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Poly (3-Hydroxyalkanoates): Biodegradable Plastics.

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ABSTRACT

During the 1920's, a polyester called poly (3-hydroxybutyrate) was discovered in bacterial cells. This compound, otherwise known as PHB, is part of a polyester family called polyhydroxyalkanoates (PHAs). Polyhydroxyalkanoates are used as an energy and carbon storage compound within certain bacterial cells. Polyhydroxyalkanoates (PHAs) are thermoplastic, biodegradable polyesters synthesized by some bacteria from renewable carbon sources. However, their application is limited by high production cost. Polyhydroxyalkanoates (PHAs) have attracted research and commercial interests worldwide because they can be used as biodegradable thermoplastics and also because they can be produced from renewable resources. This review will present an overview on synthesis and degradation of polyhydroxyalkanoates (PHAs), development as biodegradable plastics and its potential production from renewable resources such as palm oil products.

INTRODUCTION

Polyhydroxybutyrate (PHB), a biodegradable plastic, is the most common polyhydroxyalkanoate (PHA) produced as storage material by bacteria under restricted growth conditions [1]. PHA was first discovered almost 80 years ago but only in the last few decades have its thermoplastic and elastomeric properties been recognized [2]. Biodegradable plastics can be degraded completely in relatively quick time to CO_2 and H_2O under optimal conditions [3]. PHA can be used to produce a wide range of environmental-friendly industrial polymers. The production of a bioplastic was first attempted in *Arabidopsis thaliana* by Poirier *et al*. [4].

PHA_{MCL} copolymers can be produced using a variety of substrates including plant oils. Due to their long carbon number, these substrates have high energy content which is excellent for good cell growth and energy metabolism. Furthermore, the structural similarity of various fatty acids with the linear PHA_{MCL} made it an even more attractive choice.

PHA_{MCL} might be produced from fatty acids and vegetable oil via a β-oxidation pathway of fatty acids as the sole PHA biosynthetic route [5]. Palm oil is desirable feedstock for PHAs production because they are relatively cheap compared to most sugars. Theoretically, the yield of PHAs from glucose ranges from 0.3 – 0.4 g of P (3HB) per g of glucose [6]. On the other hand, plant oil is predicted to produce higher PHA yield because it contains higher carbon content per weight than simple sugars.

There are only few reports on production of PHAs using cheap renewable carbon sources like palm oil [7].

Production of PHAS

Researchers have followed several different avenues in pursuit of a high-yield, cost effective method for producing PHA in plants. The chloroplast was chosen as the site of expression due to its high content of the polymer precursor, acetyl-CoA (normally used for fatty acid biosynthesis). [8]. The plants pro-ducing PHB in this fashion had a threshold of approximately 3% before a chlorotic phenotype was expressed. Chlorosis is a condition in which the plants produce insufficient levels of chlorophyll, which leaves the plant with little ability to photo-synthesize and produce the carbohydrates it needs to grow [9].

Sugars [10], plant oils [11,12,13,14] and several agricultural byproducts such as beet molasses [15], alphechin wastes[16] and starch are among the various relatively cheap renewable resources that are being studied for production of PHA's.

Properties and Practical Application of PHAS

PHAs have a potential use as bioplastics owing to their high molecular weight, chiral polymeric structure, and biodegradable aliphatic esters [17].These materials have properties similar to those of petrochemical-derived thermoplastics and elastomers, but are not toxic to the environment [18].Bacteria degrade PHAs in the environment using several enzymes, such as PHA depolymerase, lipases, and esterases [19].PHAs are generally classified as either short or medium chain length PHAs (SCL- and MCL-PHA, respectively).

The physical and thermal properties of PHA copolymers can be regulated by varying their molecular structures and copolymer compositions. The P(3HB) homopolymer is a relatively stiff and brittle material. The introduction of HA comonomers into a P(3HB) chain greatly improves its mechanical properties [20,21]. The PHA family of polyesters offers a wide variety of polymeric materials exhibiting various properties, from hard crystalline plastics to elastic rubbers. The PHA materials behave as thermoplastics with melting temperatures of 50-180^{0}C [20]

PHAs are promising materials for various applications, because they have useful mechanical properties and are biodegradable and biocompatible. Therefore, PHAs have recently attracted interest in the biomedical field [22], [23]. Elastomeric MCL-PHAs are better suited for biomedical applications due to their physical properties. But, until now, these applications have been limited by low physical properties and high hydrophobicities of these polymer [24]. Moreover, in order for MCL-PHAs to serve as the material of choice in the biomedical field, their hydrophilicity must be tailored to suit specific applications. Therefore, attempts to modify the properties of MCL-PHAs by chemical and physical methods, such as blending, crosslinking, and graft copolymerization, have attracted a great deal of interest. [25].

Biodegradability of PHAS

Bioplastics, regarded as the cutting edge of sustainable living, can be divided into three categories: chemically synthesized polymers such as polylactic acid (PLA), poly(3-caprolactone) PCL, polyvinyl alcohol (PVA) and poly (ethylene oxide) (PEO); starch-based biodegradable plastics namely starchpolyethylene (PE) and finally polyhydroxyalkanoates (PHA) which are microbially synthesized 100% biodegradable polymer [26,27] showed that poly (3-hydroxybutyrateco- 3-hydroxyvaerate) PHBV completely degraded after 6, 75 and 350 weeks in anaerobic sewage, soil and sea water, respectively. The main advantage of PHAs over other types of biodegradable plastic is that they do not require special environmental conditions and can be rapidly degraded in both aerobic and anaerobic conditions, thereby solving the space problem in landfill [28].

CONCLUSION

Raw materials, such as inexpensive vegetable oil and waste vegetable oil, are alternative substrates that can be used to decrease the production cost of PHA. In this context, the interest on the PHA in this study lies in its potential use of degradable plastics based on waste treatment technology, with a moderate price of bioplastics products. Waste vegetable oil is a very useful substrate for the production of PHA from bacteria, since it has a similar composition [glycerol, palmitic acid (16:0), oleic acid (18:1), and linoleic acid (C18:2)]. [29].

The objective of this review is to initiate the production of PHAs in oil palm and to study the oil palm biochemistry comprising of the synthesis and degradation of PHAs from palmitic acid in which PHAs acts as a terminal carbon sink and lastly, to produce transgenic oil palm synthesizing PHAs for commercialization.[30]

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Based on the wealth of information that has been gathered to date, PHA seems to hold great promise as an environmentally friendly polymeric material. In a world with shrinking petroleum reserves and increasing environmental issues, PHA is definitely a potential candidate that deserves further exploration. The biocompatible nature of PHA and its potential applications in the medical field should also not be overlooked. [31]

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