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# Bioplastics: A Greener and Sustainable Future Plastic

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## ABSTRACT

Bioplastics are a viable substitute for petroleum-based plastics due to their ability to reduce environmental pollution while still providing excellent barrier properties, stiffness, tensile strength and tear strength. Natural and renewable raw materials are utilized in the production of these items, utilizing either chemical or microbial processes. The utilization of agro-industrial wastes as a substrate for production helps mitigate the negative impact on the environment caused by the disposal of these wastes, as well as the greenhouse gas emissions linked to petroleum-based plastics. Their eco-conscious and easily degradable properties make them a prominent player in the future plastic market and their wide range of applications.

**Keywords:** Bioplastic, Agro-industrial waste, Eco-friendly, Packaging, Eco-conscious, Renewable

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## INTRODUCTION

The global concern regarding the sustainability of our natural resources and the urgent need to combat plastic pollution has spurred the development of alternative materials, with bioplastics emerging as a prominent solution. Bioplastics offer a promising eco-friendly alternative to traditional plastic, paving the way for a more sustainable future. In recent years, the production of plastic from fossil fuels has significantly increased, resulting in environmental pollution and harm to living organisms due to its non-biodegradable nature. This is why sustainable solutions have focused on the creation of biodegradable plastics to address this issue. Plastic ranks as the third most widely used petroleum derivative worldwide, with a staggering annual consumption of 200 million tons. Approximately 90% of plastics produced are derived from petroleum-based sources (Agenda, 2016)[1].

Unfortunately, the detrimental impact of plastics on the environment often goes unnoticed. The non-biodegradable nature of traditional petroleum-based plastics, owing to their chemical structure, makes them resistant to microbial degradation. Consequently, this leads to the accumulation of plastic waste in different environments, particularly terrestrial and marine ecosystems, severely affecting the flora and fauna within these ecosystems. Given the current crisis, the significance of bioplastics has grown exponentially as a viable and eco-friendly alternative. Bioplastics possess similar properties to conventional plastics, such as durability and flexibility, while also being biodegradable or compostable. They help reduce dependency on fossil fuels, greenhouse gas emissions, carbon footprint, and plastic accumulation in the ecosystem. With their versatility and eco-friendliness, bioplastics are paving the way for a greener and more sustainable future.

Bioplastics, also known as bio-based plastics or renewable plastics, are produced using renewable or recycled raw materials obtained from natural resources. They can be derived from various sources, including plants (such as cellulose, corn starch and vegetable oils), animals (such as collagen and keratin), agricultural waste, and microorganisms. These materials offer a potential solution to mitigate the environmental impact caused by conventional petroleum-based plastics. According to the definition provided by the International Union of Pure and Applied Chemistry (IUPAC), bioplastics are polymers derived from biomass or monomers derived from biomass that can be shaped through flow during the manufacturing process (Vert et al., 2012)[2].

## TYPES OF BIOPLASTICS

Bioplastics are mainly classified into bio-based, which are made entirely from renewable resources, biodegradable, which can break down into harmless substances under specific conditions and compostable bioplastics, that are biodegradable under composting conditions.

## BIO-BASED BIOPLASTICS

Bio-based Bioplastics are the ones known for their eco-friendly nature, hold immense potential in various applications. Primarily, they are widely utilized for food packaging purposes. This category encompasses bioplastics derived from natural sources as well as those produced from synthetic bio polymers like cellulose, starch blends, and polyesters such as PLA and PHA.

The production of bio-based plastics involves the utilization of different methods. However, according to Shen et al 2009, the three principal approaches for producing bio-based plastics are as follows: (i) utilizing natural polymers that can be modified while still retaining a significant portion of their original structure (ii) producing bio-based monomers through fermentation or conventional chemistry and subsequently polymerizing these monomers in a subsequent step (e.g., polylactic acid); and (iii) directly producing bio-based polymers within microorganisms or genetically modified crops. The first and second methods are commonly employed for large-scale bio-based plastic production.

Approximately half of the bioplastics produced for commercial use are derived from starch. These starch-based bioplastics are easily manufactured and commonly employed in packaging applications (Marichelvam et al., 2019)[3]. The bioplastics from polyesters are synthesized by microorganisms, typically through various metabolic pathways involving hydroxy-acyl-CoA derivatives. These bioplastics exhibit variations in their monomer composition, macromolecular structure, and physical properties depending on their microbial origin. However, majority of them are both biodegradable and biocompatible, which makes them highly intriguing from a biotechnological perspective (Luengo et al., 2003)[4]. Microorganisms, such as bacteria or yeast, are utilized to ferment biomass feedstock to produce monomers. These monomers are then extracted and polymerized to form bioplastics. Polysaccharides as Starch, protein as keratin, Polylactic acid (PLA), polyhydroxyalkanoates (PHA), polybutylene adipate terephthalate (PBAT) and polyhydroxybutyrate (PHB) falls under this category.

Bioplastics support sustainable agricultural practices and potentially incentivize the conservation of biodiversity by utilizing plant-based feedstocks. These practices promote responsible land use and encourage the adoption of sustainable farming methods. However, it is crucial to recognize that not all bioplastics offer the same environmental benefits. Some bioplastics are not biodegradable, and the biodegradability of others depends on specific environmental conditions.

Moreover, to maximize the environmental advantages of bioplastics, efficient waste management and proper end-of-life disposal methods, such as composting or industrial composting facilities, are essential.

## 1. Starch-Based Bioplastics

Starch-based bioplastics dominate the global market as one of the most prevalent types of bioplastics. Derived from renewable plant resources such as corn, wheat, rice, potatoes, and tapioca, these bioplastics were among the first to be commercially produced (Shen et al., 2010; Narancic et al., 2020)[5,6] The applications of starch-based bioplastics are extensive, encompassing various commercial sectors. They are utilized in the production of biodegradable bags, packaging materials, and cutlery and tableware, including forks, knives, spoons, plates, and cups.

Additionally, these bioplastics find use in the textile industry, as well as in the medical and pharmaceutical fields. Notably, thin layers of edible starch are commonly employed as coatings for food products. These coatings enhance the shelf life of the food by reducing moisture migration, minimizing gas exchange, delaying structural changes, and maintaining the food's integrity.

Despite the drawbacks of starch-based bioplastics, such as their high hydrophilicity, low heat resistance, and brittleness, efforts have been made to overcome these limitations. One approach is to blend starch-based plastics with other biodegradable polymers, which helps enhance their mechanical and chemical properties. Blending of starch with other additives or bio plastics improves water resistance, processing properties, tensile strength, elongation properties and other chemical properties etc.

## 2. Cellulose-Based Bioplastics

Bioplastics made from cellulose and cellulose-derived materials are known as cellulose-based bioplastics. Cellulose, a naturally abundant polymer consisting of glucose monomer units connected by Glycosidic linkages, is an excellent choice for manufacturing bioplastics due to its renewable nature, affordability, biodegradability, and eco-friendliness. Typically, cellulose-based bioplastics are produced using plant materials. Common sources of cellulose used in bioplastics production include wood pulp, cotton, sugarcane bagasse, rice straw, oregano waste, and algae (Aguilar et al., 2019; Bilo et al., 2018; Tran et al., 2020)[7,8,9].

Blending cellulose with additional polysaccharides, such as pectin and chitosan, has been found to enhance the mechanical stability and various other properties of cellulose-based bioplastics. This blending process improves the flexibility, strength, and transparency of the resulting material (Shah et al., 2021; Yaradoddi et al., 2020).[10,11] The utilization of cellulose-based bioplastics and their derivatives extends to a wide range of applications, including packaging films, the biomedical and pharmaceutical industry, 3D printing, eyeglasses frames, the textile industry, food packaging, and other disposable biodegradable products.

## 3. Chitosan-Based Bioplastics

Chitosan based bioplastics are derived from chitosan, a cationic polysaccharide that can be found in the shells of crustaceans like crabs, lobsters, and shrimps, as well as in insects and fungi. In fact, chitin, the precursor to chitosan, is the second most abundant natural polymer in the world, second only to cellulose. It is widely used in the production of biodegradable plastics and films. This is because chitosan possesses remarkable properties such as biodegradability, mechanical strength, low toxicity, biocompatibility, antimicrobial activity and compatibility with other polymers (Jiang et al., 2023).[12] The applications of chitosan-based bioplastics are diverse and include food packaging materials, textiles and apparel, cosmetics, drug delivery systems, and other biodegradable materials. However, despite its immense potential, chitosan has certain limitations. It is not resistant to high temperatures, has limited barrier properties, and is sensitive to water. These factors can compromise its mechanical stability and restrict its usage in certain contexts.

Various techniques have been employed to enhance the mechanical and other attributes of chitosan. These include the utilization of plasticizers and cross-linkers, as well as the blending of chitosan with other natural biopolymers such as cellulose, starch, and PLA. Additionally, the incorporation of natural extracts and nano materials has been explored (Priyadarshi and Rhim, 2020)[14].The addition of citric acid as a crosslinker and glycerol as a plasticizer can enhance the physicochemical properties of chitosan-based bioplastic thin films. These additives contribute to improvements in thickness, weight, porosity, water vapor absorption, swelling, pH resistance, and thin film biodegradability. However, they also lead to a decrease in hydrophobicity (Lusiana et al., 2020)[13]. One commonly employed method to enhance the mechanical properties of chitosan-based bioplastics is through the blending of chitosan with starch (Xu et al., 2005)[15].

## 4. Protein-Based Bioplastics

Protein-based bioplastics are a highly significant category of bioplastics that enjoy global acceptance. These bioplastics are derived from both plant and animal protein sources. Plant proteins, such as wheat gluten, soy proteins, pea protein, oilseed cake after oil extraction, agri-food waste, and animal proteins like collagen, gelatin, casein, and keratin, are the primary sources used in their production (Wu et al., 2019; Qazanfarzadeh and Kumaravel, 2023; Cristofoli et al., 2023; Ryder et al., 2020).[16-19] Protein-based bioplastics can be produced using two types of proteins: fibrous proteins (e.g., keratin) and globular proteins (e.g., soy protein). Fibrous proteins possess a fibrillar structure and exhibit desirable qualities such as biodegradability, water resistance, compatibility with living organisms, robustness, the ability to form hydrogen bonds, and low toxicity. On the other hand, globular proteins are spherical or globular in shape and are composed of various types of bonds, including ionic, hydrogen, hydrophobic, and disulfide bonds. Before being used in the production of bioplastics, globular proteins require partial degradation through thermal or chemical methods. Globular proteins also possess properties like biodegradability, low toxicity, solubility in water, adhesive properties, and good film-forming ability (Vicente et al., 2011)[20].

The flexibility and elongation at the break of the protein film can be enhanced by the addition of plasticizers such as glycerol, ethylene glycol, and diethylene glycol (Ullsten et al., 2016)[21]. To enhance the stability and shelf life of protein-based bioplastics, natural antioxidants and antimicrobial agents like essential oils can be incorporated. Furthermore, the properties of protein-based bioplastics can be further improved by incorporating other natural biopolymers like chitosan and cellulose, as well as other bioplastics such as PBA, PLA, and PHA (Bhaskar et al., 2023)[22].

Soy proteins are the commonly used proteins to produce protein-based bioplastics. These bioplastic films are biodegradable, environmentally friendly and possess excellent oxygen barrier properties. Additionally, they contribute to the preservation of packaged food items, extending their shelf life (González and Igarzabal, 2013)[23]. Another cost-effective and renewable source abundant in keratin protein is chicken feather keratin, which can also be utilized to produce bioplastics (Ramakrishnan et al., 2018)[24]. Keratin protein-based bioplastics share similar characteristics, such as biodegradability, eco-friendliness, reduced carbon footprint, high durability and biocompatibility. Protein-based bioplastics find wide-ranging applications in various fields, including edible packaging materials, biomedical applications such as medical devices and wound healing patches, biodegradable bags, films, toy parts, and fishing baits.

## 5. Polylactic Acid (PLA)

PLA, or polylactic acid, is a widely employed bioplastic that has gained significant popularity. This transparent bioplastic is derived from renewable resources such as corn starch, sugarcane, or other plant-based feedstocks. PLA stands out due to its optical properties, low toxicity, and commendable strength and stiffness. Moreover, it is an environmentally friendly option as it is made from renewable resources. However, PLA's low heat resistance, brittleness, and limited shelf life are notable drawbacks. Nevertheless, PLA finds diverse applications in packaging, disposable cutlery, 3D printing, and textiles.

### 6. Polyhydroxyalkanoates (PHA)

Polyhydroxyalkanoates (PHAs) are a class of bioplastics that are synthesized by specific microorganisms through the fermentation process of organic materials containing lipids and sugars. Bacteria typically rely on the TCA cycle for energy production during their metabolic activities. However, when faced with a lack of inorganic nutrients or nutrient starvation, coupled with an excess of carbon and limitations in nitrogen, phosphorus, potassium, oxygen, magnesium, and other essential elements, bacteria undergo a shift from acetyl coA synthesis to the biosynthesis of polyhydroxyalkanoates (PHA) as a stress response mechanism (Ray and Kalia, 2017)[25]. The monomers of PHAs consist of hydroxyalkanoic acid subunits, with 3-hydroxybutyric acid (3HB) being the most prevalent type found in PHAs. Additionally, other types of hydroxyalkanoic acids, such as 3-hydroxyvaleric acid (3HV) and 3-hydroxyhexanoic acid (3HHx), can also be observed in PHAs.

PHA-based Bioplastics showcase an extensive range of physico-mechanical and biological attributes. These encompass exceptional flexibility and elasticity, robustness, remarkable versatility, high melting temperature (Tm), high glass transition temperature (Tg), UV resistance, biodegradability, compostability, as well as commendable biocompatibility and barrier properties (Kootstra et al., 2017)[26]. The potential applications of PHA bioplastics are vast, spanning across food packaging, agriculture, medical devices, 3D printing, and various processing methods. They can also be employed in drug delivery systems, tissue engineering, and the production of cosmetic and personal care products

### 7. Polyhydroxybutyrate (PHB)

Poly-3-hydroxybutyrate (PHB) is a biodegradable PHA polymer that has been extensively studied. It is derived from corn starch, sugars, or plant oils. Due to its linear structure, PHB exhibits a highly crystalline and brittle nature. Like polypropylene, PHB is composed of repeating units of 3-hydroxybutyrate (Kai et al., 2018)[27]. One of the remarkable properties of PHB is its ability to withstand high temperatures, allowing it to be molded into various shapes and sizes. Moreover, PHB is non-toxic and biocompatible, making it suitable for medical applications such as sutures and tissue engineering (Savenkova et al., 2000)[28]. Additionally, PHB-based bioplastics are water-resistant, making them ideal for food packaging and other industrial uses. These bioplastics find applications in textiles, disposable products like cutlery, plates, and straws, cosmetics, biodegradable films, and even 3D printing (Kong and Hay, 2002)[29].

### 8. Bio-Based Polyethylene (Bio-PE)

Bio-based polyethylene is a prominent bio-based polymer utilized in the production of Bioplastic. The ethylene monomer is obtained through the dehydration process of bioethanol. Once the ethylene monomer undergoes polymerization, polyethylene is formed. Bioethanol, on the other hand, is derived from the fermentation of glucose molecules. The primary sources of glucose molecules include feedstock such as sugar cane, maize, and wheat. It is worth noting that bio-based polyethylene-polymer possesses the same chemical, physical, and mechanical properties as fossil-based polyethylene, particularly in terms of mechanical recycling (Morschbacker, 2009)[30]. In fact, bio-based polyethylene-polymer exhibits similar characteristics to traditional petroleum-based polyethylene, including high rigidity, durability, flexibility, and resistance to moisture. This bioplastic is extensively used in various applications such as food packaging, cosmetics, household products, sporting goods, toys, textile fabrics, agriculture, and automotive industries. Moreover, bioPE contributes to reducing the carbon footprint when compared to petroleum-based polyethylene. Notably, the Brazilian company Braskem holds the distinction of being the first to commercially produce 200,000 tons of bio-based polyethylene bioplastic annually (Siracusa and Blanco, 2020)[31].

### 9. Bio-Based Polypropylene (Bio-PP)

Bio-based polypropylene, much like bio-based polyethylene, is a type of bioplastic polymer. It is widely utilized and has a relatively high melting point of 165C. This polypropylene is manufactured from renewable sources such as vegetable oils, sugarcane, corn, and biomass. While it shares similar properties and applications with conventional polypropylene, it also provides environmental benefits. Carbon-rich sources, including agricultural wastes, sugarcane waste, corn, and bio waste, can be gasified to produce syngas, which is then converted to propanol, and undergoes dehydration to yield propylene monomer. Bio-based polypropylene exhibits properties such as light-weightiness, easy processability, exceptional chemical resistance, high thermo-mechanical characteristics, tensile strength, and flexibility.

## BIODEGRADABLE BIOPLASTIC

Biodegradable Bioplastics are a type of bioplastic that can be broken down by biological processes, specifically by bacteria, fungi, and algae. This breakdown results in the conversion of these bioplastics into water, carbon dioxide, methane, biomass and inorganic compounds. Importantly, these biodegradable materials are environmentally safe and typically decompose within a few months. They are produced using bio-based materials such as polylactic acid (PLA), polyhydroxyalkanoates (PHA), cellulose and starch. The rate of biodegradation of bioplastics is influenced by various factors, including temperature, the presence of microorganisms, oxygen availability, humidity and water content. Consequently, the degradability of bioplastics varies depending on the specific environmental conditions, such as soil, water, humid or dry climates, marine settings and artificial systems (Di Bartolo et al., 2021; Van den Oever et al., 2017)[32,33].

## COMPOSTABLE BIOPLASTIC

Compostable bioplastics refer to a specific category of bioplastics that can biodegrade when exposed to composting conditions. To achieve industrial-level composting of bioplastics, certain factors must be considered, such as maintaining higher temperatures of around 55-60°C, ensuring a high relative humidity, and providing sufficient oxygen. When compared to other biodegradation environments like soil, water, and marine ecosystems, industrial composting conditions are considered the most favorable. Although home composting is also a viable option, it tends to be slower due to lower temperatures, less stable composting conditions, and the specific materials used. The European Standard EN 13432 serves as a reliable benchmark for assessing the industrial compostability of bioplastics used in packaging materials.

In accordance with the EN13432 standard, Bioplastic packaging can only be classified as compostable if it satisfies specific requirements. These requirements include the natural biodegradability of both the packaging material and its associated organic components (>1 wt.%). Moreover, the packaging material must not pose any safety concerns or generate toxic substances that could adversely affect the compost quality and composting process. The packaging material should disintegrate within a period of 12 weeks and completely biodegrade within six months. It is essential to achieve the conversion of at least 90% of the Bioplastic into $CO_2$ within six months, as outlined in the laboratory test method EN 14046. The remaining portion should convert into water and biomass, which can contribute to the production of valuable compost (Van den Oever et al., 2017)[33]. Presently only PHA/PHB and TPS are the bioplastics compostable under home composting conditions.

## ADVANTAGES OF BIOPLASTICS OVER CONVENTIONAL PETROLEUM-BASED PLASTICS

Bioplastic, commonly known as green plastic, gained its reputation in its initial stages due to its production from plant-based materials like starch. Unlike conventional plastics, which are derived from petrochemical polymers obtained from fossil fuels, bioplastics are sourced from renewable bio-based materials such as plants, animals, and microorganisms. This distinction makes bioplastics free from petroleum-based components. These plastics, known for their high durability and inability to biodegrade, have caused extensive environmental pollution. The urgency to address plastic pollution has driven the global shift towards bioplastics.

Opting for bioplastics over conventional petroleum-based plastics brings forth several advantages, making it a more sustainable and environmentally friendly option. Derived from renewable sources like plant starches, sugarcane, corn, and agricultural waste, bioplastics alleviate the reliance on finite resources and contribute to mitigating the environmental consequences linked to the extraction and processing of fossil fuels. Bioplastic presents an extraordinary remedy for mitigating the buildup of plastic waste in both landfills and marine environments, where traditional plastics inflict substantial ecological damage.

The manufacturing process of bioplastics typically consumes less energy in comparison to conventional plastics. This disparity arises from the reduced energy demands associated with cultivating and processing plant-based feedstocks, as opposed to the energy-intensive extraction and refining of fossil fuels.

**Table 1: The major difference between bioplastic and conventional plastics**

| Properties | Conventional plastics | Bioplastics |
|---|---|---|
| Source | fossil fuels and petrochemicals | Natural resources like living matters (plants, animals and microorganisms) or biomass |
| Renewability | Non-renewable resources | Renewable resources |
| Biodegradability | Almost all non-biodegradable | Most of the bioplastics are completely or partially biodegradable or Compostable |
| Time taken for degradation | long time to disintegrate | short time to complete degradation |
| Environmental safety | Causes environmental pollution | Eco-friendly |
| Carbon footprint | Higher | Lower |
| Energy efficiency | Production requires high energy | Production requires low energy |
| Toxicity | Produce high toxic substances | Produce low or no toxic substances |
| Synthesis | Chemical synthesis | Chemical as well as biological synthesis |
| Applications | Used in food packaging | Used in eco-friendly food packaging |
| Social approval | Less | High |

Within circular economy models, bioplastics can play a significant part as they are designed for reuse, recycling, or composting purposes. Their versatility allows them to be engineered with a wide array of properties, making them suitable for diverse applications across industries including electronics, packaging, automotive, agriculture, and more. Through modifications in composition and manufacturing processes, developers can tailor the qualities of bioplastics to cater to specific applications.

Bioplastics, which are made from renewable materials, exhibit a range of advantageous properties such as flexibility, thermal stability, lightness, barrier properties, biocompatibility, UV stability, electric insulation properties, and other mechanical and chemical properties. This sets them apart from traditional plastics derived from petrochemicals (Pilla, 2011; Shamsuddin et al., 2017)[34,35].

Typically, Polysaccharide-based bioplastics exhibit brittleness, lack of continuity, rigidity, and fragility. However, to address this issue, plasticizers such as Glycerol and Sorbitol are employed as additives. These plasticizers are compatible with polysaccharides and enhance flexibility by increasing the interstitial volume of the polymeric matrix, molecular mobility, hydrophilic degree of the bioplastics, and reducing the glass transition temperature (Tg) (Abe et al., 2021; Abe et al., 2021)[36,37]. Some of the Bioplastics possess UV protection abilities, which is essential for outdoor applications to prevent material degradation over time. The gas barrier property for oxygen and water vapor is a crucial requirement for bioplastics used in food packaging applications. To enhance their mechanical characteristics and water barrier properties, these bioplastics can be effectively blended with other polymers and nano fillers (Gadhave et al., 2018)[38].

## BIOPLASTIC PROGRESSION AND FUTURE ADVANCEMENTS THROUGH 2024

Bioplastic's journey commenced in the 19th century and has experienced substantial advancements in recent years, positioning itself as a pivotal force in combating plastic pollution and promoting sustainability. During this period, the international community has observed a noteworthy shift towards prioritizing environmental consciousness in the creation of eco-friendly goods, aimed at safeguarding our natural surroundings. As an integral contributor to this ongoing initiative, the production of bioplastics has emerged as a vital stakeholder, offering innovative solutions to address the escalating environmental challenges posed by traditional plastics.

The European Union reports that bioplastics currently account for less than one percent of the total plastic production, which exceeds 390 million tons annually. The COVID-19 pandemic has also led to a decrease in bioplastic production in 2020. However, there has been a subsequent increase in bioplastic production in 2021. Recent market data, compiled by European Bioplastics in partnership with the nova-Institute, reveals that global bioplastics production capacities are expected to rise from approximately 2.2 million tons in 2022 to about 6.3 million tons in 2027. The production rate of bioplastics shows a consistent annual growth, nearly doubling between 2022 and 2025.

The production of biodegradable plastics surpasses that of bio-based non-biodegradable plastics on a global scale. In 2022, approximately 51.6% of the bioplastics produced worldwide are biodegradable, encompassing PLA, PHA, starch blends, and other variants. Among these, PLA constitutes the largest proportion, accounting for nearly 20.7% of the total bioplastic production in 2022. The increasing production of biodegradable plastics can be attributed to significant advancements in polymer development, particularly in PLAs (polylactic acids), PHAs (polyhydroxyalkanoates), fibrous proteins and other polysaccharides. On the other hand, bio-based non-biodegradable plastics contribute to approximately 48.5% (1 million metric tons) of the global bioplastic production. The packaging industry accounted for 48 percent (approximately 1.1 million tons) of the total bioplastic production in 2022, making it the largest market segment for bioplastics.

According to the European Union's predictions, there will be a notable increase in the production of biodegradable and non-biodegradable bioplastics. In 2027, it is expected that the production of biodegradable plastic will reach 3.56 million tons, accounting for 56.5% of the total production, while non-biodegradable plastic will reach 2.74 million tons, representing 43.5% of the total production. Additionally, the proportion of bio-based non-biodegradable plastic is projected to decrease from 48.5% to 43.5% in 2027.

Asia currently holds the title of the world's primary global production hub for bioplastics, with Asian countries contributing around 41% of the total production. Looking ahead, it is anticipated that Asia's bioplastic production will continue to rise, surpassing the 50% mark in 2024 and reaching nearly 63% by 2027. With a substantial 26.5 percent share, Europe stands as the second largest hub for Bioplastic producers globally.

## CONCLUSION

Currently, the bioplastic industry is witnessing significant advancements and innovations aimed at creating more sustainable and high-quality bioplastics that cater to various applications in different fields. Biodegradable polymers have emerged as a key focus of research, particularly in the biomedical sector, where they are being explored for applications such as tissue engineering, the development of 3D scaffolds, therapeutic devices, controlled drug release systems, biodegradable surgical materials, dental implants, and biodegradable wound closures.

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