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Review Article

PHB - Bio Based and Biodegradable Replacement for PP: A Review

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Abstract

Food packaging today relies heavily on plastics such as PP (polypropylene) and PE (polyethylene), from which short-lived, cost-effective packaging materials are made. Their accumulation in the environment has becomes a significant concern. PHB (Polyhydroxy butyrate) is a naturally produced polyester, which can be used as biodegradable thermoplastics. PHB has similar properties to PP and is seen as sustainable replacement candidate for this fossil commodity polymer. PHB is biodegradable, also in the marine environment. Key benefits of PHB over PP are lower carbon footprint and avoidance of "white pollution", which manifests itself e.g. as marine debris and microplastics. Bioplastics today have a market share of only 2%, and it is materials that can replace mass products such as PE and PP which can really pave the way for more sustainable plastics. PHB will play a key role here. In this review article, the state-of-the-art in PHB production and applications is discussed. PHB can be produced from sugar, but also from CO_2 using cyanobacteria. Applications include packaging in general and food packaging in, a major field for short-lived plastics products where biodegradability is a strong benefit.

Introduction

Bioplastics are polymer-based products which are either bio-based and/or biodegradable [1], according to certain standards such as biobased carbon content by the carbon 14 content [2] or biodegradability according to EN 13432 [3]. Today, bioplastics have a market share of approx. 2%, according to Endres [4]. Common bioplastics are starch, thermoplastic starch (TPS), polylactic acid (PLA), polybutylene adipate terephthalate (PBAT) [5] and polyhydroxy butyrate (PHB). Common products are cutlery, organic waste bags, shopping bags, flexible and rigid packaging, and consumer goods. There also exist partly bio based "conventional" plastics such as sugar-cane-derived polyethylene (PE) [6], which are considered bioplastics despite their non-biodegradability Figure 1 shows the similarity of PHB and PP graphically.

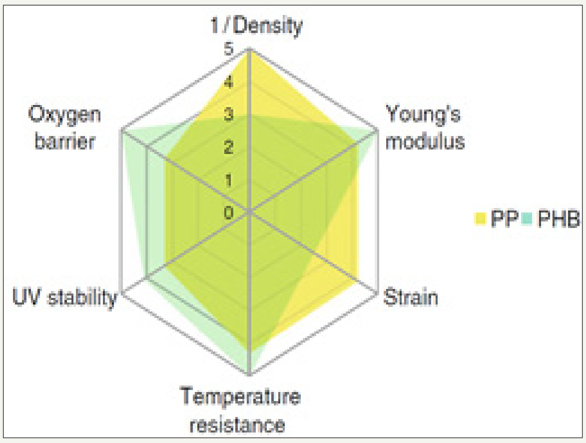

Figure 1: Diagram comparing PHB and PP reproduced [7].

PHB - A Sustainable Bioplastics Material

Polyhydroxy butyrate (PHB) is a polyhydroxyalkanoate (PHA), a class of naturally occurring polyesters. PHB is the most common PHA. It is biodegradable, also in the marine environment. The annual production capacity of PHB is estimated at approx. 30,000 tons [7], which is rather small looking at the global PP production of around 65 million tons per year [8]. Table 1 compares the properties of PHB to those of PP. One can see a striking similarity. PHB was first introduced into the market in 1982 [9]. The classic production process uses microorganisms that ferment organic matter. For instance, the bacterium *Alcaligenes eutrophus* can produce up to 80% of its dry cell weight PHB when a mixture of glucose and propionic acid is fed as nutrient [10]. The process, however, is expensive and subject to the same discussion as first generation biofuels over sustainability [11]. There is also a catalytic process, the alternating copolymerization of carbon monoxide and propylene oxide or the ring-opening polymerization of b-butyrolactone, as described by Reichardt and Rieger [10]. A novel approach is to use cyanobacteria to convert CO_2 into PHB, which some strains are known to do under nitrogen and phosphorous deficiency [12]. Recently, 37% of dry cell weight PHB were reported in cyanobacteria by Kamravamanesh et al. [12].

Table 1: Properties of PHB compared to those of PP Source [9].

Property	PHB	PP
Crystalline Melting point (°C)	175	176
Crystallinity (%)	80	70
Molecular Weight (Daltons)	5×10^5	2×10^5
Glass transition temperature (°C)	4	-10
Density(g/cm^3)	1.250	0.905
Flexural modulus (Gpa)	4	1.7
Tensile strength (Mpa)	40	38
Extension to break (%)	6	400
Ultraviolet resistance	good	poor
Solvent resistance	poor	good

Applications of PHB in Food Packaging

PHB was tested for food packaging successfully [13-15] and found to be more rigid and less flexible than PP [13]. In [16], Peelman et al. review the application of bioplastics for food packaging in general. Levkane et al. [17] studied the effect of pasteurization on a meat salad packed in conventional (PE, PP) and bio-based packaging (PLA, PHB). The authors found that PHB films could be successfully used to pack that kind of food. Bucci et al. [14] found out that PP can be replaced by PHB for the packaging of fatty products (mayonnaise, margarine and cream cheese) [17]. The authors checked physical, mechanical, sensorial and dimensional parameters. Nanoparticles in PHB were found to improve the properties for food packaging [18]. Haugaard et al. [19] found out that orange juice and dressing packed in PHB showed the same stability as in HDPE, implying that the material is suitable for liquid acidic and fatty foodstuff.

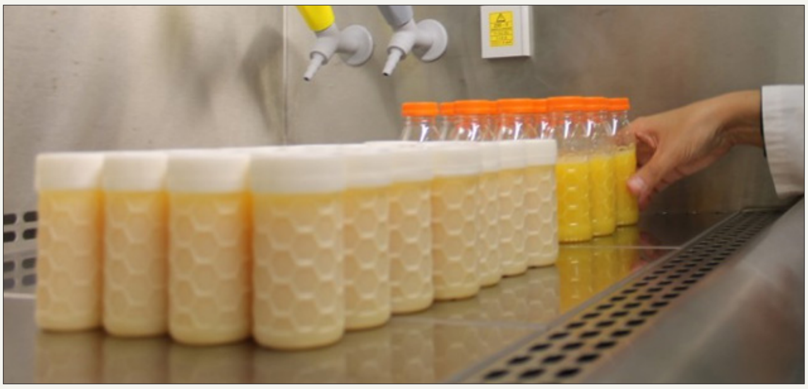

Figure 2: Bottles made from PHA [23].

Figure 3: Extrusion-coated material using PHA [24].

Muizniece et al. [20] stated that PHB materials are suitable materials for storage of sour cream. Polyhydroxyalkanoate-based multilayer structures for food packaging are described by Fabra et al. [21] where a zein interlayer could strongly increase the oxygen barrier. It is known that copolymers have improved properties over PHB, e.g. PHBV. PHBV stands for (poly-(3-hydroxybutyrate-co-3-hydroxyvalerate). The comonomer can reduce the glass transition and melting temperature, making the material less brittle and

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broadening the processing window [21]. In general, bioplastics are more temperature-sensitive than conventional, fossil polymers [22-24]. Figure 2 & 3 show typical food packaging examples made from PHA [25].

Bioplastics can be a marketing argument such as "organic food". One must study whether they bring a tangible sustainability advantage. The environmental impact of biodegradable food packaging when considering food waste is discussed by Dikes et al. [26], since it was found that approx. 50% of the environmental impact of food packaging stems from the thrown-away food contained therein, regardless of whether the packaging is biodegradable or not. Figure 4 shows the comparison of a PP package with one made from PHA and TPS. Dilkes et al. [26] found out that shows that also and particularly for biodegradable packaging, reducing food waste is a key design criterion for success. In fact, the negative environmental impacts associated with disposal of a PHA-TPS packaging in landfills with low gas capture rates (CH_4 emissions from anaerobic digestion, high GWP) can be offset if the package reduces food wastage (meat) by approximately 6% [26]. So, industry not only needs bioplastics such as PHB instead of PP, but also novel concepts for food packaging to avoid discarding foodstuff unnecessarily by the consumers.

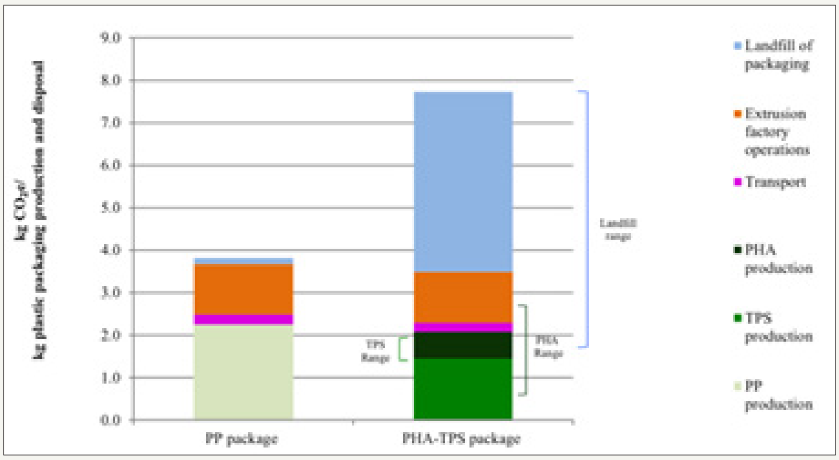

Figure 4: Kg CO_{2e} emissions (GWP100) for the production and disposal of 1kg of PP or PHA-TPS food packaging. GWP100=greenhouse warming potential with a 100-year horizon.

Conclusion

In this mini-review, the biopolymer PHB (polyhydroxy butyrate) was discussed as potential bio-based and biodegradable replacement candidate for the fossil commodity plastics PP (polypropylene). Although the global production capacity of PHB at around 30,000 tons/year is less than 0.1% that of PP, it enjoys high annual growth rates. Recently, significant advancements to produce PHB from CO_2 and sunlight were made, as described by Kamravamanesh et al. [12,13], so eventually, in the blue economy [27], PHB bioplastics will be able to replace PP for food packaging. Bioplastics are necessary, because an estimated 30% of plastic packaging materials may never be eligible for recycling or reuse [28]. "I Have a Dream and it's Green", D. Chandra Mohan stated in a recent paper. Let's share this dream and put it into practice.

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