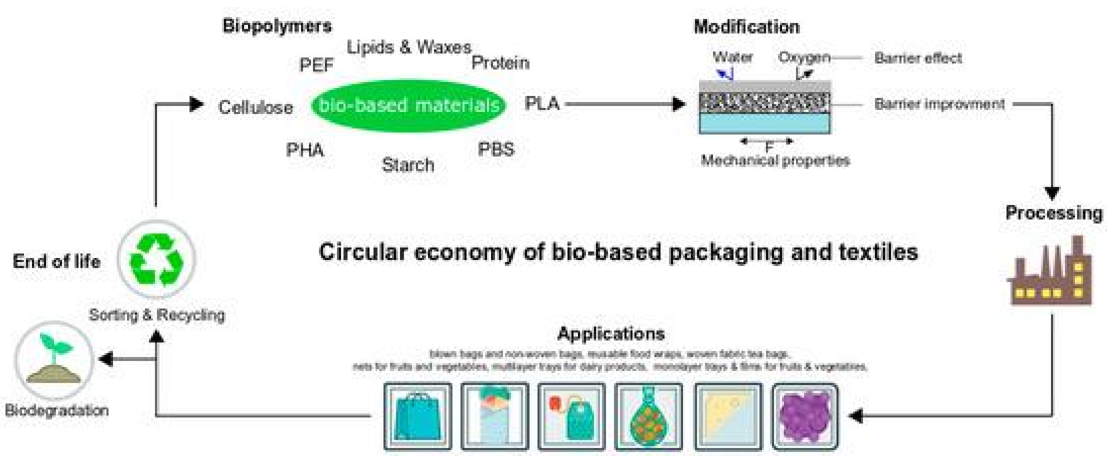
Microbially derived polymers are biosynthesized by microorganisms through fermentation processes. Polyhydroxyalkanoates (PHAs) are a prominent example in this category, produced by bacterial fermentation of sugars or oils. PHAs are biodegradable, biocompatible, and suitable for a wide range of packaging applications, from food containers to agricultural films. Another example is bacterial cellulose, which is produced by certain strains of bacteria and is characterized by its purity, flexibility, and high mechanical strength, making it an attractive material for high-performance packaging (Mukherjee et al. 2020). This classification highlights the diverse origins and properties of biodegradable polymers, offering various pathways for replacing conventional plastics in packaging. The choice of material depends on several factors including cost, availability, desired physical and mechanical properties, and end-of-life disposal methods. As the demand for eco-friendly packaging increases, research continues to focus on improving the performance and reducing the production costs of these materials, often through the development of polymer blends and nanocomposites that combine benefits from multiple sources.

BIODEGRADABILITY MECHANISMS AND ENVIRONMENTAL BEHAVIOR

The biodegradability of polymers refers to their ability to decompose into natural byproducts such as water, carbon dioxide (or methane in anaerobic conditions), and biomass through the action of microorganisms like bacteria, fungi, and algae. The degradation process is influenced by several factors including the polymer's chemical structure, molecular weight, crystallinity, environmental conditions, and the presence of suitable microbial communities (Doppalapudi et al. 2014). Biodegradable polymers typically undergo a two-step degradation mechanism: first, the polymer chains are broken down through abiotic processes such as hydrolysis or photodegradation, reducing them into lower molecular weight fragments. These smaller fragments are then metabolized by microbes through enzymatic activity, ultimately leading to complete mineralization.

Environmental behavior plays a crucial role in determining the rate and extent of biodegradation. For instance, in soil environments, microbial diversity, moisture content, and temperature can significantly affect degradation. Starch-based and cellulose-based materials tend to degrade relatively quickly in soil due to the abundance of microorganisms capable of breaking down polysaccharides. In marine environments, lower microbial activity, temperature, and oxygen levels can slow down degradation, making certain biodegradable plastics less effective if they reach aquatic ecosystems .On the other hand, industrial composting facilities provide ideal conditions—such as high temperatures, controlled humidity, and active microbial presence—for the rapid breakdown of materials like PLA and PBAT, which might not degrade efficiently in natural settings. The environmental fate of biodegradable polymers also depends on their end-of-life handling. While some materials are designed for home compostability, others require industrial composting for complete degradation. Improper disposal in landfills or marine environments may hinder the degradation process, leading to unintended persistence. Therefore, the effectiveness of biodegradable packaging materials relies not only on their chemical design but also on the availability of suitable waste management systems and public awareness.

Understanding the degradation pathways and environmental interactions of biodegradable polymers is essential for assessing their real-world sustainability. A truly sustainable material must not only degrade under ideal laboratory conditions but also exhibit predictable and harmless behavior in natural ecosystems. Ongoing research is focused on enhancing the degradability of polymers across diverse environments and developing materials that leave no toxic residues behind. The integration of biodegradability standards and certifications further helps consumers and industries identify materials that perform as intended, ultimately contributing to a more circular and responsible packaging ecosystem.



DOI: 10.48175/IJARSCT-9634C

INDUSTRIAL AND COMMERCIAL APPLICATIONS OF BIODEGRADABLE PACKAGING

Biodegradable polymers have increasingly found their place in various industrial and commercial sectors as sustainable alternatives to conventional plastics. Among these, the food and beverage industry is one of the largest adopters due to the high volume of single-use packaging it generates. Biodegradable films, containers, cutlery, and trays made from materials such as polylactic acid (PLA), starch blends, and polyhydroxyalkanoates (PHAs) are commonly used for packaging fresh produce, ready-to-eat meals, and beverages (Mangaraj et al. 2019). These materials provide adequate barrier properties to protect food items while offering the advantage of compostability, reducing the environmental impact of food packaging waste. Beyond food packaging, the pharmaceutical and healthcare industries have also embraced biodegradable polymers for applications such as blister packs, drug delivery systems, and medical disposables. The biocompatibility and biodegradability of these polymers make them suitable for packaging sensitive products that require sterile and safe containment while minimizing medical waste accumulation (Ivonkovic et al. 2017).

In the retail and cosmetics sectors, biodegradable packaging is increasingly being used for cosmetic containers, shopping bags, and product wraps. Companies are motivated by growing consumer demand for environmentally responsible products, driving innovation in biodegradable materials that offer attractive aesthetics, durability, and shelf life comparable to traditional plastics. This trend is further encouraged by stringent regulations and sustainability pledges from both governments and corporate entities. Additionally, industrial applications extend to agricultural films, seed coatings, and mulch films that biodegrade in soil, eliminating the need for labor-intensive removal and disposal, and reducing plastic pollution in farming environments. The commercial success of biodegradable packaging is often supported by life cycle assessments (LCA) which demonstrate reductions in carbon footprint, energy use, and waste generation compared to conventional plastics (Mangaraj et al. 2019). However, widespread adoption still faces challenges including cost competitiveness, supply chain readiness, and infrastructure for industrial composting. Nevertheless, ongoing research and market expansion suggest a promising future where biodegradable packaging materials become mainstream in diverse commercial applications, driving the packaging industry toward sustainability.

III. METHODOLOGY

This study is based on a comprehensive literature review combined with qualitative analysis to investigate recent advancements in biodegradable polymers for sustainable packaging. Relevant scientific articles, patents, industry reports, and regulatory documents were systematically gathered from reputable databases such as ScienceDirect, Google Scholar, Scopus, and Web of Science. The search focused on keywords including “biodegradable polymers,” “sustainable packaging,” “bioplastics,” “polylactic acid,” “polyhydroxyalkanoates,” and “biodegradation mechanisms,” with an emphasis on publications from the last decade to ensure coverage of the most current research and trends. Selection criteria prioritized peer-reviewed studies, authoritative industry analyses, and official policy documents to maintain high credibility and reliability of the data. The collected literature was analyzed qualitatively to identify key themes, technological breakthroughs, material classifications, biodegradation processes, and commercial applications. Comparative assessments were conducted to evaluate the properties, biodegradability, and environmental impact of different materials. Additionally, case studies highlighting successful industrial implementations were reviewed. The findings were synthesized to present a clear overview of the current state of biodegradable polymers in packaging, emphasizing innovations, practical applications, challenges, and future research directions. This methodological approach provides a thorough understanding of biodegradable polymers within both environmental and industrial contexts, offering valuable insights to support further sustainable development in packaging technology.

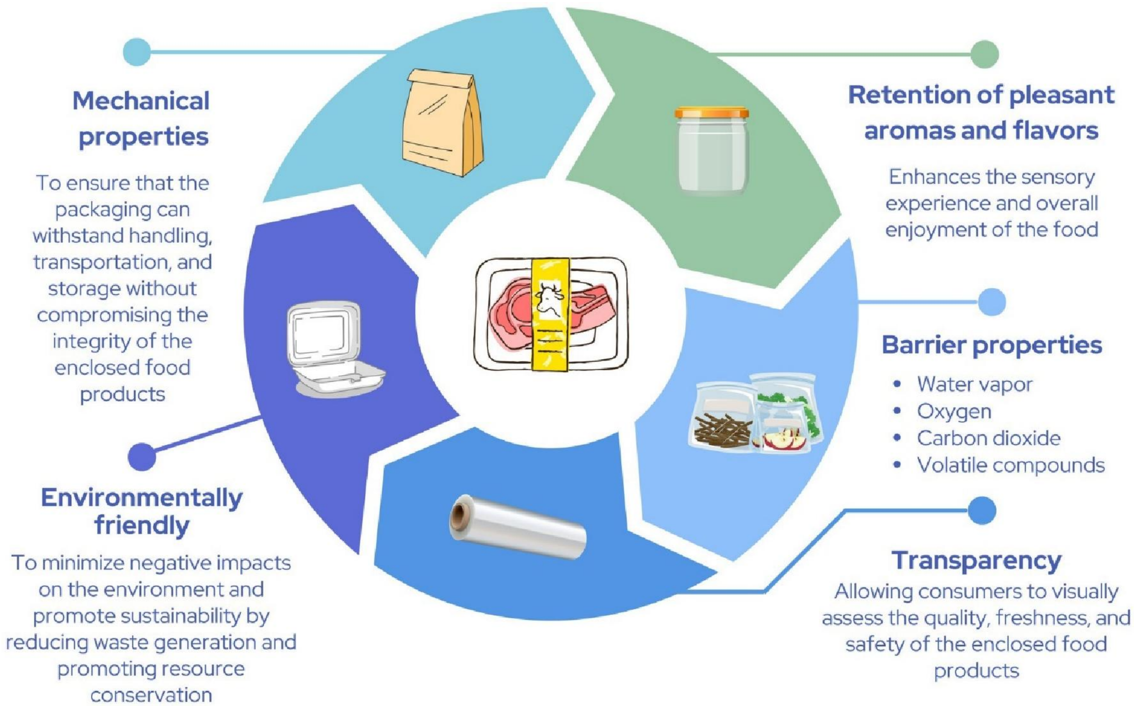
IV. RESULTS AND DISCUSSION

The review of recent literature reveals significant progress in the development and application of biodegradable polymers for sustainable packaging. Materials such as polylactic acid (PLA), polyhydroxyalkanoates (PHAs), starch-based polymers, and cellulose derivatives have demonstrated improved mechanical properties, biodegradability, and processability compared to earlier generations. Innovations including polymer blending, incorporation of nanomaterials, and chemical modifications have enhanced barrier properties and durability, addressing many of the performance limitations traditionally associated with biodegradable packaging. Industrial adoption has increased, particularly in food

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.301
Volume 3, Issue 1, March 2023

packaging and disposable items, driven by growing environmental regulations and consumer demand for sustainable products. Despite these advances, challenges remain that hinder widespread commercialization (Ashok et al. 2016).

The relatively high cost of biodegradable polymers compared to conventional plastics continues to be a major barrier, influenced by raw material sourcing and manufacturing complexity. Additionally, variability in biodegradation rates depending on environmental conditions, such as temperature and microbial activity, raises concerns about end-of-life management and effectiveness in natural ecosystems. Infrastructure for industrial composting is limited in many regions, reducing the practical benefits of compostable packaging. Moreover, recycling streams are often not equipped to handle biodegradable plastics, creating potential contamination issues (Wróblewska-Krepsztul et al. 2018).



The analysis also highlights the growing importance of regulatory frameworks and certification standards that define biodegradability and compostability criteria. These standards help ensure material performance claims are reliable and promote consumer confidence (Samir et al. 2022). Market trends indicate an increasing integration of biodegradable packaging within circular economy models, emphasizing not only biodegradability but also resource efficiency, renewable sourcing, and waste reduction. Overall, the results suggest that while biodegradable polymers have made considerable strides toward sustainability goals, continued research is needed to improve cost-effectiveness, environmental performance, and supply chain infrastructure (Hussain et al. 2021). Collaboration among scientists, industry stakeholders, policymakers, and consumers will be crucial to overcoming current limitations and enabling biodegradable packaging to fulfill its potential as a sustainable alternative to conventional plastics.

V. CONCLUSION

The advancements in biodegradable polymers represent a pivotal step toward addressing the environmental challenges posed by conventional plastic packaging. Innovations in material science have led to the development of biodegradable polymers with enhanced mechanical strength, biodegradability, and functional performance, making them increasingly viable for a wide range of packaging applications. While industries are gradually adopting these materials, barriers such as high production costs, inconsistent biodegradation in varied environments, and limited composting infrastructure remain significant challenges. Regulatory support and consumer awareness play crucial roles in driving the shift toward sustainable packaging solutions. To fully realize the potential of biodegradable polymers, ongoing research and collaboration across scientific, industrial, and policy domains are essential. Ultimately, the integration of biodegradable polymers into mainstream packaging offers a promising pathway to reduce plastic pollution and promote a circular, eco-friendly economy.

REFERENCES

[1]. Ashok, A., Rejeesh, C., & Renjith, R. (2016). Biodegradable polymers for sustainable packaging applications: a review. *IJBB*, *1*(11).

[2]. Doppalapudi, S., Jain, A., Khan, W., & Domb, A. J. (2014). Biodegradable polymers—an overview. *Polymers for Advanced Technologies*, *25*(5), 427-435.

[3]. Hussain, S., Akhter, R., & Maktedar, S. S. (2021). Advancements in sustainable food packaging: from eco-friendly materials to innovative technologies. *Sustainable Food Technology*, *2*(5), 1297-1364.

[4]. Ivonkovic, A., Zeljko, K., Talic, S., & Lasic, M. (2017). Biodegradable packaging in the food industry. *J. Food Saf. Food Qual*, *68*(2), 26-38.

[5]. Lindström, T., & Österberg, F. (2020). Evolution of biobased and nanotechnology packaging–a review. *Nordic Pulp & Paper Research Journal*, *35*(4), 491-515.

[6]. Mangaraj, S., Yadav, A., Bal, L. M., Dash, S. K., & Mahanti, N. K. (2019). Application of biodegradable polymers in food packaging industry: A comprehensive review. *Journal of Packaging Technology and Research*, *3*, 77-96.

[7]. Mukherjee, C., Varghese, D., Krishna, J. S., Boominathan, T., Rakeshkumar, R., Dineshkumar, S., ... & Sivaramakrishna, A. (2020). Recent advances in biodegradable polymers–properties, applications and future prospects. *European Polymer Journal*, *192*, 112068.

[8]. Samir, A., Ashour, F. H., Hakim, A. A., & Bassyouni, M. (2022). Recent advances in biodegradable polymers for sustainable applications. *Npj Materials Degradation*, *6*(1), 68.

[9]. Singh, P. K., Agrawal, N., Srivastav, N., Srivastav, A., Niranjan, A. K., Yadav, S., ... & Garg, A. (2021). Biodegradable packaging of food: An alternative to synthetic polymers for sustainable development. *Indian J Anim Health*, *63*(2), 62-72.

[10]. Verma, M. K., Shakya, S., Kumar, P., Madhavi, J., Murugaiyan, J., & Rao, M. V. R. (2021). Trends in packaging material for food products: historical background, current scenario, and future prospects. *Journal of food science and technology*, 1-14.

[11]. Wróblewska-Krepsztul, J., Rydzkowski, T., Borowski, G., Szczypiński, M., Klepka, T., & Thakur, V. K. (2018). Recent progress in biodegradable polymers and nanocomposite-based packaging materials for sustainable environment. *International Journal of Polymer Analysis and Characterization*, *23*(4), 383-395.

[12]. Wu, F., Misra, M., & Mohanty, A. K. (2021). Challenges and new opportunities on barrier performance of biodegradable polymers for sustainable packaging. *Progress in Polymer Science*, *117*, 101395.