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Review of Types and Applications of Bioplastics

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Abstract: The amount of plastic waste in oceans is likely to surpass the number of fish in the ocean by 2050. Hence, it is important to replace plastic with safer alternatives such as 'Bioplastics', which are biocompatible and biodegradable. Bioplastics are polymers obtained from natural renewable sources. These biodegradable polymers have wide applications in the food packaging, automobile, and biomedical industries. Many companies are investing in the research and development of more efficient bioplastics. The market trends for bioplastics are increasing due to environmental and economic reasons. This review focuses on the types of bioplastics, their composition and current applications in the market. Various advantages as well as their challenges are discussed further for their potential research and to promote their sustainability.

Keywords: Bioplastics, biodegradability, PHA, PHB, PLA.

I. INTRODUCTION

Plastic, a petrochemical derivative, is cost-effective, resistant, durable, and an essential commodity in daily life. In 2018, approximately 359 million metric tons of plastic were produced across the globe [1]. The high demand for plastic led to its increased production, uncontrolled usage and inappropriate disposal, which further contributed to serious environmental and economic problems [2]. The environmental threats of plastics include landfills [3], plastic waste in the oceans [4], release of toxic gases [5] and non-biodegradability. The clean-up operations of ecosystems are expensive; the marine ecosystem alone will cost up to thirteen billion dollars every year [6]. Such adverse effects of plastics have forced scientists and governments to seek alternatives that benefit economically and environmentally.

Biomaterials are chemically unrelated products synthesized by microorganisms, and bioplastics are one of their key family members. Bioplastics are bio-based and biodegradable materials derived from renewable resources, such as vegetables, corn and potato starch, straw, sawdust, wood, food waste and other agricultural residues [7, 8]. They accumulate as storage granules within the cells of microorganisms. These granules are polymers built from hydroxy-acyl-CoA derivatives through various metabolic pathways. Bioplastic classification is based on the sources used for synthesis, their physical properties and molecular structure. Bioplastics are biocompatible and biodegradable, which makes them the most suitable alternatives for plastic [9].

Bioplastics show similar durability to that of petroleum-based plastics such as polyethylene glycol and polyethylene terephthalate. They can be chemically engineered with similar plastic properties for industrial use. In addition, they reduce the exploitation of fossil fuel resources and emission of greenhouse gases [7]. These benefits indicate a promising sustainable future for bioplastics. The production of bioplastics is expected to grow at an annual rate of more than 15% by 2025 [10].

This review further discusses the different types of bioplastics, their composition and applications. It also discusses the potential and challenges in the development of bioplastics.

II. TYPES OF BIOPLASTICS

A. Starch-based

Starch is obtained from various sources such as corn, potato, wheat, rice, sorghum, etc. [11] Starch-based bioplastics are complex blends of starch and compostable plastic compounds, Including Polylactic Acid (PLA), polybutylene succinate, polybutylene adipate terephthalate, Polycaprolactone (PCL) and Polyhydroxyalkanoates (PHAs). These blends contribute to the water-resistance, thermal and mechanical properties of starch-derived bioplastics [12, 13].

B. Cellulose-based

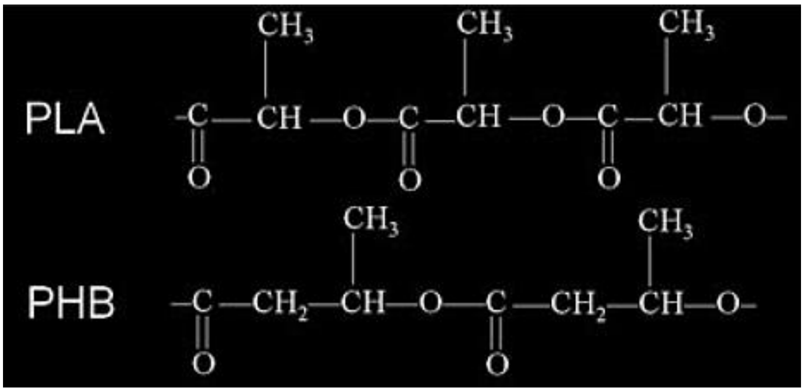
Cellulose is a natural component of plant materials. For commercial purposes, it is derived from weeds, wood pulp, fibers, bamboo, agricultural waste, and forest, etc. [14] Cellulose-based bioplastics are obtained from esters, including cellulose acetate, cellulose nitrates, cellulose butyrate and cellulose propionate [15]. Such bioplastics, when blended with starches, produce mechanically sturdy, gas-permeable and water-resistant bioplastics [16]. They can be modified into thermoplastic and used for packing.

C. Protein-based

Protein-based bioplastics are obtained from high protein sources such as wheat gluten, casein, albumin, whey and soy. Albumin and whey bioplastics exhibit similar thermal and viscoelastic properties, whereas soy bioplastics have modified viscoelastic properties and are water-sensitive [17].

D. Aliphatic polyesters

Aliphatic bioplastics are mainly produced by natural bacterial fermentation of cheap carbon sources such as molasses, sucrose, lactose, glycerol, oils and methane [9]. Moreover, they are composed of PHAs, poly (3-hydroxybutyrates (PHBs), PLAs, polyglycolic acid (PGA), PCL and poly (3-hydroxyvalerate) [18]. Among these, PHAs and PHBs are widely produced. PHAs are linear polyesters and the strongest candidates for the replacement of plastics [19]. Bacteria growing under stressful conditions produce PHB macromolecules. Bioplastics obtained from PHBs are 100% biodegradable; however, their production cost is higher than that of petrochemical plastics. It typically costs 20%–100% more than the normal plastic [20]. PLA is similar to petrochemical-based mass plastics. It is viscous and thermoplastic in nature and can be recycled without losing its mechanical properties [21].



Chemical structure of PLA and PHB [44]

E. Polyamides

Polyamide-based bioplastics are derived from the condensation of diamines and dibasic acids (e.g., ricinoleic acid, sebacic acid, 1,12-dodecanedioic acid, and pentamethylenediamine). Their production reduces the emission of greenhouse gases and consumption of various natural resources. They exhibit remarkable thermal resistance. The most commonly used varieties are polyamide 6 and polyamide 66 [22, 23]. They are used for high-performance activities such as fuel lines in automobiles, catheters, gas pipes, etc.

F. Polyethylene

Bio-based polyethylene is similar to the traditional polyethylene. Ethylene is the building block of this material, and is obtained from ethanol, which is produced by the fermentation of agricultural feedstock sources such as sugarcane or corn. Similar to polyamides, polyethylene is non-biodegradable but can be recycled [24].

G. Lipid polymers

Lipid-based biopolymers are synthesized from the triglycerides of animal and plant-derived lipid sources. Commonly used plant-based triglycerides are obtained from the oils of sunflower, palm, linseed, castor and soybean. Lipid bioplastics, including polyurethanes, PHAs and epoxy resins, are used commercially [25].

III. APPLICATIONS OF BIOPLASTICS

A. Food packaging

The use of bioplastics in food packaging is a key element in the food industry. They prevent food decomposition, maintain the nutritional component, ease transportation and increase the shelf life of the product. They are predominantly used in the packaging of both short and long shelf life products as well as in food items with a limited requirement of oxygen and water. Inventory films obtained from bioplastics are used for commercial purposes as well as for harsher packaging conditions, including modified atmosphere packing. PLA is the most commonly used bioplastic in the food packaging industry [26, 27].

Bio-Based Polymers and their Uses [27]

Types of polymer	Applications
PLA	Tea and coffee cardboard packaging
	Beverage cups and bottles
	Trays for vegetables, bakery and salads
	Yoghurt jars
	Chips and Pretzels bags
	Packaging long shelf-life foods such as pasta and chips [28]
	Salad bowls
Starch-based	Corn starch trays for milk chocolates [28]
	Corn base packing for organic tomatoes
Cellulose-based	Cellulose film wrap for fruits. E.g., Kiwi
	Films for chips
	Metalized film for sweets
	Cellulose packaging for pasta

B. Medical

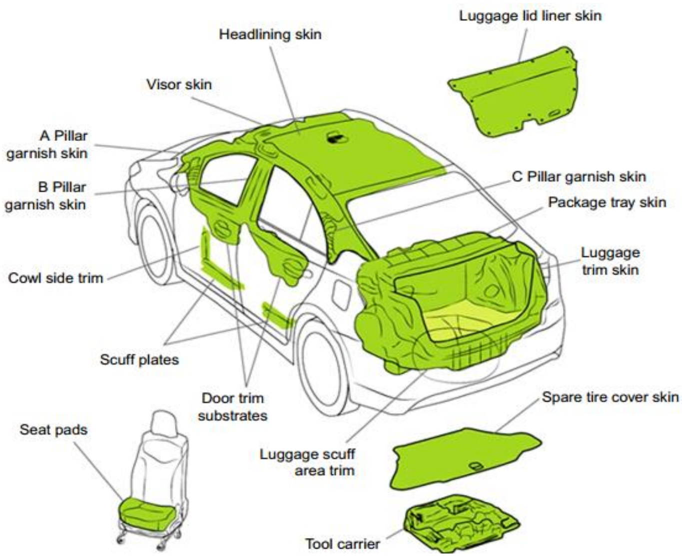
Various options for cheaper yet promising alternatives for plastics are being explored broadly in the field of medicine. Biomaterials should be able to degrade inside the body without causing any interference in the medical procedure or physical inconvenience to the patient [29]. PHA is used for the development of numerous medical devices (hernia, tendon, and nerve repair devices) and is a trusted bio-based polymer owing to its biocompatibility [30]. PHB, when in contact with body fluids, degrades into its monomer D, L-β-hydroxybutyrate and prevents cell apoptosis in a dense culture. It is used in the development of surgical tools such as staples, pins and sutures. In addition, it is employed in various tissue and cell engineering practices, including replacement of plates and bones, nerve cuffs, cardiovascular patches, blood vessel replacement, and drug delivery. Flax bandages obtained from bioplastic-producing plants are used in cell proliferation treatments. Bioplastics combined with organic or inorganic nanoparticles serve as an outstanding innovation in the fields of life sciences, biomedical engineering and nanotechnology [31]. Furthermore, they are used as dental implants and in the production of containers in the cosmetic industry [32]. The U.S. Food and Drug Administration and the European Medicine Agency have approved the use of poly (lactic-co-glycolic acid) for medical applications [33].

C. Agriculture

Top companies such as BASF SE (Germany) and Biome Technology (United Kingdom) have been developing quality bioplastics for agricultural use [34]. PLA and starch polymers account for 47% and 41% in commercial industries. Bioplastics and biopolymers are used in agriculture and horticulture for manufacturing seeding tapes and mulches. The tapes are biodegradable and mulch films provide moisture, maintain soil temperature, and prevent the growth of unwanted weeds [35, 36]. Nets and foils developed from bioplastics are used on mushroom fields to improve their quality and provide a necessary growth environment. Similarly, yarns made from bioplastics are used to cover the slopes to prevent soil erosion until the roots of the plant are fully developed. Solaplast mulching films are implemented in horticulture for vineyards and banana bushes [34]. Biodegradable burial pods are used in cemeteries and have huge growth prospects for environmental & financial benefits [37]. PLA golf tees are preferred because they nontoxic & 100% biodegradable [38]

C. Automobile

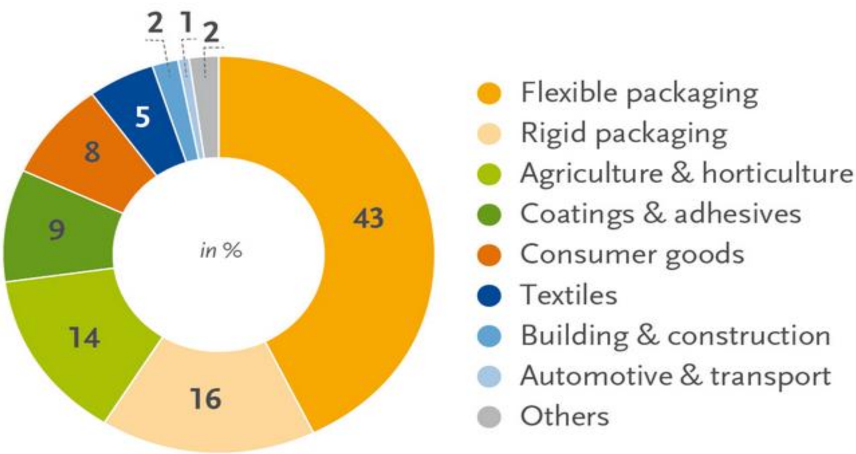
The automobile industry is focused on improving production techniques, which enables recycling of resources and prevent environmental damage. The two most essential criteria are to reduce the burden of fuel consumption and harmful emissions. According to a study, bioplastics are suitable for a large number of automotive applications, offering high performance and a unique potential for reducing a product’s environmental impact. Bio-based polyesters, polyamides and polypropylene are used to develop car components (dashboards, seat and airbag covers, steering wheels, etc.) [34]. The most commonly used bioplastics in the automobile industry include PLAs, polyamides, PHAs, succinic acid and PCLs [42]. Various car manufacturers such as Toyota models, Corolla, Lexus and Camry have implemented bioplastics in their production systems. [34].



Use of bioplastics (in green) in car components [34]

D. Electronics

Electronic companies such as Siemens, Philips, Sony, Apple [39], and Samsung [40] use bioplastics in the production of their appliances. Bioplastics improve gadget performance and its durability [41]. Currently, they are used in computers, batteries, chargers, mobile phones, touch screens, mouse, keyboards, etc. SUPLA developed high-heat-resistant PLA compounds for electronics users and the first bioplastic touchscreen computer in collaboration with Kuender. PLA blends are also used in gaming consoles, tablets and earphones [42].



Applications of bioplastics in different markets [32]

IV. CONCLUSION

Bioplastics offer an advantage to the earth by reducing the carbon footprint and the use of fossil fuels. Owing to the biodegradability and renewability of biopolymers, petroleum-based plastics can be replaced with bio-based polymers to minimize environmental risks. The biological process of recycling has given waste management a new direction. The food packaging industry predominantly uses most of the bioplastics, followed by medical, agriculture, automobile and electronics industries. The market for bioplastics is gradually increasing and recognizes maximum potential applications in various other sectors such as textiles and construction. Aliphatic bioplastics are used more than other bioplastics; however, the production cost for aliphatic bioplastics is high. Another critical challenge for bioplastics is their biodegradability. Polyamides and polyethylene-based bioplastics are recyclable but not completely biodegradable. These drawbacks indicate that further research is required to improve the functionality of bioplastics. In conclusion, owing to their excellent features and broad biotechnological applications, bioplastics possess an extremely promising future as substitutes for plastics. However, further investigation and research is required to reduce production costs, improve biodegradability, prevent negative environmental impacts and build novel strategies to involve the markets and society towards sustainability.

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