

# Review on Polyhydroxybutyrate (PHB) and Global Research Trends

Krushna Manvatkar\*<sup>1</sup>, Dr. Priya Joshi<sup>2</sup>, Krushna Mohite<sup>3</sup>, Mahesh Khatade<sup>4</sup>, Suyash Wasule<sup>5</sup>

<sup>1, 2, 3, 4, 5</sup>Dept of Applied Science and Humanities

<sup>1, 2, 3, 4, 5</sup> Pimpri Chinchwad College of Engineering Pune

**Abstract-** Polyhydroxybutyrate (PHB) is one of the most studied members of the polyhydroxyalkanoate (PHA) family. It shows promise as a biodegradable and sustainable alternative to traditional plastics. With rising global worries about plastic pollution, microplastic buildup, climate change, and dwindling fossil resources, the demand for eco-friendly polymers has jumped significantly. PHB has become a top choice due to its biodegradability, biocompatibility, and mechanical properties that are similar to polypropylene. This review looks at PHB research trends, microbial production systems, methods for using substrates, techno-economic assessments, industrial uses, and environmental benefits. It also includes insights from bibliometric studies, performance of microbial strains, and the impact of using waste-derived feedstocks to lower production costs. While PHB has excellent environmental benefits, issues like high production costs, substrate prices, complex downstream processing, and a lack of large-scale production facilities make commercialization difficult. This paper aims to bring together existing scientific literature into a detailed review for academic and industry stakeholders, offering guidance for future advancements in PHB research and the development of sustainable materials.

**Keywords:** Polyhydroxybutyrate; Polyhydroxyalkanoates; Biodegradable Plastics; Waste Valorisations; Fermentation; Bioprocess Engineering; Sustainability.

## I. INTRODUCTION

This over-reliance on plastic materials over the years has led to massive levels of pollution of the environment by millions of tons of plastic material. Traditional plastic materials, which are derived from petroleum, have a slow degradation rate and result in the formation of microplastics that have negative impacts on biodiversity, soil, and human health. With projections indicating that plastic production will surpass one billion tons biennially by the midpoint of the century, the development of biodegradable plastic materials is now an issue of utmost concern. Bioplastics are sustainable plastic materials that will decrease the use of petroleum and prevent pollution of the environment.

Polyhydroxybutyrates (PHB) are a type of polyhydroxyalkanoates (PHA) that are biosynthesized by various bacterial strains under low nutrient conditions and high carbon supplies. This polymer can serve as an energy reservoir and appears in cells as granules. Moreover, PHB can comprise up to 80% of a cell's dry matter content. Due to its biodegradability, non-toxicity, and ability to be processed under high temperatures, PHB can be applied in a wide variety of applications like medical devices and implants, packaging materials, agricultural films, carriers of drug delivery systems, or biodegradable tissue engineering scaffolds.

Notwithstanding its myriad advantages, there are several limitations in the commercialization of PHB on a larger scale. They are as follows:

1. Cost of carbon substrates
2. Inefficient downstream processing
3. Lower productivity in wild strains
4. Energy-intensive extraction processes

Presently, there has been emphasis on the development of fermentation processes, genetically modified strains, inexpensive substrates, the usage of the concept of the circular economy, and improvement in extraction methods.

The review will offer a holistic, single-column, and thesis-format literature review on PHB. The broad topics would be global research trends, microbial production, substrates, industrial feasibility, ecologically significant topics, and challenges to be overcome for mass production of PHB as an identical biodegradable bioplastic.

## II. LITERATURE REVIEW

### 2.1 Global Importance and Current Status of PHB

According to a report by Gautam et al. in 2024, PHB has been gaining popularity due to an innovative response to ever-growing demands regarding the status of today's planet and its shortcomings in conventional plastic materials. According to statements made by Gautam et al., despite biopharm or biopolyesters like PHAs currently accounting for

less than 1% of total biopolymer production on an average global perspective, they are still regarded as one of the most promising biodegradable biopolymers because of their close resemblance to conventional petroleum-based plastic materials and ease of biodegradation. This demands growth in biopolymer consumption because companies in Europe, Asia, and the United States have been experiencing growth

PHB and PHA production plants. Such materials include Kaneka's PHBH™, biologically based materials from Danimer Scientific, and AirCarbon™ from Newlight Technologies, and these materials illustrate that large-scale production of biodegradable bioplastics can be achieved. However, the production costs, in which the substrate costs contribute almost 40%, show that PHB is relatively costly compared with other plastics.

## 2.2 Microbial Production of PHB

The list of bacteria being used to formulate PHB includes *Cupriavidus necator*, *Bacillus megaterium*, *Azotobacter vinelandii*, and recombinant *E. coli*. Out of these, *Cupriavidus necator* bacteria stand as the most proficient in PHB production, contributing to the maximum (up to 80%) PHB accumulation per dry cell mass. Other bacteria, which have attracted considerable attention with respect to their efficiency in growth using low-cost materials and in adapting to adverse environmental conditions, include *Bacillus* species. Alshehrei (2019) isolated bacteria from soil samples in different Saudi Arabian regions, and among them, *Bacillus* sp. F15 manifested maximum PHB accumulation in optimized conditions of pH and temperature, which are 7 and 30°C, respectively. The suitable source of carbon material has been identified as glucose, and nitrogen source as ammonium sulfate.

## 2.3 Fermentation Strategies

There are several methods of fermentation that have been used in attempts to enhance the productivity of PHB:

- Batch fermentation involves simplicity but usually has a limiting factor of the consumption of the substrate and the inhibitory by-products.
- Fed-batch fermentation allows the fermentation course to add substrate, hence increasing
- Continuous fermentation means there is a constant production with reduced operational cost.

Ventura & Ventura 2024 performed techno-economic analysis for the production of PHB biopolyester from the hydrolysate of corn stover, and found that a continuous process reduces the price of the polymer from USD 11.80/kg to USD 6.55/kg. The conclusion from this is that continuous processes are more productive, scalable, and viable, and even better when efficient methods of pretreatment are in place.

## 2.4 Substrate Utilization and Cost Reduction

Substrate cost is noted to be the major economic limitation in PHB production. While glucose, sucrose, and molasses have been effective carbon sources, they are rather costly. Therefore, there has been an immense interest in utilizing cheaper carbon sources such as:

Crop residuals: corn stover, rice straw, sugarcane bagasse  
Whey, Glycerol, and Molasses, Waste Products from

- Municipal wastewaters
- Lignocellulose

In these, steam explosion, dilute acid hydrolysis, and enzymatic saccharification are some of the major processes in pretreating lignocellulose to produce fermentable sugars. According to Ventura & Ventura, 2024, steam explosion has been more economical; it increased the digestibility of biomass, reducing the cost of the overall process.

## 2.5 Mixed Microbial Cultures (MMCs) for PHB Production

One of the strong advantages in mixed microbial cultures is their robustness, cost-effectiveness, and ability to use complex wastes. Abidin et al. (2025) reviewed the research trends of PHB and underlined the increasing interest in the area of mixed microbial cultures. Mixed microbial cultures are widely used in wastewater treatment plants for simultaneous waste treatment and production of PHB. The largest producers of PHB-related publications are China, India, the United States, and Brazil. Genetic improvement, bioreactor, low-cost materials, and circular economy were pointed out as hotspots in the bibliometrics study.

## 2.6 Environmental Significance of PHB

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## 2.7 Applications of PHB

PHB has many applications in its biocompatibility form, together with its other physical properties:

- BIO-medical applications: sutures, scaffolds, carriers for drug delivery
- Packaging: packaging films, containers for food
- Agriculture: mulching films, seed coatings
- Electronics: Biodegradable components of circuits
- Textiles: Fibre Production

As it resembles polypropylene in terms of mechanics, it has replaced petroleum-based plastics in various industries.

## 2.8 Downstream Processing Challenges

Downstream processing of PHB includes cell harvesting, cell lysis, polymer extraction, and purification. Traditionally, solvents such as chloroform and dichloromethane are used, but these are costly, hazardous, and unsuitable for large-scale production. Alternative methods include:

- Mechanical disruption
- Enzymatic digestion
- Aqueous two-phase extraction

Gautam et al. (2024) emphasize that downstream processing contributes significantly to production cost and environmental impact, and innovations in this stage are critical for PHB commercialization.

## III. CONCLUSION

PHB itself has been an excellent example within itself in the area of biodegradable polymers and thus holds immense potential in addressing issues related to the environment caused by plastic waste itself. Therefore, based on the development of microbial augmentation, whether it is through the technology involved in fermentation or simply through processing of the waste itself, it has already been made possible to develop innovations within itself by making it highly innovative itself. However, since it involves high cost

in its manufacturing stage itself and inefficient processing systems within itself either, there are immense points against its development level of itself itself. However, due to awareness generated by every person on the face of the earth about plastic waste itself, there are immense possibilities of it becoming a huge player within itself itself.

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