International Journal of Advanced Technology in Engineering and Science
Vol. No. 11, Issue No. 10, October 2023
www.ijates.com
ijates
ISSN 2348 - 7550

UNVEILING THE POTENTIAL OF POLYHYDROXYBUTYRATE (PHB) IN SUSTAINABLE MATERIAL SCIENCE AND BIOMEDICAL ENGINEERING

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ABSTRACT:

Biopolymers, the recent outcome of biomaterial engineering, have numerous applications in our daily lives due to their compatibility with human lifestyle and eco-friendly nature. These polymers, derived from living organisms, constitute a significant portion of cells and offer various advantages.Polyhydroxybutyrates (PHB), a well-characterized type of polyhydroxyalkanoate, are synthesized and catabolized by various organisms. Naturally, PHB serves as a carbon assimilation product under conditions of nutrient stress, and it is metabolized for energy when other energy sources are unavailable. PHB stands out as a promising alternative to petroleum-derived polymers owing to its excellent mechanical properties.Extensive research has explored the biocompatibility and cytotoxicity of PHB in different cell cultures and animal models, consistently revealing it as a non-toxic and biocompatible material. These properties have attracted significant interest in the medical, chemical, and pharmaceutical industries.In summary, the unique characteristics of PHB make it a versatile material with vast potential in various sectors, contributing to sustainable and environmentally friendly solutions.

KEYWORDS: Biopolymer & polyhydroxybutyrate.

I. INTRODUCTION

Polyhydroxybutyrate (PHB) stands as a prominent member of the polyhydroxyalkanoate (PHA) family, with over 300 microorganisms currently capable of its production through microbial fermentations [1]. PHBs are synthesized intracellularly in various microorganisms under unbalanced growth conditions, such as limited oxygen, nitrogen, phosphorous, sulfur, or trace elements, alongside high carbon concentrations [2]. Additionally, recombinant bacteria and future agricultural approaches hold promise for PHB production [3].PHB represents an eco-

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www.ijates.com
ijates
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friendly polymer, easily biodegradable under both aerobic and anaerobic conditions, making it a favorable alternative to petroleum-derived polymers [4]. Its versatility allows for various industrial applications, including packaging, cosmetic containers, medical implants, and drug delivery devices [5].

II. Structure and Properties of PHB

PHBs are sugar-based biopolymers composed of D (-) β-hydroxybutyrate monomers linked by ester bonds, with molecular weights ranging from 50,000 to a million [7]. Despite its degradability, PHB exhibits hydrophobicity, rendering resistance to hydrolytic degradation. Soluble in chloroform and chlorinated hydrocarbons, PHB's properties include a melting point (Tm) between 171–182 °C and a glass transition temperature (Tg) around 5-10 °C. However, its brittleness hinders practical applications, albeit improvements have been achieved with UV stabilizers and antioxidant additives [9].

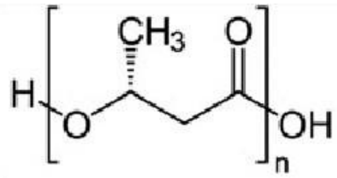

Figure1 Structure of PHB

III. PHB Producers

Initially isolated from Bacillus sp., PHB accumulates in various bacterial species, fungi, and even transgenic yeasts [10]. High-yielding bacteria include Alcaligenes eutrophus, Azotobacter vinelandii, and recombinant Escherichia coli [10]. Marine microbes and transgenic yeasts also contribute to PHB production [12].

PhysicalProperty	PHB	Polypropylene
Molecularweight ($10^5 gmol^{-1}$)	1-8	2.2-7
Density[$g\ cm^{-3}$]	1.23-1.25	0.905-0.94
MeltingpointT$_m$[^{0}C]	171-182	171-186
Crystallinity[%]	65-80	65-70
GlassTransitionTemperatureT$_g$[^{0}C]	5-10	5-15
Oxygen permeability[cm^3/m^2atmd]	45	1700
UVresistance	Good	Bad
Solvent resistance	Bad	Good
Flexuralmodulus[GPa]	3.5-4	1.7
Tensilestrength[MPa]	40	39
Extensiontobreak [%]	6-8	400
Biodegradability	Yes	No

Table1PhysicalPropertiesofPHBandPolypropylene[10]

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IV. PHB BIOSYNTHESIS

PHB biosynthesis initiates with acetyl CoA, derived from glucose, under starvation conditions, diverting acetyl units from the citric acid cycle [10]. Three enzymatic reactions catalyze PHB synthesis, involving β-ketothiolase, acetoacetyl CoA reductase, and PHB synthase [10].

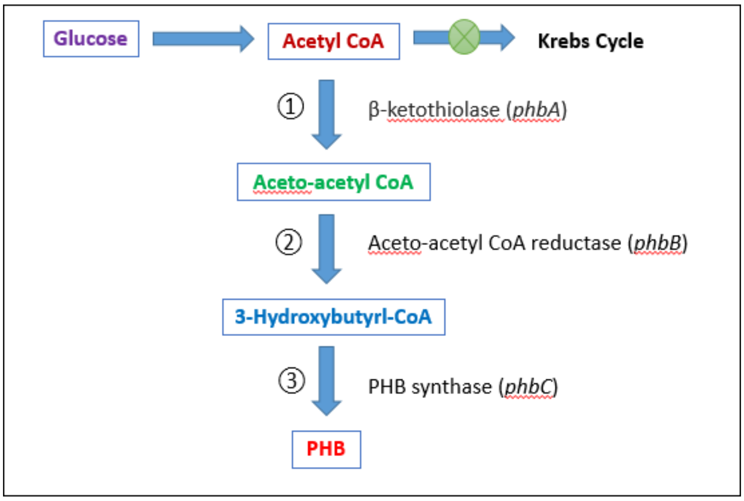

Figure2BiosynthesisofPHB

V. COMMERCIAL PRODUCTION OF PHB

Approximately 24 companies engage in large-scale polyhydroxyalkanoate production, with PHB among the four PHAs produced commercially [14]. Its properties, akin to polypropylene, foster considerable interest in PHB production [14].

Trade Name	Company	Location
Biomer	Biomer	Germany
Minerv	Bio-on	Italy
Biocycle	PHB Industrial	Brazil
Mirel	Telles	USA
Biogreen	Mitsubishi	Japan

Table2CommercialPHBintheMarket

VI. BIODEGRADATION OF PHB

PHB depolymerases facilitate extracellular biodegradation, breaking down PHB into hydroxy acids under aerobic conditions, and carbon dioxide and methane under anaerobic conditions

[15]. These enzymes, isolated from various microorganisms, contribute to PHB's biodegradability [15].

VII. MEDICAL APPLICATIONS OF PHB

PHB finds utility in cardiovascular implants, drug carriers, wound dressings, surgical sutures, and nerve conduits [16, 17, 18, 19, 20]. Notably, its in vivo degradability enhances its suitability for cardiovascular implants and wound management [16, 18]. Furthermore, PHB-based nerve conduits facilitate peripheral nerve regeneration [20].

PHBasadrugcarrier

Polyhydroxybutyrate can be used as a potential chemoembolization agent. Microspheres with a size of 5- 100 μm were loaded with drugs by a solvent evaporation technique by utilizing the solvent such as methylene chloride, distilled water, and polyvinyl alcohol, dispersion medium, and emulsifier, respectively. The size of microsphere was changed by changing the initial polymer/solvent ratio, emulsifierconcentration, stirring rate, and initial drug concentration.
The drug loading capacity of microsphere was very high and up to 407.6 mg rifampicin/g, PHB was achieved. Drug release rates were very rapid and almost 90% of the drug-loaded was released in about 24 h [17].

WOUND MANAGEMENT

Researchers are developing novel materials for enhancing the wound healing, because of the limitations of traditional dressings. Wound dressing materials constructed from PHB polymer as films and electrospun membranes were examined for wound healing properties. The degradable P(3HB/4HB) polymers reduce inflammation and improve the angiogenic properties of the skin and healing of the wound was observed at day14 [18]. PHBis alsoused in medical areas to manufacturesurgical sutures which avoid theformation of a fibrous capsule, reduce the size of the scar, and also degrade into non-toxic and even beneficial products [19].

NERVE CONDUITS

Peripheral nerve regeneration is a complicated process after the peripheral nerve injury. The nerve regeneration requires suitable guides for bridging the gap in nerve injury in order to restore nerve functions. Hazari et al., compared the level of regeneration in PHB conduits with nerve auto grafts in a 10-mm nerve gap of the rat sciatic nerve. Good angiogenesis were detected at the nerve ends and through the walls of the conduit. No failure was observed in any of the implanted conduits. Long re absorption time of PHB conduits ensured the regeneration and maturation of the nerve, thus enabling the nerve to withstand the stress of mobilization [20].

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