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Bioplastics: A Sustainable and Environment-Friendly Alternative to Plastics

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ABSTRACT

Petrochemical-based plastics have been widely used as packaging materials, as they have good barrier properties, stiffness, tensile strength, and tear strength. Plastics, despite being in high demand, have several drawbacks, including a very low water vapor transmission rate and non-biodegradability. The proper disposal of plastic has recently emerged as a persistent and perhaps worldwide environmental problem. Recently, the disposal of plastic has become a chronic and possible global environmental issue. Dumping plastic debris on both land and sea decreased soil fertility and inappropriate plastic disposal has caused the deaths of millions of animals. Newer ideas about the usage of bioplastics came into effect while keeping in mind the pollution and harm done to the environment. Bioplastics are made from biological materials like banana peels, corn, sugarcane, wheat, and potato peels. These plastics are safer than those made from petroleum since they are biodegradable and environmentally friendly. These biodegradable plastics dissolve upon breakdown into carbon dioxide, water, and inorganic chemicals. They do, however, have significant drawbacks, such as high costs, recycling, using fewer raw resources, terminology being misused, and a lack of legislation. Some aspects of bioplastics will be highlighted in the current review.

Keywords: *Bioplastic, Biodegradable, Advantage, Disadvantage*

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INTRODUCTION

Plastic materials are currently considered very important materials due to their properties and performance over other materials such as metal and wood (Wang *et al*., 2016; Thakur *et al*., 2018; Reichert *et al*., 2020; Ortiz *et al.,* 2022). Organic substances that are flexible and artificial or semi-artificial makeup synthetic plastic. Due to their fascinating qualities, such as mechanical strength, lightness, flexibility, and durability, synthetic plastics have transformed society since the 1940s. These qualities are attributed to a material with a low cost and the ability to replace products made from other materials, such as paper, glass, and metals (Albuquerque & Malafaia, 2017). 300 million tonnes of petroleum-based plastic waste were reported to be produced in the year 2015 (Mellinas *et al*., 2016). Plastic is particularly difficult to degrade; during this process, a significant amount of CO_2 and other hazardous substances are released (Filiciotto & Rothenberg, 2020). According to estimates, burning 1 kg of plastic releases roughly 2.8 kg of CO_2 (Jahirul *et al*., 2022).

The government and people are now more concerned with the negative environmental effects of plastics made from petrochemicals (Maroufan *et al*., 2019; Kryukova et al., 2021). Scientists have done several studies to manage the planet's plastic trash by identifying environmentally beneficial alternatives to the use of plastic. As it is made from renewable resources like cellulose, starch, sugar, etc., biodegradable plastic will be an easy substitute for petroplastic (Thiruchelvi *et al*., 2021). Natural microorganisms such as bacteria, algae, and fungi break down biodegradable plastic (Elahi *et al*., 2021). Temperature, water content, oxygen content, and the chemical makeup of the polymer determine how quickly it degrades. The continuous synthesis of biodegradable plastic is highlighted by the extremely low CO_2 emission during bioplastic breakdown (Narancic *et al*., 2020). The biodegradability of bioplastics has been widely highlighted in society, and large-scale retailers' demand for packaging is rising quickly (Albuquerque & Malafaia, 2017). The focus of the current review will revolve around the necessity of educating the public about bioplastics and their current state of development.

MATERIALS AND METHODS

Bioplastics

European Bioplastics, a European umbrella organization for bioplastics, is credited with coining the term "bioplastics." The word "bioplastics" refers to both biobased plastics, or those produced of biogenic components, and biodegradable plastics, including petrochemical ones. However, not all biobased plastics are biodegradable. However, certain biodegradable polymers could come from petrochemical sources (Penkhrue *et al*., 2015; Haider *et al*., 2019; Kawashima *et al*., 2019; Gombra *et al.,* 2022). A plastic that is either biobased, biodegradable, or both are referred to as bioplastic. The chemical makeup and physical structure of the finished product, as well as the environment in which it is intended to decay, all affect how biodegradable plastics are. Due to their unique polymer structures, some biobased plastics may be biodegradable, while others may not be. Additionally, under the same conditions, certain polymers degrade in a matter of weeks while others take several months to do so. European Bioplastics has created a straightforward two-axis model that covers all plastic kinds and potential combinations to demonstrate this distinction **(Figure 1)**.

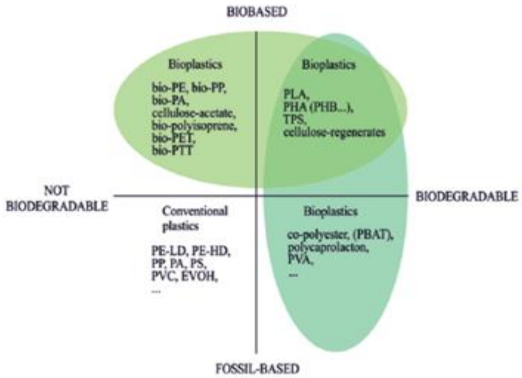

Figure 1. The material coordinate system of bioplastics
EVOH: ethylene vinyl alcohol; PA: polyamide; PBAT: polybutylene adipate terephthalate; PE: polyethylene; PE-HD: high-density polyethylene; PE-LD: low-density polyethylene; PET: poly(ethylene terephthalate); PHA: polyhydroxyalkanoate; PHB: polyhydroxybutyrate; PLA: polylactic acid; PP: polypropylene; PS: polystyrene; PTT: polytrimethylene terephthalate; PVA: polyvinyl alcohol; PVC: polyvinyl chloride; TPS: thermoplastic starch.

Plastics have been categorized into four characteristic classes, as shown in **Figure 1**. Plastic's biodegradability is indicated on the horizontal axis, while the source of the material—renewable or petrochemical—is indicated on the vertical axis. This opens the door for four groups.

1. Plastics that are not biodegradable and are made from petrochemical resources, which are commonly known as classical or traditional plastics such as polyethylene, polystyrene, polyvinyl chloride, etc.
2. Biodegradable plastics from renewable resources: plastics that exhibit biodegradation and are made from biomass feedstock material. Examples of this category of materials include starch blends made from starch that has been thermoplastically modified and other biodegradable polymers, as well as polyesters made from PLA or polyhydroxyalkanoate (PHA).
3. Biodegradable plastics from fossil resources: Plastics made from fossil fuels yet with the potential for biodegradation. Polycaprolactone (PCL), polybutylene succinate (PBS), polybutylene adipate terephthalate (PBAT), and others are examples of these plastics.
4. Non-biodegradable plastics from renewable resources: Polyvinyl chloride (bio-PVC), polyethylene terephthalate (bio-PET), and polypropylene (bio-PP) are examples of plastics made from biomass but without the ability to biodegrade.

Degradability and bioplastics

When a polymer undergoes any physical or chemical change as a result of environmental factors such as light, heat, moisture, chemical conditions, or biological activity, plastic degradation occurs (Chamas *et al*., 2020). Degradable polymers are divided into four categories as described in **(Figure 2)**.

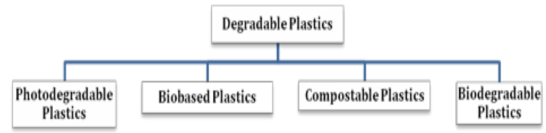

Figure 2. Types of Degradable Plastics.

1. Light-sensitive groups are added directly to the polymer's backbone in photodegradable bioplastics. Long-term ultraviolet exposure (a few weeks to months) might cause their polymeric structure to break, leaving them vulnerable to further bacterial deterioration (El-Kadi, 2010).
2. As per the Business-NGO (non-government organization) Working Group on Safer Chemicals and Sustainable Materials, biobased bioplastics are defined as polymers in which 100% of the carbon is generated from renewable agricultural and forestry resources such as maize starch, soybean protein, and cellulose (Alvarez-Chavez *et al*., 2012).
3. Similar to other biodegradable materials, compostable bioplastics biologically degrade during the composting process without producing any obtrusive harmful waste. Standard tests must be used to establish a plastic's overall biodegradability, degree of disintegration, and potential ecotoxicity of the degraded material before it can be designated as bio-compostable (Sarasa *et al*., 2008; Keshavarz *et al.,* 2022).
4. Microorganisms completely break down biodegradable bioplastics without leaving any hazardous residues that can be seen. In contrast to biobased sustainable materials, the term "biodegradable" refers to substances that can naturally decompose or break down into biogases and biomass (mostly carbon dioxide and water) when exposed to a microbial environment and humidity, such as those found in soil. This reduces the amount of plastic waste generated. The fourth class of bioplastics is quite promising since microorganisms utilize them (El-Kadi *et al*., 2010).

Properties of bioplastic

Regarding bioplastics, attributes like physical, mechanical, and thermal qualities are taken into account. Mold shrinkage, density, and apparent viscosity are taken into account as physical characteristics. Melting point, heat distortion temperature, and Vicat softening temperature are all parts of the thermal property. Mechanical properties include tensile strength, shrinkage, compressive modulus, flexural strength, Izod impact strength, hardness, bending module, moisture absorption, transparency, and oxygen barrier. They also include compressive yield strength, compressive modulus, hardness, and hardness elongation brake. Other characteristics including stackability, puncture resistance, and crystallinity are also taken into account (Mathew, 2015; Venkatachalam & Palaniswamy, 2020).

Carbon cycle of bioplastics

Plastic made from fossil fuels upsets the natural cycle, speeds up the release of carbon dioxide into the atmosphere, and contributes to the greenhouse effect. The carbon cycle, which is the process by which carbon is traded among the spheres of the planet, is a crucial element that needs to be emphasized. Carbon dioxide is absorbed by the plants as they grow, and when the plants biodegrade, the carbon dioxide is released back into the atmosphere. To create polymers, these natural resources go through many procedures. Bioplastics are created by further processing polymers. Carbon dioxide is returned to the atmosphere as bioplastics degrade. Thus, a closed cycle is formed in which carbon dioxide that is removed from the environment is cycled back into the atmosphere by going through many steps **(Figure 3)**. When disposed of in a municipal composting facility, many bioplastics are 100% biodegradable and often biodegrade in 180 days or less. These materials are then absorbed back into the earth as soil nutrients. Bioplastics can save up to 35% of energy and produce harmful greenhouse gas emissions by two-thirds (Venkatachalam & Palaniswamy, 2020).

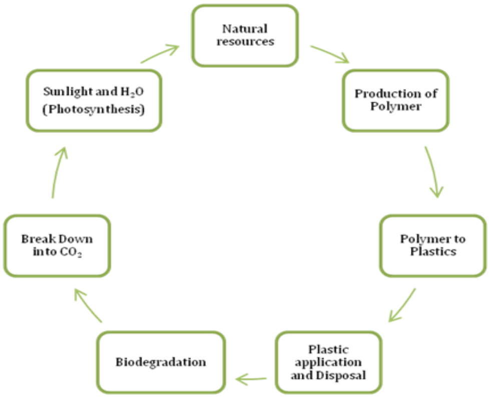

Figure 3. Bioplastic Cycle.

Bioplastic market

Researchers have developed several tools to help in the decision-making about plastic selection. The plastic spectrum is one of them **(Figure 4)**.

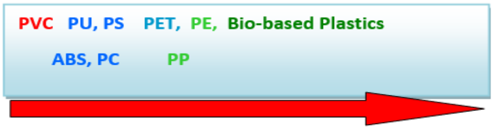

Figure 4. Plastics spectrum (PVC: polyvinyl chloride; PU: polyurethane; PS: polystyrene; ABS: acrylonitrile butadiene styrene; PC: polycarbonate; PET: polyethylene terephthalate; PE: polyethylene; PP: polypropylene)

In this category, biobased bioplastics indicate that they are preferred because they are manufactured using renewable resources and are compostable and biodegradable (Alvarez-Chavez *et al*., 2012). Because these items have a relatively short shelf life and are readily disposed of in landfills, bioplastic containers and packing films are a better solution. Biodegradable bioplastics are used in a wide range of biomedical applications, including bone plates, screws, tissue engineering scaffolds, and drug delivery vehicles (Ansari *et al.*, 2021). For their fast-food service and delivery, McDonald's in America has already begun to produce biodegradable containers. Numerous businesses, including Dupont, Nike, Danone, Bayer, Dow Cargill, etc., manufacture biodegradable packaging materials (Shah *et al*., 2021). The worldwide bioplastics market is expanding at a rate of 20% to 25% annually. Bioplastics' share of the global plastics market climbed by 10%–15% in 2020, reaching 25%–30%. The market for bioplastics could reach $1 billion in US dollars in 2007 and $10 billion in 2020. The market for bioplastics is seeing a lot of investment, which is good news for the environment.

Advantages and disadvantages of bioplastics

Biodegradable plastics have a bright future ahead of them. The benefits of bioplastics are as follows:

1. Fewer greenhouse gases are produced by bioplastic, and it is toxin-free. Yu and Chen (2008) observed that with just 0.49 kg CO_2 emitted during the manufacturing of 1 kilogram of resin, bioplastics contribute significantly to the goal of reducing GHG emissions. It has the potential to reduce global warming by roughly 80% when compared to petrochemical competitors' 2–3 kg CO_2.
2. The carbon footprint of bioplastic products, which are made from renewable resources like corn, sugarcane, soy, and other plant sources, is lowered, which lowers greenhouse gas emissions.
3. Additionally, 65% less energy is used in the manufacture of bioplastics than it is in the production of petrochemical plastics. The bioplastics would be used for energy recovery and recycling.
4. The use of bioplastics can help to prevent environmental issues including the careless disposal of waste into the ocean and on land, as well as the subsequent hazardous gas emissions.
5. Bioplastic derived from plant resources can effectively handle plant residues or waste.

However, possible problems might come along with the use of bioplastics. Here are the disadvantages of bioplastics:

1. Bioplastics are more expensive to manufacture than conventional plastic. Cost reduction will be anticipated if the use of bioplastics on a big scale industrial scale becomes more widespread.
2. If bioplastic material is recycled with ordinary plastics, there could be a concern with contamination.
3. Due to their hydrophilic nature, packaging materials made of starch and cellulose-based plastic have poor processability, are brittle, are susceptible to deterioration, have limited long-term stability, and have inferior mechanical qualities.
4. Bioplastics made from sustainable resources could result in a reduction in raw material stocks. Exploiting food byproducts is also a recent trend in order to decrease energy consumption during the manufacture of bioplastics, avoid potential rivalry with agricultural resources for food, and supply additional sources of raw materials.

CONCLUSION

Bioplastic is a key component of the innovation needed in the modern world to reduce pollution caused by plastic waste since it provides a sustainable and environmentally beneficial alternative. Biodegradable plastics will solve issues like recycling, dumping, and the lengthy time it takes for plastic trash to degrade. Although the cost of commercial bioplastic production may be high right now, it might become a wonderful and feasible endeavor in the future with advancements in technology, such as the usage of genetically modified organisms.

For the large-scale manufacture and commercialization of bioplastic products to be successful globally, more intensive research is required.

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