

Design, Development, and Environmental Implications of Biodegradable Polymers as Sustainable Alternatives to Conventional Plastics

Rafael Costa*

Department of Materials Science, University of São Paulo, Brazil,

*Corresponding author: Rafael Costa, Department of Materials Science, University of São Paulo, Brazil,

Email: rafael.costa.polymer@gmail.com

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Abstract

Biodegradable polymers have emerged as a promising solution to mitigate the environmental challenges posed by persistent plastic waste. This article provides an in-depth analysis of the sources, synthesis, degradation mechanisms, and applications of biodegradable polymers, with a particular focus on their role in sustainable development. Materials such as polylactic acid (PLA), polyhydroxyalkanoates (PHA), and starch-based polymers are discussed in terms of their structural characteristics, biodegradability, and performance. The article also explores the environmental benefits of these materials, including reduced carbon footprint and minimized ecological impact.

Keywords: Biodegradable polymers, sustainability, PLA, PHA, eco-friendly materials

Introduction

The widespread use of conventional plastics has led to severe environmental consequences, including pollution of land and marine ecosystems, accumulation of non-degradable waste, and adverse effects on wildlife [1]. In response to these challenges, biodegradable polymers have gained significant attention as environmentally sustainable alternatives [2]. These materials are designed to undergo degradation through biological processes, resulting in harmless by-products such as carbon dioxide, water, and biomass [3]. Biodegradable polymers can be derived from renewable resources, including agricultural products and microbial processes, which further enhances their sustainability profile [4]. Among the most widely studied biodegradable polymers are polylactic acid, polyhydroxyalkanoates, and starch-based materials, each offering unique properties and applications. In addition to packaging, these polymers are extensively used in biomedical applications such as drug delivery systems, sutures, and tissue engineering scaffolds

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due to their biocompatibility and controlled degradation behavior [5]. Despite their advantages, biodegradable polymers face several limitations that hinder their widespread adoption. Issues such as lower mechanical strength compared to conventional plastics, higher production costs, and limited processing capabilities remain significant challenges. Current research efforts are focused on improving material properties through advanced techniques such as copolymerization, reinforcement with nanomaterials, and optimization of processing methods.

Conclusion

Biodegradable polymers represent a crucial advancement in the pursuit of sustainable materials and environmental protection. While significant progress has been made in their development and application, further research is required to address existing limitations and enhance their performance. The integration of scientific innovation, industrial collaboration, and supportive policy frameworks will be essential for realizing the full potential of biodegradable polymers in replacing conventional plastics.

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