IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Production Of Microbial Biopolymers And Its Application-A Review

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Abstract:

Due to the high cost of petroleum products and the environmental effects of synthetic plastics, it has to be replaced by biopolymers because they are potentially strong and have a degrading capacity in nature. The alternative for plastic could be polyhydroxyalkanoates (PHAs), polyhydroxybutrate (PHBs) and polylactic acid (PLAs). They are abundant in starch and sugar industrial agro waste which helps to produce biopolymers at low cost which are then successfully converted into PHAs, PHBs, and PLAs. This conversion is mediated by the microbial isolates or genetically modified microbes by converting microbial biomass into biopolymers and optimizing the conditions for the fermentation of sugar obtained from the agro-industries. Easily available starch and sugar industrial agro wastes contain nutritional value. So, it is being used as the substrate for microbial growth. Nowadays the research aspects were critically increased on microbial biopolymer and its production. In this paper, the different aspects of biopolymer production and the challenges involved in overcoming the problems are being reviewed.

Keywords:

Biopolymers, Types of bioplastics, PHAs, PHBs, PLAs, Synthetic plastic

1 Introduction:

Plastics are considered to be an inevitable material in day-to-day life due to their mechanical properties when compared to other materials like glass, metal, and clothes. Plastics often contain harmful additives like phthalates and BPA, which can leach into the environment and accumulate in living organisms. These chemicals, known for disrupting the endocrine system, pose health risks to humans and animals. Research shows that exposure to plastics can lead to reproductive issues, developmental abnormalities, and increased disease risks. Efforts to mitigate these risks involve regulations, alternative materials, and increased awareness about the impact of plastic additives on health and the environment (Meeker et al. 2009). Mostly these plastics are produced by the packaging industries. Half of the plastics are thrown off after single use in the environment, which leads to land pollution. The plastics that are dumped into the marine ecosystem affect the life of marine organisms. So a fast replacement is needed instead of plastic packaging industries because it is estimated to grow to 25 million tons by 2023.

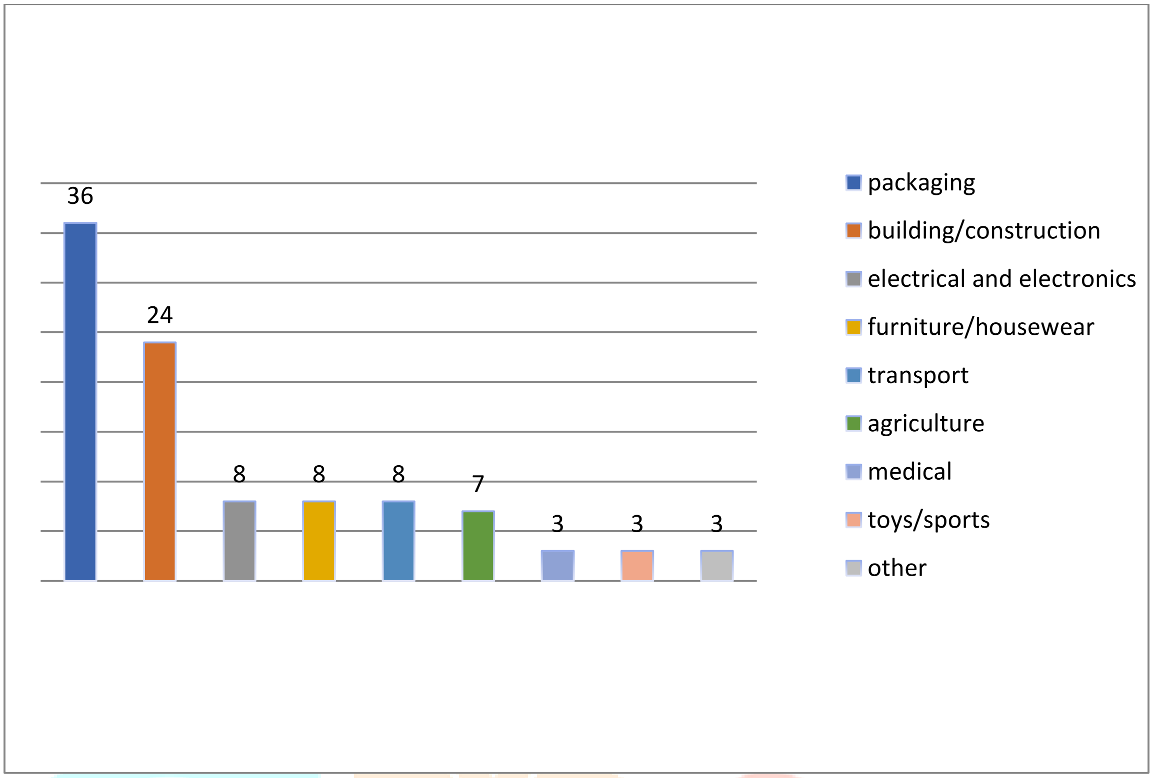

Figure 1. Percentage usage of plastics in various sectors

Currently, researchers are working on the exploration of new approaches for producing biologically synthesized biopolymers that are biodegradable, eco-friendly, and are produced from resources like microbial sources as an effective alternative for synthetic plastic (Nduko et al. 2015; Alcântara et al. 2020). These bioplastics include polyesters, polyhydroxyalkanoates (PHAs), polyhydroxybutrate (PHBs), and polylactic acid (PLA), which contains similar mechanical and physicochemical properties to synthetic plastics (Taguchi, 2010; Kourmentza et al. 2017). PHA comes under the class of natural biodegradable polyesters that are produced from microorganisms accumulated as intracellular granules or extracellular polysaccharides under unbalanced growth conditions such as abundant carbon sources and limited essential nutrients like nitrogen, phosphorous, and oxygen. (Tarrahi et al. 2020). Depending on the various microorganisms the monomer composition and physico-chemical properties will change.

The disadvantage in the commercial production of biopolymers is in high production cost (Sudesh K et al. 2000). Nowadays, advancement in genetic engineering led to their biosynthesis in various recombinant microorganisms (bacteria, fungi, yeasts) (Breuer U et al. 2002 and Park S et al. 2005). It helps in improving the yields and reduces the overall costs.

The major advantage of these biopolymers is completely biodegradable under aerobic and anaerobic conditions and have similar properties to various synthetic plastics. Biopolymers can be produced by polymer processing methods. The disadvantages in commercial production of biopolymers is in high production cost (Sudesh K et al. 2000). Now a days, advancement in genetic engineering led to their biosynthesis in various recombinant microorganisms (bacteria, fungi, yeasts) (Breuer U et al. 2002 and Park S et al. 2005). It helps in improving the yields and reduces the overall costs.

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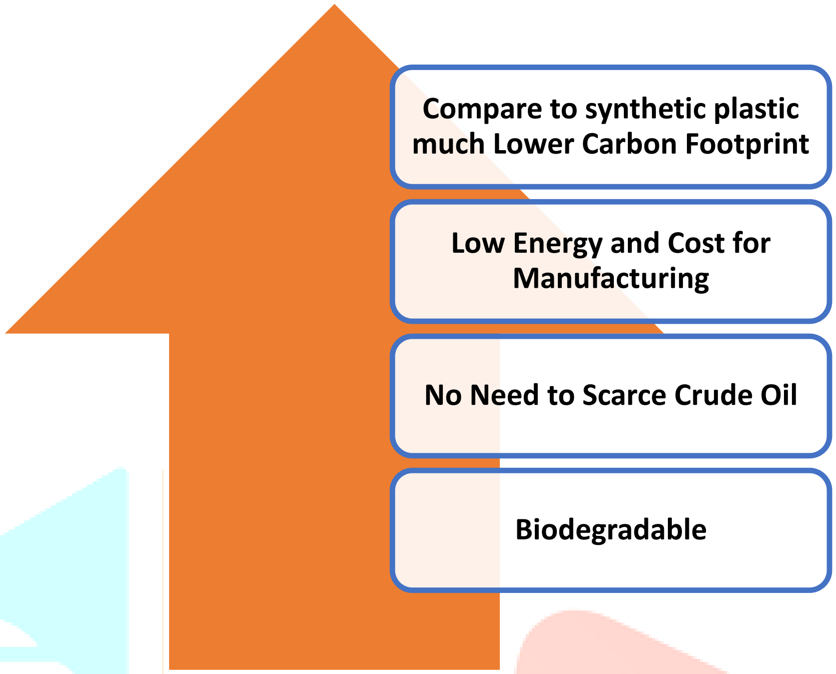


2 Microbial biopolymer history:

2.1 Early Exploration (Late 19th Century):

The concept of microbial biopolymer production can be traced back to the late 19th century when researchers began to study microorganisms and their metabolic capabilities.

Early studies focused on natural microbial polymers, such as bacterial cellulose and microbial exopolysaccharides, which were discovered in various microbial species. (Anderson, A. J., & Dawes, E. A. et al. 1990).

2.2 Polylactic Acid (PLA) Discovery (1930s):

The production of poly(lactic acid) (PLA), a biodegradable and biocompatible polymer, was first investigated in the 1930s, but it gained significant attention in the latter half of the 20th century. (Blasi, P et al. 2019)

2.3 Polyhydroxyalkanoates (PHA) Research (1960s-1980s):

Polyhydroxyalkanoates (PHA) are a group of biodegradable biopolymers produced by various microorganisms. Research into PHA production began in the 1960s and gained momentum in the 1980s with the isolation and characterization of PHA-producing bacteria.

The discovery of a wide range of PHA-producing microorganisms and the development of genetic engineering techniques expanded the possibilities for PHA production. (Keshavarz, T., & Roy, I. et al. 2010)

2.4 Microbial Exopolysaccharides (EPS) (1980s-1990s):

Microbial exopolysaccharides (EPS) are secreted polysaccharides produced by microorganisms. They have various applications in the food, pharmaceutical, and cosmetic industries.

Extensive research on EPS production by microorganisms, such as xanthan gum from *Xanthomonas campestris* and gellan gum from *Sphingomonas spp*., took place during this period. (Rehm, B. H. et al. 2010)

2.5 Advancements in Genetic Engineering & Commercialization:(2000s-Present):

Advances in genetic engineering techniques have enabled the optimization of microbial biopolymer production strains. Researchers have modified microorganisms to enhance biopolymer yields and properties. (Anderson LA et al. 2018)

The 21st century saw significant progress in the commercialization of PHA biopolymers. Biopolymer industries are now started producing PHA biopolymer on a larger scale. (Koller M et al. 2022)

PHA-based bioplastics have found applications in packaging, agriculture, and medical devices, contributing to the reduction of conventional plastic use.

2.6 Growing Interest in Sustainable Materials (Present):

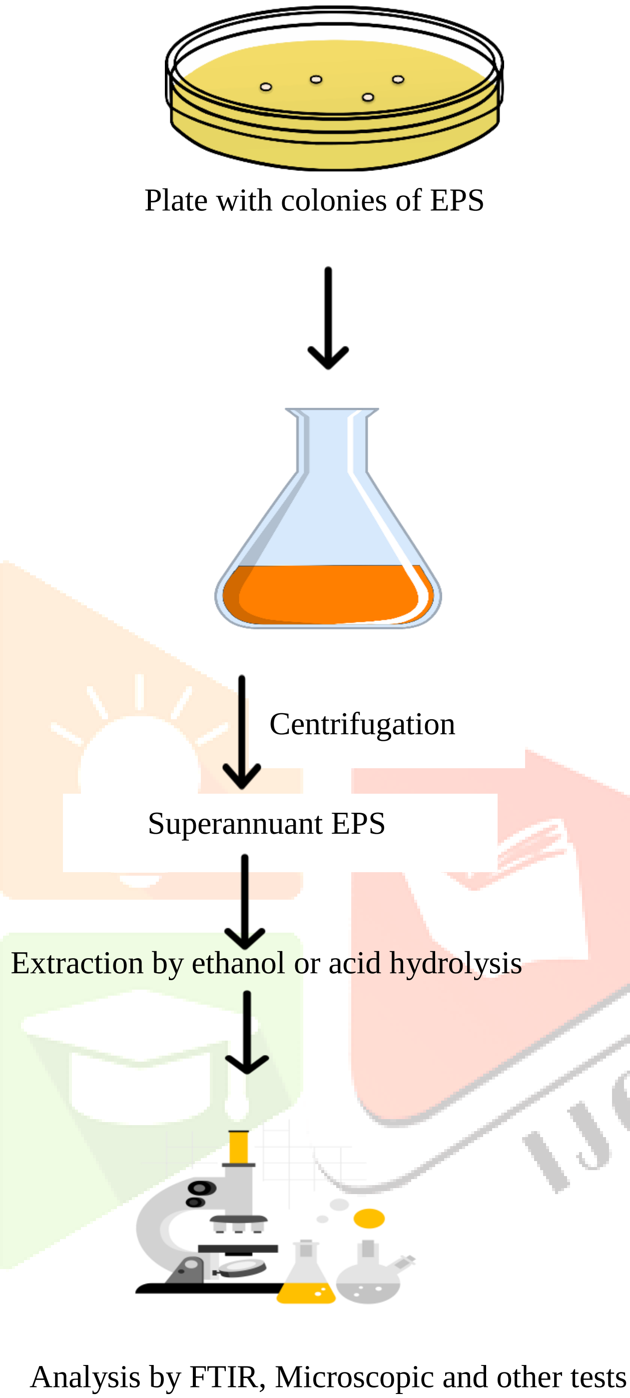
The increasing global awareness of environmental issues and the need for sustainable materials have driven interest in microbial biopolymer production.

Ongoing research and development are focused on reducing production costs, improving the properties of biopolymers, and expanding their use in various industries.

3 Microbes involved in bioplastic production:

Microorganisms are potentially capable of converting microbial biomass into biopolymer and optimizing the conditions for the fermentation of sugar. Easily available starch and sugar industrial agro waste contains high nutritional value. So it used as a substrate for microbial growth.

Basic steps involved in the isolation of EPS from microbes



Microbes will produce biopolymer in abiotic stress like,

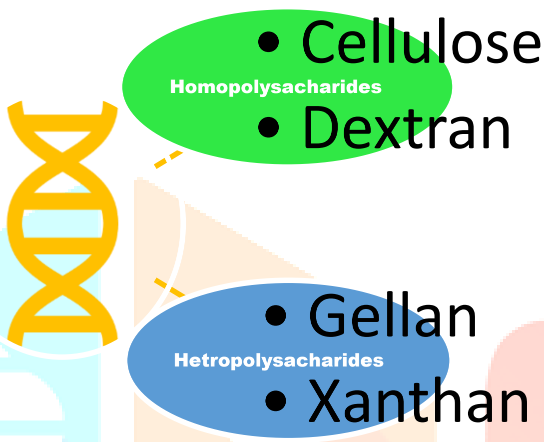
- Heat
- Light
- Moisture
- Humidity

Biopolymers produced from microbes it will degrade in aerobic and anerobic conditions.

The various forms of biopolymers are,

- Polysaccharide
- Polyamide
- Polyester
- Polyphosphate

The polysaccharide are sugars mainly glucose, divided in to two major groups



Cellulose is extracted from various microbial species, such as *Acetobacter, Agrobacterium, Aerobacter, Achromobacter, Azotobacter, Rhizobium, Sarcina,* and *Salmonella* (Schink B et al. 1992)

Genetically modified microorganisms (GMO) are also capable of producing biopolymers from recombinant *E. coli* and recombinant *Pseudomonas olevorans*.

Singh RS et al. has conclude that pullulan has produced from *Aureobasidium pullulans* by use of agro-industrial wastes as a cost-effective and environmentally friendly substrate. The microbial exopolysaccharide, which was previously generated using resource-intensive methods, becomes an environmentally friendly option by tapping into waste materials containing carbon, nitrogen and other essential nutrients. Pullulan's unique features find use in a variety of food sectors, because of its two types of fermentation techniques, submerged and solid-state. This revolutionary technique not only solves environmental problems, but it also converts waste into a profitable resource.

Table 1 Applications of microbial EPSs

S.No	EPS	Microbial source	Applications	Reference
1.	Dextran	*leucononstock mesenteriods*	Polymer coating material	Nicolescu CM et al. 2023
2.	Xanthan	*Xanthomonas campesteris*	Food additive, stabilizer	Bhat, I.M et al. 2022
3.	Pullulan	*Aureobasidium pullulans*	Food additive providing bulk and texture	Hu H et al. 2022
4.	Gellan	*Sphingnomonas eloda*	Thickener, stabilizer and binder	Li A et al. 2019
5.	Curdlan	*Agrobacterium Sp*	Improving the texture of food products	Mangolim CS et al. 2017
6.	Bacterial cellulose	*Gluconacetobacter xylinus*	Wound dressing	Moniri M et al. 2017
7.	Schizophyllan	*Schizophyllum commune*	Therapeutic application	Stoica et al. 2023
8.	Alginate	*Azotobacter vinelandii*	Gelling and emulsifying agents	Núñez C et al. 2022

3.1 Polyhydroxyalkanoatos (PHAs):

PHA based polymers are linear polyesters poly (3-hydroxyalkanoates) such as innumerous monomers formed by fermenting sugar and lipids with help of microbes (Madison LL et al. 1999) This is produced in microbes for storing carbon and energy sources (Anderson AJ et al. 1990). This biopolymer is extracted from microbes in large scale production for industrial application. PHA has similar properties to synthetic plastics such as Polypropylene (PP). The biosynthesis of biopolymers usually gets in response to stress conditions like nutrient deficiency such as nitrogen or phosphate. *Cuprividus necator* takes carbon dioxide and nitrogen gases it will convert them as copolymers in gas fermentation process. PHA is also produced by other bacterial species such as *Pseudomonas aernginosa*, *p.oleoverans* (M.J. Fabra et al. 2016).

In terms of sustainable production, studies have looked into the use of Bacillus megaterium for PHA production. Furthermore, agro waste, specifically bagasse and sugarcane molasses, has been used as a carbon source in the PHA production growth media. This method emphasizes the possibility of obtaining the required carbon sources from agricultural waste, which leads to more sustainable and environmentally friendly practices (Kulpreecha et al. 2009).

3.1.1 Application:

PHA is being used as an alternative for metal in tissue engineering to develop scaffolds and also contains various applications in the field of pharmacology and medicine (Simmon et al. 2002).

3.2 Polylactic acid (PLAs):

PLA is one of the most widely produced biopolymers globally, polylactic acid (PLA) holds a significant position in the polymer market. Polylactic acid is an aliphatic polyester with the unique property of being derived from both natural resources and microbial processes. PLA is created through an intriguing process in which bacteria convert glucose into lactic acid through fermentation, and this lactic acid is then polymerized into PLA films.

The drying process is an important stage in the production of PLA because it ensures the final product's quality and properties. This step typically entails desiccant drying, in which PLA is exposed to specific conditions in order to remove moisture content. The drying process for crystalline PLA typically takes 2 to 4 hours at 60 degrees Celsius. In contrast, amorphous PLA is dried at a slightly lower temperature of 45 C. To achieve the desired properties and characteristics of PLA products, this carefully controlled drying process is required (Garlotta et al. 2001).PLA's widespread use and versatility, as well as its low carbon footprint, make it a desirable option in the world of biopolymers and sustainable materials. Its manufacturing processes are constantly refined to improve efficiency and ensure consistent quality of PLA products.

3.2.1 Application:

Its one of the most promising biopolymers used in biomedical field for bone fixation screws and drug delivery devices. PLA requires very less energy 25-55% compare to the petroleum-based polymers. (Stori and Lattuada 2017)

3.3 Polyhydroxybutrate (PHBs):

Poly(3-hydroxybutyrate), or PHB, was found in microorganisms such as *Bacillus megaterium* and Methylobacterium sp. as the first isolated biopolymer. These microorganisms are capable of produce PHB, a valuable biopolymer, through a process that involves the accumulation of carbon sources such as glucose and nitrogen in the growth medium. To increase the accumulation of PHB in the aqueous phase, the amount of glucose and nitrogen in the medium containing *Bacillus megaterium* should be increased. This method can make use of renewable resources such as starch and agro waste from sugar manufacturing industries.

PHB production from such sources has the potential to reduce production cost while utilizing renewable waste materials (E. V. Torres et al., 2017). However, that PHB has limitations. Because of its high degree of crystallinity, it has low elasticity and a melting temperature of around 180°C. As a result, when compared to other biopolymers such as polyhydroxyalkanoates (PHA), PHB may be limited in certain manufacturing applications. PHA's tunable properties may make it a more flexible and desirable option for specific industrial needs.

3.3.1 Application:

PHB is used in medical devices for dental, orthopedic, hernioplasty, skin surgery and biological screws.

Table 2 Applications of microbial biopolymers in different fields:

Field	Form	Use	Application	Reference
Environmental Sustainability	Biodegradable Packaging	Packaging materials	Reducing plastic waste and pollution.	Ncube LK et al. 2020
Medicine	Biomedical Implants	Compatible implants-screws & scaffolds	Bone and tissue regeneration	Girón J et al. 2021
Drug Delivery Systems	Drug carriers	Controlled release of medications	Drug formulations for targeted drug release	Adepu S et al. 2021
Food Industry	Food Packaging	Edible Films & Coatings	Enhancing the shelf life	Rossi-Márquez et al. 2023
Pharmaceutical	Wound Dressings	Promoting healing	Preventing infections	Dhivya S et al. 2015
Textile Industry	Eco-Friendly Textiles/ Fabrics	Sustainable textiles	Reducing the environmental impact	Patti A et al. 2020
Water Treatment	Biodegradable Flocculants	Flocculants in water treatment processes	Remove impurities and pollutants.	Koul et al. 2022
Oil Spill Cleanup	Biodegradable Sorbents	Sorbents to clean up oil spills	Eco friendly alternative to conventional sorbents	ZamparaM et al. 2020
Cosmetics and Personal Care	Cosmetic Formulations	Film-forming & thickening agents	Improving skin texture	Guzmán et al. 2022

These detailed applications showcase the versatility and environmental benefits of microbial biopolymers in a wide range of industries, thereby contributing to sustainability and decreasing environmental impact. The ability of these biopolymers to adapt to a number of challenges highlights the possibility for transforming various industries in more ecofriendly and responsible ways.

4 Conclusion:

Bioplastic is the need of the hour in day-to-day life, from packing industry to the grocery shopping and facilitating the public. Biopolymers have some similar properties, like Polypropylene (PP). The biopolymers usually get good response in stress conditions like nutrient deficiency such as nitrogen or phosphate and oxygen. Nowadays microbial biopolymer such as PHAs, PHBs and PLAs research and production are also increased. The synthetic plastics have to be replaced by biopolymers and its better alternative for synthetic plastic and to make sustainable environment.

Acknowledgement:

The authors express their gratitude towards the host Institution Dr. N.G.P. Arts and Science college and DST-FIST Scheme, DBT-Star Scheme, Management, Principal, Deans, Head of the Department, guide and other staff of the Department of Biotechnology for provide all the facilities and support. Communication no: DrNGPASC 2022-23 BS031

Conflicts of Interest: The authors declare no conflicts of interest.

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