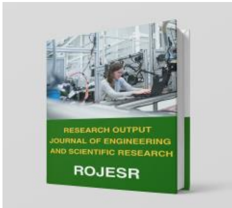

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Biodegradable Plastics and Sustainable Packaging

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ABSTRACT

This essay explores the role of biodegradable plastics in promoting sustainable packaging practices. It discusses the types of biodegradable plastics, including starch-based plastics, polylactic acid (PLA), and polyhydroxyalkanoates (PHA), and their potential applications in reducing environmental pollution. The essay also addresses the advantages and challenges associated with biodegradable plastics, emphasizing their role in waste reduction and sustainability. By examining the biodegradation processes, commercial availability, and future prospects of biodegradable plastics, the essay highlights their significance in achieving a more sustainable packaging industry.

Keywords: Biodegradable Plastics, Sustainable Packaging, Starch-based Plastics, Polylactic Acid (PLA), Polyhydroxyalkanoates (PHA).

INTRODUCTION

Packaging plays an important role in providing protection, convenience, and information to consumers. Due to concerns about environmental pollution and the impacts of global warming, issues related to sustainability have been brought to light. Consumers have become more conscious of environmental issues and prefer eco-friendly products. The packaging industry is under pressure to develop products that impose less harm on the environment. Packaging made of recyclable materials and biodegradable plastics reduces the carbon footprint and helps protect the environment [1, 2]. The present essay focuses on the potential applications of biodegradable plastics for sustainable packaging. The essay covers applications of biodegradable plastics in packaging, the biodegradation of biodegradable plastics, their role in active packaging, and edible packaging. In addition, special attention is given to biodegradable plastics that are commercially available in the market [3]. Sustainable packaging is the practice of environmentally-friendly packaging, which is a form of packaging that provides for the social, economic, and functional needs of the present while being mindful of the environmental requirements of the future. It is about sustainability through product lifestyle, not just a reduction in the environmental impact of the product. In the field of food packaging, the use of plastic packaging is raising public concern regarding the environmental impact of the huge amount of plastics employed. To decrease the huge amount of plastic packaging, the packaging industry has put many efforts into developing packaging films with good mechanical and barrier properties, which are, at the same time, also biodegradable. Biodegradable plastics offer an effective method for reducing the continued buildup of polymeric material in the environment that is not currently degradable. Plastics that are considered biodegradable are not generally considered to be compostable [4].

TYPES OF BIODEGRADABLE PLASTICS

Two packages of biodegradable plastics based on different compositions of materials are already formulated, such as natural and synthetic polymers. The resulting potential biodegradable plastics from natural polymers to improve food quality are based on varieties of starch, polylactic acid (PLA), and polyhydroxyalkanoates (PHA). Starch-based materials are widely developed nowadays because their behavior resembles desirable polymers like plastics, films, gels, and nanoparticles, while remaining biodegradable after disposal. Starch-based plastics are often made impermeable to water by incorporating more hydrophobic polymers than starch. In research, about 5% of glycerol-containing starch/polyethylene materials were developed into a combination of native and natural polymers and manufactured in a blown film with a maximum thickness of 179.80 μm. Furthermore, starch could also be fabricated into nanoparticles that could be used as packaging materials. Usually, it replaces a common type of plastic so that the properties of the new materials resemble those of conventional plastic [5]. A higher E-module, tensile strength, and elongation are typically indicated by the presence of a more polar OH group and a small particle size, as well as fewer grain defects, increasing the interaction between the matrix and the filler, and at the same time, the thickness of the film. PLA belongs to a group of biopolyesters composed of lactic acid, which is derived from sugar fermentation and derived from natural raw materials based on nature, and can also be derived from petrochemical raw materials. It has the potential to be used as a starting raw material of thermoplastic polymer films because it is degradable in vivo and in vitro. Presented research shows that the use of polylactic acid inhibits the growth of spoilage microorganisms by combining it with biodegradable bamboo fillers, which can be beneficial in promoting the shelf life of the product. The compatibility and stability of biodegradation are a major advantage of thermoplastic starch and PLA polymers as coatings for cellulose-derived substrates. Polyhexanediol has four to five times higher flexural strength and modulus than commonly used polymers but lacks a balance of properties such as tensile strength, elongation, and modulus [6, 7].

STARCH-BASED PLASTICS

Starch is an abundant natural polymer in nature. It is made by nature, sunlight, air, water, and nutrients to which plants would convert into food. The chemical composition of starch is a mixture between a high-molecular-weight (HMW; amylose, 20-25%) and a low-molecular-weight (LMW; amylopectin, 70-75%) linear glucose units with some branches (3-6%) [8]. Starch has a natural susceptibility to hydrolytic plant and enzymes, making it attractive as a basis for biodegradable materials which can be applied like a film. Usually, the biodegradable characteristic that a plastic can be biodegradable as soon as less than six weeks, but it isn't a standard time that must be fulfilled. More than that, starch-based biodegradable plastics are based on renewable resources that minimize world dependence on petrochemicals, which is sustainable for a long period, and CO2 neutral source. Nowadays, the use of biodegradable plastics is still less considered in the community, but with the development of environmentally friendly technology, it is possible to produce low-cost biodegradable plastics. However, in general, this plastic has central problems between supply and demand, together with the excessive availability of raw materials and the lack of processing plants. Besides some of the advantages that have been discussed, the use of biodegradable plastic has economic and environmental drawbacks. But with the same developmental value and environmental understanding of irresponsible plastic waste management, the manufacture will continue to grow and develop for environmentally friendly purposes, especially in agriculture, pharmaceuticals, and packaging [9].

POLYLACTIC ACID (PLA) PLASTICS

Polylactic acid (PLA) plastics represent a type of biodegradable plastics derived from renewable sources. This class of materials comprises a wide range of applications, including food packaging, disposable cutlery and catering utensils, agricultural mulch films, bags and sacks, films and coatings for paperboard and paper products, blister packing, trays, and food service ware in general. Another popular use of these materials is in 3D printing, as they can be melt-processed into various shapes. Production of PLA amounts to about 200,000 tons per year as of 2020 [10, 11]. There are multiple routes by which PLA is produced today, including a classic polymerization pathway of lactic acid monomer produced via the fermentation of crude sugars (e.g., glucose, cornstarch) derived from corn, wheat, sugarcane, and yellow peas, among others. The biodegradability of PLA plastic has been widely acknowledged in the literature for many years and can be implemented through anaerobic or composting processes. In general, the biodegradation rate of PLA plastics varies in the range of a few months to a few years depending on the environmental conditions and the presence of any comonomers. Importantly, such comonomers can also modify other essential features, such as mechanical properties and glass transition temperatures, widening the range of potential applications [7]. The degradation of PLA occurs by means of the hydrolysis of ester bonds between lactic acid units, followed by an intramolecular and stage-by-stage process that ends up producing lactic acid as the final product. The environmental impact of these materials is positively susceptible in the publications, since PLA is ESA-approved (European Sustainable Alliance) and fully compatible with food use. Producing PLA from biotechnological feedstock helps mitigate potential biodegradation effects and GHG emissions unless these large-scale cropping activities lead to inducing other adverse ecological effects. In the future, increased market shares are likely to include the automobile and textile industries. The textile chain is becoming particularly environmentally friendly, due to its biodegradability. More eco-friendly PLA copolymers are on the market on a pilot scale, including green plasticizers as fully biodegradable alternatives. In terms of replacing plastics, PLA consumption is likely to double in the next 5 years if current production capacities are utilized. The International Energy Agency considers European regions as a potential leader in this market. The relatively low cost of production is another factor that can increase the wide use and positive impact of PLA. Furthermore, investments in research and development related to knowledge of the alternatives to PLA and ways to extend its life in marine ecosystems are changing. The possibility of in-vessel systems for PLA recovery from organic waste is also likely to be studied, thus being treated as raw materials for higher value-added products. As mentioned, these parameters should have a positive impact on global warming and surplus/deficit mineral shutdown of resources [12, 13].

POLYHYDROXYALKANOATES (PHA) PLASTICS

Polyhydroxyalkanoates (PHA) are a class of naturally occurring biodegradable polyesters produced by microorganisms. These materials have physical and mechanical properties similar to commodity plastics, such as polypropylene or polyethylene, and have similar commercial applications. The mechanical properties of PHA range from thermoplastic elastomers to stiff, brittle plastics, and they are used in some specialized commodity applications, including in personal care and first-aid products, and as aliphatic co-solvents. Like many biopolymers, PHA can be bonded into sustainable composite materials, making them popular materials for sustainable packaging applications. Products can perform the same function as petrochemical-based packaging and can be landfilled, composted, or recycled with existing waste streams [14]. Microorganisms can produce many different PHA plastic materials from a range of biorenewable chemical building blocks, which is an advantage over some other biological polymers that are limited to specific feedstocks. These feedstocks can be derived from waste materials, particularly agricultural waste and refinery byproduct streams. This has raised some environmental issues in the past, particularly relating to the use of foodstuff for non-essential products, but also related to the water requirements of some crops. Efficient utilization of biorefinery and agriculture byproduct streams has now been shown to offer a number of environmental benefits. PHAs are produced in P3HB yield of between 50% - 90% of the dry cell weight of the microbe, so there are significant challenges associated with increasing productivity in practice. In addition, there are some issues with process management, since large intracellular stores of PHA can be rapidly broken down when the cells are stressed out, particularly when undergoing the extraction and purification stages of the process. Given the technical constraints of current production processes, PHB plastics are significantly more expensive than conventional petrochemical-based plastics. However, this may not preclude some of their applications and, in the case of sustainable pharmaceuticals, PHB can offer additional value to product ranges [15, 16].

ADVANTAGES OF BIODEGRADABLE PLASTICS

Biodegradable plastics have multiple environmental advantages. They typically emit less CO_2 (if not the same amount) during their production processes when compared to the production of traditional plastics due to the fact that biodegradable plastics are made from renewable resources (those resources already sequester a good amount of CO_2). Produced at a wide scale, biodegradable plastics could represent a formidable solution to waste problems by reducing the amount of solid waste sent to landfills. Indeed, they offer a safe disposable alternative to traditional plastics with countless waste minimization consequences. A reduction in solid waste sent to landfills can also lead to savings in quantity-based waste management expenses, such as waste transport, handling tax and costs (which are proportionally calculated on the amount of waste produced), and less need for incinerator combustion. Moreover, because biodegradable plastics degrade due to the activity of microorganisms present in the waste, they effectively contribute to biodegradable municipal waste treatment systems used in many countries [11, 7]. Concerns about the carbon dioxide (CO_2) released in the aerobically rooted degradation of biodegradable plastics are likely overestimated and misinterpreted in the context of total climate change. Non-biodegradable plastics also lead to the release of the same amount of CO_2, and much faster, by incineration or deep anaerobic biodegradation. Producing biodegradable plastics at the mass consumption level is not expected to lead to large-scale deforestation, which would be impossible to sustain due to degraded soils and the direct and indirect release of CO_2 from the clearing and burning of forests. The transformation of the global economy from oil to biomass and its products, including biodegradable plastics, demands an economic reorganization that represents a change in basic functioning, benefitting innovation and rapidly renewable energy and materials. Biodegradable plastics offer potential economic advantages in terms of raw material costs; the oil-based plastic market is currently seeing price volatility, and manufacturers are turning to more secure renewable resources for this reason [18, 19].

CHALLENGES AND LIMITATIONS IN BIODEGRADABLE PLASTICS

While biodegradable plastics provide certain benefits in reducing waste and recovering resources, unfortunately, there are still considerable challenges and limitations to their widespread adoption in a variety of applications. Most importantly, cost and performance are highly relevant in the eventual application of these materials: in some cases, the cost of new biodegradable materials ranges from two to five times that of standard plastics, while the performance level of the materials also is a critical aspect to consider, especially within the current framework of a certain circular economy model. Moreover, today there is still no extensive regulation regarding the application of biodegradable plastics for packaging which, if misapplied, can even lead to negative environmental consequences [11, 9]. There are still technical barriers to the use of biodegradable plastics in food packaging, related mainly to their permeability to water and odor, and their mechanical and thermal performance. Similarly to other biogeneric products, effectively marketed biodegradable packaging products would have to reach competitive prices in order to be able to convince retailers, marketing companies, and ultimately consumers, of the properties linked to the sustainability of their source and end-of-life treatment, thereby inducing the relevant industry to invest in such solutions. One of the main limitations to a further spreading of the use of biodegradable plastics goes precisely through these issues. Moreover, the actual logistics (in terms of collection and transportation) for eventual final composting of the packaging can be considered a limitation. Finally, a certain focus should be put on the final disposal [20].

APPLICATIONS OF BIODEGRADABLE PLASTICS IN SUSTAINABLE PACKAGING

Different applications and commercial uses of biodegradable plastics in the field of sustainable packaging to reduce environmental hazards are given here. Applications of biodegradable plastics for sustainable packaging could produce outstanding results regarding waste management related to the environment, agriculture, and industry. Their different applications in different fields are discussed below: [21].

Food packaging: Biodegradable plastics are found suitable for the packaging of certain dry or frozen foods. Polylactides (PLAs) are biodegradable and also safe for chilled foods. Plastic shopping bags, robust enough to reuse and tough enough to handle, could degrade into the environment. Such compostable bags are made from PBAT. The flow wrap for fruit and vegetables made from laminated starch and polylactic acid (PLA) is compostable. Liners for organic-waste caddies and wheelie-bins: Many local authorities supply compostable caddy liners and kerbside waste bags to encourage the separation of organic waste. Conference-case bioplastic molded inserts: Bio firm is a molding compound based on natural polymers, widely used for vegan food and confectionery packaging. It degrades fully in the natural environment in less than 12 weeks. Most likely, the first biodegradable packaging that is widely available with the mass-market appeal, Bio firm has been used extensively because of the need to build the corporate eco-friendly image [22, 23].

Other compostable packaging: Most of the compostable products such as carrier bags, refuse sacks, dog waste bags, packaging films, salad containers, plant-pot liners, and labels are made from starch and seal as a thermoplastic. BFD packaging such as air-fill cushions, polystyrene replacements (IC-Fill), and starch-based foam trays is compostable. Reusable and durable plastics: Some polymers are made additive such that they can be safely used in several applications many times over without damaging the environment. Starch plates and cutlery packaging: Many companies specialize in manufacturing and selling biodegradable tableware such as plates, see-through fruit/nut packaging bags made from bioresin, birch wood plates, and utensils, and biodegradable food packing foam [24].

CONCLUSION

Biodegradable plastics present a promising solution to the environmental challenges posed by traditional plastics. Their ability to decompose naturally reduces the accumulation of waste in landfills and lowers carbon emissions. Starch-based plastics, PLA, and PHA offer diverse applications in food packaging, agriculture, and other industries, making them viable alternatives to conventional plastics. However, their widespread adoption faces challenges related to cost, performance, and regulatory standards. Continued research and development, along with supportive policies, are essential to overcome these hurdles and fully realize the potential of biodegradable plastics in sustainable packaging. By embracing biodegradable plastics, the packaging industry can contribute significantly to environmental preservation and the promotion of eco-friendly practices.

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