



INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Biopolymer And Bioplastic- A Sustainable Alternative For Conventional Textiles

Ms. Himali Pimpale & Dr. Ritu Madhan

Research Scholar & Associate Professor

Department of Textile and Fashion Technology

College of Home Science, Nirmala Niketan,

49, New Marine Lines, Mumbai, Maharashtra 400020.

Abstract: This review discusses and examines the emerging role of biopolymers and bioplastics as sustainable alternatives to conventional textile materials, addressing eco-friendly solutions in the fashion and textile industry as a critical need. The focus of the study is about two biopolymers: Polylactic Acid (PLA), derived from renewable resources that is corn starch and sugarcane, While, Polyhydroxyalkanoates (PHA), is synthesized by microorganisms through bacterial fermentation. An assessment of mechanical properties, biodegradability, and production scalability, the research demonstrates that biopolymer-based textiles can achieve comparable performance to traditional synthetic materials and offers substantial environmental and economic advantages. PLA exhibits excellent tensile strength and natural antibacterial properties, while PHA provides biodegradability and versatility in textile applications. Environmental benefits in comparison to conventional polymers include a reduction in greenhouse gas emissions, lower energy consumption during production, and under industrial composting conditions a complete biodegradation within 3-6 months. Economic advantages such as on reduction on usage of petrochemical resources, lower carbon credits, alignment with environmental regulations, and a growing demand in market for sustainable textiles. The review explores technological advancements in biopolymer processing, including melt spinning of PLA fibres and optimization of PHA production, its parameters, and their integration into existing infrastructure textile manufacturing. Reviews indicate that both PLA and PHA-based textiles offer a better and reduced carbon footprint, biodegradable, and durable compared to conventional alternatives. While, PLA can be used in fashion and technical textiles, PHA could give a unique opportunity in medical and smart fabric applications. This study concludes that biopolymers represent solutions that are viable, sustainable for the textile industry, and the challenges for a widespread adoption needs to be addressed in cost-effectiveness and large-scale production.

Keywords: Polyhydroxyalkanoates- PHA, Polylactic Acid- PLA, Biopolymers, Bioplastic, Sustainable textiles, Eco-friendly textiles.

Introduction:

Polymers were a revolutionary man-made material that fundamentally transformed industry and daily life. Since its initial development in the early 20th century, application of polymer was used for all types of industries. These are artificially created macromolecules, synthesized through various polymerization processes, due to which, it exhibits versatility in its chemical composition, structure, and properties. Derived primarily from petroleum-based feedstocks, its controlled synthesis has enabled the production of polymers to have tailored characteristics to get specific application requirements.

Polymer are the macromolecules, composed of repeating structural units called monomers, since its emergence, thermoplastics, thermosets, and elastomers are various categories in the development of synthetic polymers, each type offers vast properties and applications. Utilized synthetic polymers such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polyethylene terephthalate (PET) have dominated the industrial production, with annual production exceeding 350 million metric tons globally. Extensive applications across diverse sectors, including packaging, construction, automotive, electronics, and medical devices, owing to their exceptional mechanical properties, chemical resistance, and cost-effectiveness.

Recent advances in polymer chemistry have led to the development of high-performance synthetic polymers, including liquid crystal polymers, conducting polymers, and shape-memory polymers. These innovations have expanded the application spectrum of synthetic polymers into advanced technologies such as 3D printing, flexible electronics, smart materials, and aerospace components. Additionally, the emergence of controlled polymerization techniques has enabled the synthesis of polymers with precise molecular weight distributions, complex architectures, and specific functional groups.

However, the widespread use of conventional synthetic polymers has raised significant environmental concerns, particularly regarding their persistence in ecosystems and dependence on non-renewable resources. This has prompted intensive research into sustainable alternatives and recycling technologies, aiming to address these challenges while maintaining the beneficial properties that have made synthetic polymers indispensable in modern society.

Polymers represent one of the most versatile and ubiquitous materials in modern society, playing a crucial role across diverse sectors including textiles, packaging, construction, and medical applications. The fundamental classification of polymers into natural and synthetic categories underscores their diverse origins and applications, with natural polymers such as cellulose, proteins, and DNA serving as essential building blocks of life, while synthetic polymers like polyethylene, polypropylene, and polyester dominate industrial applications.

In recent decades, growing environmental concerns regarding conventional synthetic polymers have catalysed intensive research into sustainable alternatives. The persistence of traditional petroleum-based polymers in ecosystems, coupled with their contribution to greenhouse gas emissions, has highlighted the urgent need for environmentally compatible solutions. This paradigm shift has led to increased focus on biodegradable polymers and bio-based alternatives that maintain the desired mechanical and physical properties while offering enhanced environmental sustainability.

The evolution of polymer science has been marked by significant technological advances in synthesis, characterization, and processing methods. Modern analytical techniques, including spectroscopy, chromatography, and microscopy, have enhanced our understanding of polymer structure-property relationships, enabling the development of materials with tailored characteristics. Furthermore, the emergence of smart polymers, responsive to environmental stimuli, has opened new frontiers in applications ranging from drug delivery systems to adaptive textiles.

Despite these advances, challenges persist in optimizing production efficiency, reducing costs, and improving the performance of sustainable polymers. The complex interplay between polymer chemistry, processing conditions, and final properties continues to drive research efforts toward developing innovative solutions that balance technological requirements with environmental responsibility.

Literature Review:

Biopolymers are derived from renewable biological sources, present a sustainable alternative to traditional synthetic polymers in the textile industry. Examples of biopolymers include cellulose, starch, chitin, proteins and peptides, DNA, and RNA. Their derivatives are abundant, exhibit fascinating properties, and are important for different applications. Some other examples of biopolymers are chitosan, alginate, carrageenan, poly(hydroxyalkanoic acids), poly(malic acid), and cutin. One of the applications of biopolymers is in drug delivery systems. For example, hydrogels are potential nano-scale drug delivery systems. Biopolymers can also be used for military purposes. There are opportunities and environmental implications to consider for military use of biopolymers. These polymers are increasingly sought to develop textiles with enhanced properties and eco-friendly characteristics. The growing demand for sustainable practices in textile manufacturing, coupled with the need for innovative materials, has fuelled researches into incorporating biopolymers into various stages of textile production, from sourcing to application. One of the classification systems, as described in *Open Access Research Journal of Science and Technology*, have categorizes biopolymers based on their source:

- Polymers from biomass: This category includes polymers like starch and cellulose derived from agricultural resources.
- Polymers synthesized from bio-based monomers: Polylactic acid (PLA) exemplifies this category, where lactic acid, derived from biological sources, is polymerized.
- Polymers obtained by microbial production: Examples include polyhydroxyalkanoates (PHAs) produced by microorganisms.

Biopolymers in the Textile Industry is another book, that provides a comprehensive exploration of this evolving field, encompassing the procurement, properties, and applications of biopolymers in textiles. Contribution of many experts from academia and industry, have offered insights into the latest research findings, case studies, and perspectives on the potential of biopolymers into a sustainable future for textiles. Specific applications of biopolymers in textiles, such as sustainable dyeing and printing, aromatherapeutic textiles, textile-based scaffolding for wound healing, and insulation materials are some concerns the book delves into. Addressal of the environmental impact and economic benefits that are associated with the use of biopolymers in the textile industry, highlighting their role in promoting sustainability.

A class of polymers derived from living organisms, offer a wide range of applications due to their unique properties, including biodegradability, biocompatibility, and renewability. Such natural sources and can be classified into different categories, such as polysaccharides, proteins, and polyesters. For example, alginate and carrageenan, extracted from seaweed, are instances of naturally occurring anionic polysaccharides. Offering a promising solution as these materials can decompose naturally, and reduce plastic waste and promoting eco-friendly practices. Investigated for a wide range of applications, including food packaging, medical devices, and tissue engineering. The selection of a suitable biopolymer for a particular application will depend entirely on its specific properties, such as mechanical strength, biodegradability, and biocompatibility. The potential to address the issue of plastic pollution and microplastics in the environment, caused due to Medical and Fashion industry, has heightened. For instance, polyglycolide (PGA), a highly crystalline biopolymer, has excellent fiber-forming ability and biodegradability and is used in resorbable sutures. Another biodegradable polymer that has gained popularity in orthopedic fixation and sutures due to its high tensile strength and slow degradation rate is Poly(lactic acid) (PLA). These aliphatic polyesters, such as polycaprolactone (PCL) and Poly(lactic acid) (PLA), degrade through a two-step process involving fragmentation into oligomers and monomers, followed by mineralization by microorganisms, yielding carbon dioxide, methane, water, and biomass. However, environmental conditions may differ the biodegradability of these polymers significantly due to their behaviour in physiological settings. Factors such as availability of oxygen, temperature, and the presence of microorganisms can influence the degradation rate and profile. Studies have shown that PLA, a commercially available biodegradable polymer, exhibits slow degradation in soil and water environments. Hence, making it an ideal biomaterial for various biomedical applications. Plasticization is a cost-effective method for enhancing the flexibility of PLA by increasing free volume and improving molecular mobility.

Poly(ethylene glycol) (PEG) is studied as a plasticizer for PLA due to its high miscibility with PLA and its effectiveness in improving flexibility. Investigated by Benkraled et al. (2024) the impact of plasticization on the thermal, mechanical, and properties of PLA using low molecular weight PEG. The study demonstrated that increasing PEG content up to 20 wt per cent resulted in a decrease in the glass transition temperature (T_g) and cold crystallization temperature (T_{cc}), indicating enhanced chain mobility. Furthermore, the crystallinity and crystallization rate of PLA increased with increasing PEG content, suggesting that PEG facilitates the chain folding process during crystallization. The researchers also found

that annealing PLA/PEG blends led to improved heat resistance, as evidenced by the increased storage modulus at elevated temperatures.

The journal *Biopolymers* (ISSN 1097-0282), published monthly by Wiley Periodicals LLC, have featured articles on various topics related to biopolymers, including their characterization, fabrication, modification, and applications. The *Biopolymers* issue of November 2024 includes articles on aspects of biopolymer research, such as starch granule architecture, cellulose nanocrystals, polydopamine-modified cellulose hydrogels, and silk fibroin/vitreous humor hydrogel scaffolds. A different perspective offered by The Quadruplex (G4) World Hypothesis, proposes that guanine-rich sequences are capable of forming quadruplex structures. It is a study published in the journal *Biopolymers* investigating the folding patterns of both DNA and RNA guanine-rich sequences. The stability and structural characteristics of quadruplexes formed by sequences, were focuses of the study providing insights into their potential roles in the prebiotic world.

The design and synthesis of Polyhydroxyalkanoates (PHAs), a potential replacement for petroleum-based plastics which are biodegradable and biocompatible polyesters produced by bacteria. Engineering advances in PHA synthesis have enabled the production of block copolymers with a wider range of material properties. One strategy is to synthesize block copolymers containing both hard and soft segments. Kawakami et al. (2024) reported the biosynthesis of PHA-based biomaterials with enhanced mechanical properties for various applications.

Another study highlights the potential of incorporating meso- Manganese peroxidase (MNPs) into cryogel scaffolds for the development of advanced biomaterials for tissue engineering applications. The composite scaffolds have magnetic properties that could be harnessed for targeted drug delivery, have magnetic stimulation of cells, and such types of therapeutic strategies. Because of Cryogel scaffolds, its tissue engineering applications have given a biocompatible, high porosity, and interconnected pore structure. Demir et al. (2024) developed a composite cryogel scaffold by incorporating mesoporous iron oxide nanoparticles (meso-MNPs) into a chitosan: gelatin cryogel matrix. The scaffolds demonstrated effects against both gram-negative (*Escherichia coli*) and gram-positive (*Staphylococcus aureus*) bacteria. In the food industry, edible coatings are made with biopolymers, packaging materials, and food additives. Guar gum is widely used as a thickener, stabilizer, and emulsifier in various food products due to its low cost and natural composition.

Analysis:

Biopolymers are polymers produced by living organisms. Biopolymers and their derivatives are abundant, exhibit fascinating properties, and are increasingly important for different applications. Polyhydroxyalkanoates (PHAs), have applications in the textile industry. PHAs are a group of polyesters produced by microorganisms. Palm oil mill effluent (POME) is a potential feedstock for PHA production using a two-stage process. The first stage is anaerobic acidogenic fermentation, and the second stage is an aerobic process. This process has been shown to successfully produce PHAs from mixed cultures under feast-famine and microaerophilic-aerobic conditions. Produced by microorganisms like *Azotobacter*

vinelandii, these biopolymers have potential applications in drug delivery, surgical sutures, and tissue engineering. Their biodegradability and biocompatibility make them attractive alternatives to synthetic polymers. Research efforts will be focusing on optimizing biopolymer production and exploring their potential in emerging fields like nanotechnology and agriculture.

Biopolymers are a promising class of sustainable materials with applications in the food and medical industries. Due to their biodegradability and biocompatibility, biopolymers offer a more sustainable alternative to traditional petroleum-based plastics. In the medical field, biopolymers such as chitosan, collagen, and alginate are being investigated for applications such as wound healing, tissue engineering, and drug delivery. The growing demand for sustainable and biocompatible materials is driving the growth of the global biopolymer market. As research and development in this field continue to advance, biopolymers are expected to play an increasingly important role in addressing environmental challenges and improving human health. The increasing emphasis on sustainability and environmental protection has led to increase in research on biopolymers.

Conclusion:

In conclusion, biopolymers represent a promising avenue for the development of sustainable and functional materials across various industries. Their inherent biocompatibility, biodegradability, and diverse functionalities make them attractive alternatives to conventional synthetic polymers. Ongoing research continues to unveil the full potential of biopolymers, paving the way for innovative applications in textiles, medicine, and beyond.

Cellulose and lignin, derived from plant biomass, have been studied extensively for their thermal properties and potential as biofuels. Research suggests that these materials could serve as renewable energy sources, contributing to efforts in mitigating climate change.

The paper explores the multifaceted property of polymers, contrasting conventional synthetic polymers, which may revolutionized industries. They pose environmental challenges due to their petroleum origins and persistence, but with biopolymers, a sustainable alternative is derived from renewable biological sources. The sources above detail the properties, applications, and advancements in both types, including high- performance synthetic polymers for advanced technologies and biopolymers for textiles, drug delivery, and food applications, emphasizing their biodegradability and biocompatibility. Research efforts focus on sustainable polymer development, including biodegradable and bio-based options, enhanced recycling technologies, and improving the performance of these environmentally conscious materials. Furthermore, the texts highlight recent studies and innovations in polymer science, such as controlled synthesis, characterization techniques, smart polymers, and the engineering of biopolymers.

References:

- Agarwal, S. (2020). Biodegradable Polymers: Present Opportunities and Challenges in Providing a Microplastic-Free Environment. *Macromolecular Chemistry and Physics*, 221(6). <https://doi.org/10.1002/macp.202000017>
- Baranwal, J., Barse, B., Fais, A., Delogu, G. L., & Kumar, A. (2022). Biopolymer: A Sustainable Material for Food and Medical Applications. *Polymers*, 14(5), 983. <https://doi.org/10.3390/polym14050983>
- Benkraled, L., Assia Zennaki, Latifa Zair, Khadidja Arabeche, Abdelkader Berrayah, Barrera, A., Zohra Bouberka, & Maschke, U. (2024). Effect of Plasticization/Annealing on Thermal, Dynamic Mechanical, and Rheological Properties of Poly(Lactic Acid). *Polymers*, 16(7), 974–974. <https://doi.org/10.3390/polym16070974>
- Chandrashekhar Upadhye, M., Chetan Kuchekar, M., Revansiddhappa Pujari, R., & Uttam Sable, N. (2022). Biopolymers: A comprehensive review. *Open Access Research Journal of Science and Technology*, 4(1), 013–018. <https://doi.org/10.53022/oarjst.2022.4.1.0070>
- Getahun, M. J., Kassie, B. B., & Alemu, T. S. (2024). Recent advances in biopolymer synthesis, properties, & commercial applications: a review. *Process Biochemistry*, 145, 261–287. <https://doi.org/10.1016/j.procbio.2024.06.034>
- Hassan, M., Bai, jun, & Dou, D.-Q. (2019). Biopolymers; Definition, Classification and Applications. *Egyptian Journal of Chemistry*, 0(0). <https://doi.org/10.21608/ejchem.2019.6967.1580>
- Kankia, N., Lomidze, L., Stevenson, S., Musier-Forsyth, K., & Kankia, B. (2024). Defined folding pattern of poly(rG) supports inherent ability to encode biological information. *Biopolymers*, 115(6). <https://doi.org/10.1002/bip.23615>
- Kawakami, T., Tomita, H., Hien, P. T., & Matsumoto, K. (2024). Biosynthesis of High Toughness Poly(3-Hydroxypropionate)-Based Block Copolymers With Poly(D-2-Hydroxybutyrate) and Poly(D-Lactate) Segments Using Evolved Monomer Sequence-Regulating Polyester Synthase. *Biopolymers*, 115(6). <https://doi.org/10.1002/bip.23618>
- Lignocellulosic Biomass - an overview | ScienceDirect Topics*. (2018). Sciencedirect.com. <https://www.sciencedirect.com/topics/engineering/lignocellulosic-biomass>
- Modenbach, A. A., & Nokes, S. E. (2013). Enzymatic hydrolysis of biomass at high-solids loadings – A review. *Biomass and Bioenergy*, 56, 526–544. <https://doi.org/10.1016/j.biombioe.2013.05.031>
- Polyhydroxyalkanoates (PHAs): Types, Properties, Chemical Structure & Toxicity*. (n.d.). Omnexus.specialchem.com. <https://omnexus.specialchem.com/selection-guide/polyhydroxyalkanoate-pha>
- Sahu, A. K., Mitra, I., Kleiven, H., Holte, H. R., & Svensson, K. (2022). *Cambi Thermal Hydrolysis Process (CambiTHP) for sewage sludge treatment*. ScienceDirect; Elsevier. <https://www.sciencedirect.com/topics/engineering/hydrolysis-process>