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A Review of PHB Production by Cyanobacteria and Its Applications

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Abstract

A significant worry is the impact of non-biodegradable plastic garbage. Consequently, efforts are being made to make bioplastics from living resources based on those materials' capacity to decompose. The cost-effectiveness of these resources has led scientists to explore alternatives, such as photoautotrophic cyanobacteria. The prospective significance and rising popularity of exploiting cyanobacteria as a PHB resource are described in this review. Numerous studies demonstrate that under stressful conditions, different cyanobacterial species build up intracellular poly-hydroxybutyrate granules as carbon and energy stores. PHB is thermoplastic that is biocompatible, environmentally benign, and degradable. They may be utilized in numerous ways, comparable to many non-biodegradable petrochemical plastics now in use, and vary in hardness and flexibility, depending on their composition. Promising methods include genetically modifying microorganisms to incorporate manufacturing routes under study over the past 20 years. This type of study focuses on the use of alternate substrates, innovative extraction techniques, genetically altered species, and mixed cultures to produce PHB from cyanobacteria. We have also discussed various applications of polyhydroxybutyrate in this review.

Keywords: Cyanobacteria, Biopolymer, Polyhydroxybutyrate, Bioplastic

Introduction

A common intracellular storage substance discovered in prokaryotic organisms is poly-hydroxybutyrate as shown in **Figure 1** (Ranganadhareddy, 2022). Pure poly-hydroxybutyrate (PHB) may be an alternative to conventional plastics due to its features, which include thermoplastics' total biodegradability and absolute water resistance (Ranganadha *et al.*, 2019). Additionally, this would work well with modern waste management techniques. Due to its high manufacturing cost in comparison to several commonly used petroleum-derived plastics, the usage of PHB generated by bacterial fermentation as a commodity polymer is constrained (Zia *et al.*, 2017). Epoxides and polysulfones are among the most frequently used goods on the planet thanks to the quantity, varieties, and prospective attributes that have significantly expanded their production.

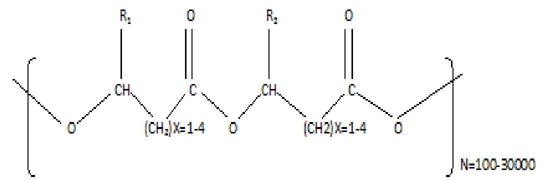

Figure 1. Polyhydroxybutyrate structure

Pure PHB has thermoplastic processability, hydrophobicity, total biodegradability, biocompatibility, and optical purity among its features (Sathya *et al.*, 2018). They are receiving more and more attention as a source of raw materials for biodegradable polymers. Due to their low food needs and photoautotrophic nature, cyanobacteria may be thought of as an alternate host system. Under photoautotrophic conditions, cyanobacterial species can accumulate PHB homopolymer (Akhtartavan *et al.*, 2019). PHB can accumulate in cyanobacteria. The advantage of utilizing cyanobacteria in industrial PHB production is that it uses solar energy to transform waste CO_2, a greenhouse gas, into environmentally benign polymers (Syahirah *et al.*, 2021). Many different cyanobacterial species build up a lot of Polyhydroxybutyrate (Daniel *et al.*, 2020). This review has been put together and published with a clear view of the existing state, future potential, and areas that still need development based on the literature that is now accessible on the generation of PHB by cyanobacteria.

PHB Synthesis in Cyanobacteria

Three enzymatic processes convert acetyl coenzyme Ainto poly-hydroxybutyrate (Zhao *et al.*, 2019). Three enzymes are required for the conversion of two acetyl coenzyme A molecules into one aceto acetyl coenzyme A molecule: 3-ketothiolase, NADPH-dependent acetoacetyl- coenzyme A reductase, and PHB synthase, which catalyzes the ester bonding of the D-3-hydroxybutyryl moiety to an existing PHB molecule **Figure 2**.

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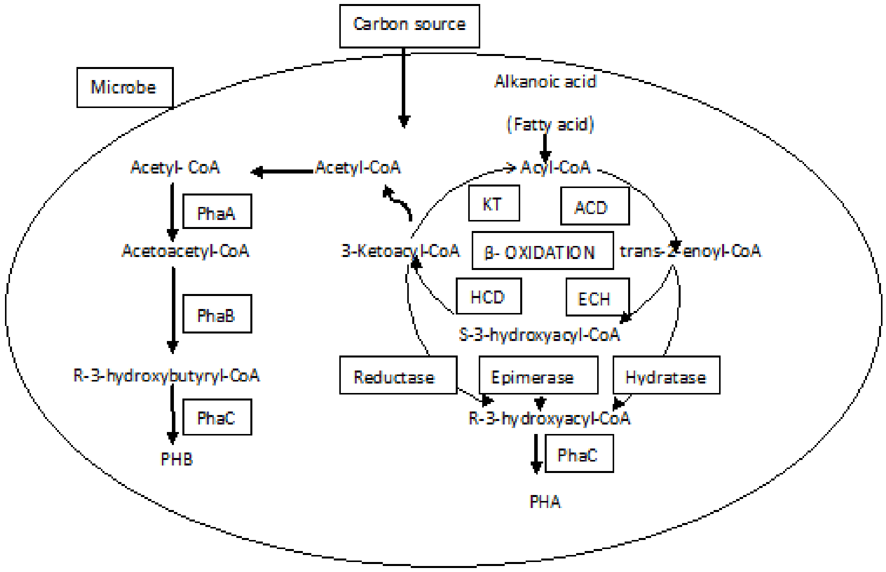

Figure 2. Polyhydroxtbutyratyesynthesis in cyanobacteria (Ranganadhar & Chandrasekhar, 2021)

Cyanobacterial Polyhydroxybutyrate Production

Due to their low nutritional needs and photoautotrophic nature for PHB synthesis, cyanobacteria may be thought of as an alternate host system (Mehariya *et al*., 2021). Under photoautotrophic conditions, cyanobacterial species can amass the homopolymer of PHB. For their growth and reproduction, cyanobacteria, a group of oxygen-evolving photosynthetic bacteria with a short generation time, require some straightforward inorganic nutrients, such as phosphate, nitrate, magnesium, and calcium as macronutrients, ferrous, manganese, zinc, cobalt, and copper as micronutrients (Saratale *et al*., 2021). The cyanobacterium's modest size and bulk were likely to blame for the comparatively low weight of PHB there compared to other bacteria. The capacity of the cyanobacterium to synthesize PHB may be pretty comparable to that displayed by the majority of bacteria in nature, according to what they also reported (Amina *et al.,* 2018). The industry will grow more and more attracted to the benefits of the highly efficient and environmentally friendly synthesis of biodegradable and frequently biocompatible polymers (Devadas *et al*., 2021).

Applications

3D Printing Technology

Recently, 3D bioprinting has emerged as a rapidly evolving technique. Several materials can be made that are biocompatible and might be used for tissue and organ regeneration (Ranganadhareddy, 2022). The process can be carefully planned to produce a useful component with a well-organized structure. These materials are often made using an explicit layer-by-layer method that incorporates biochemicals, biomaterials, and live cells. Calculating the biomaterial's degradation rate, biodegradability, and biocompatibility is also crucial. Gelatin, collagen, chitosan, alginate, and lignin are a few natural polymers that can be utilized as bioink (Reddy, 2022). They may be molded into the proper shape throughout the operation and can be used to mend bones, nerves, and skin, rebuild muscles in the skeleton, and more. The use of biopolymers in 3D printing is generally constrained, although they may be combined with synthetic polymers, such as polylactic acid (PLA), to provide new and enhanced characteristics (Ranganadha *et al*., 2021).

Development of Microdevices

Recently, innovative equipment made of biopolymeric materials hasbeen developed. Microfluidic devices, lab-on-a-chips, and organ-on-a-chips are the three primary categories of such items. Devices called organs-on-a-chip are often acquired for use in a particular field of biomedicine. All aspects of the illness are taken into account during the thorough planning that goes into the development and synthesis of the systems (Ranganadhareddy, 2022c). A system is supplemented with mutant cells, pharmacological and biophysical stimulants, and certain cells that are directly taken from patients. To develop certain chips, biopolymers like gelatin, collagen, chitosan, or alginate are employed (Ranganadha & Chandrasekhar, 2021). They may be readily used for the repair of muscles, bones, and joints as well as the regeneration of skeletal muscles. They can even function as an organ, such as the liver or lung. Synthetic chips can reduce the use of animals in testing, streamline and hasten the process of monitoring and understanding the efficacy and safety of active chemicals on certain organs and tissues, and reduce the number of animals used in testing (Reddy *et al*., 2015). Several biomechanical activities, like lung respiration and renal infiltration, which are essential for healthy bodily function, can potentially be triggered by an organ-on-a-chip. In addition to organ-on-a-chip technology and its priceless benefits, there are also cutting-edge lab-on-a-chip gadgets. With minimal expense, these solutions may automate and streamline conventional processes. They operate more quickly than the standard method due to the shorter diffusion distances and little risk of human mistake and sample contamination. Poly (dimethylsiloxane) and glass are combined to create one of the most often utilized matrices. Several papers describe the assemblage of CO_2, glucose, and oxygen sensors using these components. Although they offer many benefits, such as good gas diffusion, they also unavoidably have certain drawbacks, such as biofouling and silicon's and glass's weak bonding capabilities with other substances. Fortunately, various biopolymers may also be employed to make similar devices, including elastin, silk, collagen, alginate, chitosan, and hyaluronic acid (Reddy *et al*., 2015). They may be applied to tissue engineering to enhance a variety of biological system functions, especially those of the nervous system, which can keep track of vital processes for the organism's overall health (Ranganadhareddy & Chandrsekhar, 2022).

Agriculture Sector

Interestingly, the most common plastic product used in agriculture is the bag. Grow bags and fertilizer bags are two examples of their typical varieties. One of the most common uses for polymer grows agriculture bags is to raise seedlings in nurseries before moving young crops to open areas. These bags sometimes referred to as planter bags or seedling bags, reduce the need for regular watering while maintaining moisture levels in the soil and regulating soil temperature. PEs are the most often used material for packaging and agricultural applications, particularly Low-Density Polyethylene (Ranganadhareddy, & Varghese, 2022). PHA grow bags for agriculture provide various benefits. First off, unlike plastic bags, which emit toxic emissions and release dangerous organic matter, this biodegradable polymer leaves no poisonous legacy on the earth. Second, it effectively takes nitrogen out of water. As a result, the use of PHA grows bags does not pollute the nearby bodies of water. In contrast to PE bags, these bags do not result in any root deformation, making them root-friendly (Ranganadhareddy *et al*., 2022). Grow bags may therefore impact the crops' development, disease immunity, and capacity to swiftly anchor into the ground following transplantation. PHA grow bags also do away with recycling used bags and two-handed handling (Abd El-malek *et al*., 2020).

Conclusion

Cyanobacteria do have the capacity to manufacture biopolymers like PHB from CO_2 as the only carbon source, and the production of PHB could be boosted using a variety of techniques such as nutrition restriction, stress, various PHB-enhancing precursors in vitro, etc. The production processes for bioplastics based on algae are currently in the research stage and are not yet widely available. Algal-based bioplastics have significant potential as an environmentally responsible and biodegradable replacement for traditional plastics. Biopolymers' important characteristics, such as their biodegradable and biocompatible nature, have made them suitable for use in 3D Printing, the agriculture sector, the biomedical industry, and cancer detection. As a result of this report, it is possible to conclude that PHB is a durable class of biopolymers that may be utilized to improve the design of new applications in a variety of industries. However, our perspective should be one of a green environment to support the next generation's ability to live in a world free of plastic pollution, where the contributions of PHB-producing cyanobacteria will be remarkable.

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