Review Article

Journal of Scientific Enquiry
Vol:3(1), Pages:66-74

A Sustainable and Environmentally Friendly Alternative to Plastics: Bioplastics

Somnath Choubey*

Department of Chemistry, Government General Degree College at Manbazar-II, Susunia, PO-Kumari, PS-Boro, District- Purulia, Pin-723131, West Bengal, India

Received: 02.05.2023; accepted: 30.05.2023; published online: 30.06.2023

Abstract
Traditional plastics made from petrochemicals continue to be extensively employed in packaging because of their strong barrier qualities, rigidity, and tensile and tear strengths. Despite their popularity, plastics have a number of disadvantages, such as a relatively low water vapour transmission rate and a lack of biodegradability. In recent years, we have seen the correct disposal of plastic become a persistent and possibly global environmental issue. Millions of animals have died as a result of improper plastic disposal and land and marine garbage disposal, which reduced soil fertility. Newer concepts for using bioplastics were implemented while keeping in mind the environmental damage and contamination. Bioplastics are a rapidly growing segment of the plastics industry, and they have the potential to play a significant role in addressing some of the environmental challenges posed by traditional petroleum-based plastics. This review aims to provide an overview of the current state of the bioplastics industry, including its brief history, the types of bioplastics that are available, their properties, production processes, and end-of-life considerations. Additionally, the review will explore the advantages and disadvantages of bioplastics compared to traditional plastics, and will consider the future prospects of this rapidly evolving industry.

Keywords: Bioplastics, Biodegradable, Advantage, Disadvantage

1. Introduction:

Plastics have become an integral part of modern life due to their characteristics [1] and superior performance over other materials such as metal and wood. Some of the fascinating qualities of plastics are low density, high strength-to-weight ratio, lightness, flexibility, high durability, ease of design and manufacture, and low cost. These characteristics result in widespread plastics use, which has seriously harmed the environment [2]. Traditional plastics are made from petroleum, a non-renewable resource, and they can take hundreds of years to break down, creating long-lasting waste that can harm the environment and wildlife [2-4]. In recent years, there has been growing interest in finding sustainable and environmentally friendly alternatives to traditional plastics, and bioplastics [5, 6] have emerged as a promising solution. Bioplastics are made from renewable resources such as corn starch, sugarcane, and potatoes, and they can be biodegradable, compostable, or both. Natural microorganisms such as bacteria, algae, and fungi break down biodegradable plastic [7-9]. Temperature, water content, oxygen content, and the chemical makeup of the polymer determine how quickly it degrades. This review article will explore the various types of bioplastics [10], their advantages and limitations, and their potential for widespread use as a sustainable and environment friendly [6, 11] alternative to traditional plastics. Additionally, the focus of the article will revolve around the necessity of educating the public about bioplastics and their current state of development [12].

The concept of bioplastics dates back to the early 20th century, when scientists first started exploring the possibility of using renewable resources such as starch and cellulose to produce plastics. However, it wasn't until the 1960s and 1970s that bioplastics started to gain significant attention as a more sustainable and environmentally friendly alternative to petroleum-based plastics [13]. In the 1980s, new developments in biotechnology and genetic engineering paved the way for the creation of bio-based plastics made from renewable resources such as corn, sugarcane, and potato starch including vegetable oils and waste from agricultural and forestry industries. These materials were found to have similar properties to traditional petroleum-based plastics but with a smaller carbon footprint and improved biodegradability.

2. Types of Bioplastics

Bioplastics can be broadly categorized into two main groups: biodegradable plastics and bioplastics. Biodegradable plastics are designed to break down into smaller pieces over time and eventually disappear completely, while bioplastics are made entirely from renewable resources and can be either biodegradable [7-9] or non-biodegradable [14].

Email: somnathchoubey@gmail.com
 DOI: https://doi.org/10.54280/jse.233112

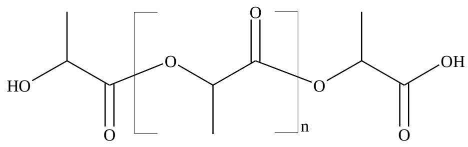
2.1. Biodegradable Plastics:

Biodegradable plastics [7-9] are typically made from polylactic acid (PLA), which is produced from corn starch, sugarcane, or other plant-based materials. These plastics can be broken down by microorganisms such as bacteria, algae and fungi. Temperature, water content, oxygen content, and the chemical makeup of the polymer determine how quickly it degrades. These plastics are typically used for applications such as food packaging, disposable cutlery, and shopping bags.

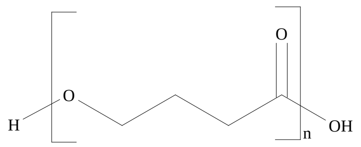
2.2. Bioplastics:

Bioplastics are made from renewable resources such as corn starch, sugarcane, and potato starch, and they can be either biodegradable or non-biodegradable [7-9, 14]. Non-biodegradable bioplastics, such as polyethylene (PE), are made from bio-based materials but have the same properties as traditional petroleum-based PE. Biodegradable bioplastics, such as polybutylene succinate (PBS), are made from bio-based materials and are designed to break down in the environment. There are mainly three types of bioplastics which are biodegradable and biobased, biodegradable and fossil-based, and non-biodegradable and biobased while non-biodegradable and petroleum based are known as conventional plastic. Chemical structures of various types of conventional and bioplastics are shown **Fig. 1** and **Fig. 2** respectively. The **Table 1** summarises types of bioplastics with examples as described above. Some most common types of bioplastics include:

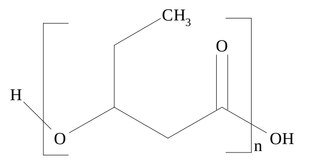
Fig. 1. Chemical structures of some Conventional Plastics



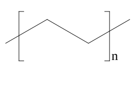
Polylactic acid (PLA)



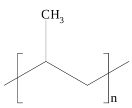
Poly-4-hydroxybutyrate (P4HB)



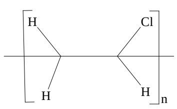
Poly-3-hydroxyvalerate (PHV)



Polyethylene (PE)



Polypropylene (PP)



Polyvinylchloride (PVC)

Fig. 2. Chemical structures of some Bioplastics

Table 1: Types of Bioplastics

	Bio-Based	Petroleum Based
Biodegradable	Bioplastics Eg: Polylactic acid (PLA), Polyhydroxyalkanoates (PHA), Cellulose-based, Starch-based	Bioplastics Eg: Polybutylene succinate (PBS), Polybutylene adipate terephthalate (PBAT), Polycaprolactone (PCL)
Non-biodegradable	Bioplastics Eg: Bio-polypropylene (bio-PP), Bio-polyethylene (bio-PE), Bio-polyethylene terephthalate (bio-PET), Bio-polyvinyl chloride (bio-PVC) etc.	Conventional plastics Eg: Polypropylene (PP), Polyethylene (PE), Polystrene (PS), Polyvinyl chloride (PVC) etc.

Starch-based bioplastics: Starch is a widely available and renewable resource that can be easily converted into bioplastics [15, 16]. Corn starch is the most commonly used starch, but other sources, such as potatoes or rice, can also be used. These bioplastics are usually used for packaging and disposable products.

Polylactic acid (PLA): This type of bioplastic [17, 18] is made from lactic acid, which is derived from corn starch or sugarcane. It has similar properties to traditional petroleum-based plastics, including transparency and strength. PLA is commonly used for food packaging, disposable cutlery, and 3D printing.

Polyhydroxyalkanoates (PHA): PHA is a type of bioplastic [19] that is produced by bacteria. It is made from sugar or fatty acids and has similar properties to traditional petroleum-based plastics. PHA is often used for food packaging, as it is both biodegradable and compostable.

Lignocellulose and hemicellulose bioplastics: These are sustainable and biodegradable materials derived from lignocellulosic biomass, such as wood, agricultural residues, and energy crops. Lignocellulose-based bioplastics [20-22] utilize the cellulose, hemicellulose, and lignin components, while hemicellulose-based bioplastics [16] specifically focus on the extraction and utilization of hemicellulose, a branched polysaccharide. These bioplastics offer advantages such as renewable resource utilization, reduced environmental impact, and potential biodegradability. They can be used in various applications including packaging, agriculture, biomedical fields, and additive manufacturing.

2.3. Fungal mycelium and seaweed polysaccharides:

Fungal mycelium and seaweed polysaccharides are two types of natural materials that have gained attention for their potential applications in sustainable bioplastics. Here's a brief description of each:

Fungal Mycelium: Fungal mycelium refers to the network of fine, thread-like structures produced by fungi. It can be harnessed to create bioplastics through a process known as mycelium-based bioplastic [23] production. The mycelium acts as a binder and grows on agricultural waste or other organic substrates, forming a solid, durable material. This bioplastic alternative is often referred to as "mycelium leather" or "mushroom leather" due to its leather-like appearance and texture. Fungal mycelium-based bioplastics [23] are renewable, biodegradable, and can be produced using low-energy processes. They have potential applications in various industries, including fashion, packaging, and construction.

Seaweed Polysaccharides: Seaweeds are marine macroalgae that contain polysaccharides, complex carbohydrates that can be extracted and utilized in bioplastic production. Common seaweed polysaccharides [24, 25] used in bioplastics include agar, carrageenan, and alginate. These polysaccharides possess unique gelling and film-forming properties, making them suitable for bioplastic applications [24, 25]. Seaweed-based bioplastics are renewable, biodegradable, and can offer advantages such as good barrier properties, flexibility, and low environmental impact. They find applications in food packaging, agricultural films, and other areas where biodegradability and sustainability are important.

Both fungal mycelium-based bioplastics [23] and seaweed polysaccharide-based bioplastics [24, 25] offer potential benefits in terms of renewable resource utilization, biodegradability, and reduced environmental impact compared to conventional plastics. Ongoing research and development efforts are focused on optimizing production processes, enhancing material properties, and exploring new applications for these sustainable bioplastic alternatives.

3. Degradability and Bioplastics

Plastic degradation happens when a polymer experiences any physical or chemical change as a result of environmental elements like light, heat, moisture, chemical conditions, or biological activity. Degradable polymers are divided into four categories as described in **Fig. 3**

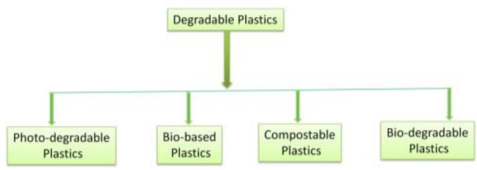


Fig. 3. Types of Degradable Plastics.

1) In photodegradable bioplastics [16-19], light-sensitive groups are directly attached into the polymer's main structural unit. Their polymeric structure could be damaged by prolonged ultraviolet exposure (a few weeks to months), leaving them readily accessible to further bacterial deterioration.
2) The term "biobased bioplastics" refers to polymers made entirely from renewable

agricultural and forestry resources, such as cellulose, soybean protein, and corn starch.

3) Compostable bioplastics, like other biodegradable materials, biologically decompose during the composting process without generating any prominently toxic waste. Before a plastic may be deemed to be bio-compostable, standard tests must be applied to determine its general biodegradability, level of disintegration, and potential ecotoxicity of the degraded material.
4) Biodegradable bioplastics [16-22] are totally broken down by microorganisms without any visible toxic remains. The term "biodegradable" refers to compounds that can naturally breakdown or break down into biogases and biomass (mainly carbon dioxide and water) when exposed to a microbial habitat and humidity, such as those found in soil. This is in contrast to biobased sustainable materials. As a result, less plastic garbage is produced. Given that microorganisms use them, the fourth class of bioplastics is very promising.

4. Properties of Bioplastics:

The properties of bioplastics [26] can vary widely depending on the type of material used, but they generally have several key advantages over traditional petroleum-based plastics. These include lower greenhouse gas emissions, lower use of finite fossil fuels, and improved biodegradability [7-9]. Bioplastics can be broken down by microorganisms into water, carbon dioxide, and biomass, reducing the amount of plastic waste in the environment.

Bioplastics also tend to have lower melting points than traditional plastics, which can be an advantage in certain applications. Additionally, they are typically stiffer and stronger than traditional plastics, which can be an advantage in applications where high strength is required. Bioplastics can be added to compost piles and will break down into compost along with food waste and yard trimmings. Bioplastics are made from renewable resources [15-25], reducing the reliance on finite petroleum reserves. They are made from natural materials that are non-toxic, making them safe for use in food packaging and medical applications which made them biocompatible.

5. Comparison of Various Parameters of Traditional plastics and Bioplastics:

Plastics and bioplastics are both types of polymers used in various applications. While plastics are derived from fossil fuels, bioplastics are made from renewable sources such as plant-based materials. Here is a comparison between plastics and bioplastics based on a number of factors [26], such as tensile strength, elongation at break, and contact angle:

Tensile Strength: Tensile strength is the maximum stress a material can withstand before breaking under tension. Plastics generally have high tensile strength, depending on their composition. Common plastics like polyethylene (PE), polypropylene (PP), and polyvinyl chloride (PVC) have tensile strengths ranging from 10 to 50 MPa. Bioplastics, on the other hand, typically have lower tensile strengths [26] compared to traditional plastics. Their tensile strengths range from 5 to 30 MPa, depending on the specific bioplastic material.

Elongation at Break: Elongation at break measures the ability of a material to stretch before it breaks. Plastics generally exhibit lower elongation at break values, typically ranging from 100% to 500%. This means that plastics are more rigid and less flexible. In contrast, bioplastics often have higher elongation [26] at break values, ranging from 200% to 800%. This higher flexibility allows bioplastics to withstand deformation and stretching before ultimately breaking.

Contact Angle: Contact angle refers to the angle formed at the interface between a solid surface and a liquid droplet resting on it. It provides information about the wet ability and surface energy of a material. The contact angle of plastics can vary widely depending on their surface properties and composition. For hydrophobic plastics like polyethylene and polypropylene, the contact angle [26] is generally high, often above 90 degrees, indicating low wet ability. Bioplastics, especially those derived from hydrophilic sources, tend to have lower contact angles, indicating higher wet ability. However, it is important to note that the contact angle can also be influenced by surface modifications or coatings applied to the material.

It's worth mentioning that the specific properties [26] of plastics and bioplastics can vary depending on their formulations, processing methods, and additives used. Therefore, the values provided here are general ranges and can differ for different types and grades of materials within each category.

6. Carbon Cycle of Bioplastics:

Traditional fossil fuel-derived plastic disrupts the natural cycle, increases the atmospheric release of carbon dioxide, and adds to the greenhouse effect. A major component that needs to be focused is the carbon cycle, which is the mechanism by which carbon is traded among the spheres of the globe. As plants grow, they take up carbon dioxide, which is then released back into the atmosphere as the plants decompose. The carbon cycle **(Fig. 4)** of bioplastics [27] is different from traditional plastics because the carbon used to create bioplastics comes from renewable biomass sources, such as corn starch, sugarcane, and potato starch etc. When plants grow, they take in carbon dioxide from the atmosphere through photosynthesis and store it in their tissues. This carbon is then used to create bioplastics. When bioplastics are used and eventually disposed of, the carbon in the plastic can either be released back into the atmosphere as carbon dioxide or can be sequestered in landfills or through composting [28]. If the bioplastics are composted, the carbon in the plastic can be broken down by microorganisms [7-9, 23-25] and returned to the soil, where it can be used to support new plant growth. However, it's important to note that the production of bioplastics still requires energy and resources, and the carbon footprint of bioplastics can vary depending on the specific material and production process used. Additionally, the disposal of bioplastics can also have environmental impacts [11], such as the release of methane gas from landfills where bioplastics are not properly composted [28].

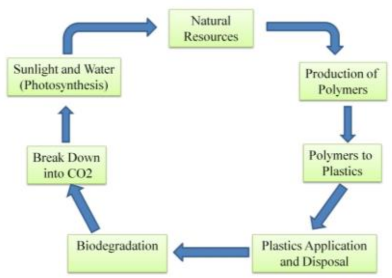


Fig. 4. Bioplastics Cycle.

7. Major Applications Bioplastics:

Bioplastics have a number of applications due to their biodegradability and sustainability benefits compared to traditional petroleum-based plastics. Some of the most common applications [12, 29-31] of bioplastics include:

Packaging: Biodegradable packaging [30] made from bioplastics is used for a variety of products, including food, beverages, and consumer goods.

Agriculture: Bioplastics are used in the production of mulch films (a special type of film that to prevent contamination of the crops and the soil from atmospheric agents), plant pots, and seed trays, which help to conserve soil moisture and reduce waste [29].

Textiles: Biodegradable and bio-based fibers are used in the production of clothing, upholstery i.e. soft materials [29] used to cover chairs, car seats, and carpets etc. which offer a more sustainable alternative to traditional synthetic fibers.

Medical devices: Biodegradable medical devices, such as sutures, implants, and drug delivery systems [31], can reduce the risk of long-term health problems associated with traditional petroleum-based medical devices.

Automotive: Bioplastics are used in the production of automotive parts [29], such as interior trim, dashboards, and seat covers, which offer a more sustainable alternative to traditional petroleum-based plastics.

Consumer goods: Bioplastics are used in the production of consumer goods [29], such as toys, toothbrushes, and razors, which offer a more sustainable alternative to traditional petroleum-based plastics.

Electronics: Biodegradable and biobased electronics [12, 31], such as smartphones and laptops, are being developed as a more sustainable alternative to traditional electronics made from petroleum-based plastics.

Table 2 is showing the various application of bioplastics depending on their material. So, bioplastics offer a promising solution to many of the environmental and waste-related problems associated with traditional petroleum-based plastics.

Table 2. Applications of bioplastics

Material	Application
Starch	Packaging materials, Agricultural Application (mulch films, seed coatings, and plant pots), Medical devices, Textiles, Automotive and transport, Building and Construction Materials, Consumer Goods etc.
Cellulose	Reinforced films, packaging, Disposal household, Medical devices, Electronic devices
PLA	Films, Food packaging
PHA	Coating, Food packaging, Medical Implant

8. Production Processes:

Bioplastics are produced using a process known as biopolymer synthesis [21, 25]. This process involves using microorganisms, such as bacteria or yeast, to produce polymers such as polylactic acid (PLA) or polyhydroxyalkanoates (PHA) from renewable resources, such as corn starch or sugarcane.

Here is a general overview of the bioplastic production process:

Raw material preparation: The raw materials, such as corn starch or sugarcane, are prepared for use in the biopolymer synthesis process [21, 25]. This may involve grinding, mixing with water, and adding enzymes to break down the sugars into simple sugars such as glucose or fructose.

Microbial cultivation: Microorganisms, such as bacteria or yeast, are grown in a nutrient-rich environment, typically in large fermentation tanks. The microorganisms consume the simple sugars and produce the desired biopolymer.

Polymer extraction: The biopolymer is extracted from the microbial culture, typically by separating it from the nutrient broth using centrifugation or filtration.

Polymer purification: The extracted biopolymer is purified to remove impurities and improve its quality. This may involve washing, drying, and melt-processing to produce a solid polymer.

Pelletization: The purified biopolymer is then pelletized, or formed into small, uniform beads, which can be easily molded into various shapes and sizes.

Molding: The pelletized biopolymer is melted and molded into the desired product shape, typically using injection molding or extrusion processes.

Finishing: The molded bioplastic product may be subjected to additional finishing processes, such as trimming, sanding, or polishing, to achieve the desired surface finish and appearance.

Overall, the bioplastic production process [21, 25] is a sustainable alternative to traditional plastic production methods, as it uses renewable resources and produces a biodegradable material with a lower carbon footprint.

9. Environmental impact of bioplastics:

Bioplastics are often promoted as more environmentally friendly alternatives to traditional petroleum-based plastics. However, it is important to consider the overall environmental impact [11] of bioplastics throughout their lifecycle [32, 33], including their production, use, and disposal. Here are some key points to consider regarding the environmental impact of bioplastics:

Renewable Resource Utilization: One of the main advantages of bioplastics is their use of renewable resources, such as plant-based feedstocks [15, 20-22]. By reducing reliance on fossil fuels, bioplastics have the potential to lower greenhouse gas emissions and decrease resource depletion.

Energy and Resource Consumption: The production of bioplastics can still require significant amounts of energy, water, and agricultural resources. The cultivation, processing, and conversion of feedstocks into bioplastics can result in environmental impacts [11], including deforestation, land use change, water consumption, and pesticide use. It is important to consider the sustainability of feedstock production and ensure responsible sourcing practices.

Biodegradability and Compostability: Some bioplastics are designed to be biodegradable or compostable [7-9] under specific conditions, such as industrial composting [28] facilities. While this can offer benefits in terms of waste management and reduction of plastic pollution, it is crucial to ensure proper waste management infrastructure is in place to effectively capture and process biodegradable or compostable bioplastics. Improper disposal, such as mixing bioplastics with conventional plastics, can hinder their biodegradation and lead to environmental harm.

Life Cycle Assessment: Comprehensive life cycle assessments (LCAs) [32, 33] are necessary to evaluate the environmental impact of bioplastics holistically. LCAs consider factors such as raw material extraction, production processes, transportation, use phase, and end-of-life scenarios. These assessments help identify potential environmental hotspots and guide the development of more sustainable bioplastic alternatives.

Recycling Challenges: Due to variations in their chemical characteristics, bioplastics and conventional plastics normally cannot be recycled together. If not properly sorted and recycled separately, the contamination of conventional plastic waste streams with bioplastics can hinder recycling efforts and increase overall environmental impact [11]. Some bioplastics can be recycled within specific closed-loop systems or through specialized recycling processes.

Land Use and Food Security: The use of agricultural feedstocks for bioplastics raises concerns about competition with food production and potential impacts on food security. The responsible selection of feedstocks, utilization of waste or by-products, and development of non-food-based feedstocks can help mitigate these concerns.

In summary, the environmental impact of bioplastics depends on various factors, including the specific type of bioplastic, feedstock sourcing, production processes, waste management infrastructure, and end-of-life scenarios [32, 33]. It is crucial to consider a holistic approach, including sustainable feedstock production, efficient production processes, proper waste management, and recycling systems, to minimize the environmental footprint of bioplastics and maximize their potential environmental benefits.

10. Advantages and Disadvantages of Bioplastics:

One of the biggest advantages [34-39] of bioplastics is that they are biodegradable, meaning that they can break down naturally into the environment and won't contribute to plastic pollution. Unlike traditional petroleum-based plastics, which can take hundreds of years to break down, bioplastics can break down in as little as a few months. This is particularly important because plastic pollution is a serious problem, with an estimated eight million tons of plastic ending up in the oceans each year. Another advantage of bioplastics is that they are made from renewable materials such as corn starch, sugarcane, wood, agricultural residues, and potato starch. This means that they are more sustainable and less reliant on finite resources such as petroleum. Additionally, the production of bioplastics often has a lower carbon footprint than traditional plastics, as they are made from materials that are produced through photosynthesis, which captures carbon dioxide from the atmosphere. Bioplastics also offer several benefits over traditional plastics in terms of their performance and durability. For example, some bioplastics are as strong and durable as traditional plastics, and they can be used in a wide range of applications [29-31], from packaging to medical devices. Additionally, bioplastics often have a lower melting point than traditional plastics, which makes them more suitable for some applications, such as in food packaging [30] where it is important to maintain the freshness of the food.

While bioplastics have many advantages, there are also some disadvantages [12, 34, 35, 39, 40] to consider. One of the biggest challenges [35] with bioplastics is that they can be more expensive to produce than traditional plastics. This is largely because the raw materials used to make bioplastics are often more expensive than petroleum, which is used to make traditional plastics. Additionally, the production of bioplastics is often more complex and requires more specialized equipment, which can also contribute to higher costs. Another challenge with bioplastics is that they are not always as widely available as traditional plastics. While there has been a significant increase in the production of bioplastics in recent years, they are still not as widely used or produced as traditional plastics. This means that they may not be as readily available for certain applications, and may require a change in the supply chain to make them more accessible. Finally, there is still some debate about the environmental impact of bioplastics [11, 39, 40]. While they are generally considered to be more environmentally friendly than traditional plastics, some experts have raised concerns about the potential impact of large-scale production of bioplastics on food security, land use, and water use [32, 33]. For example, the production of bioplastics requires large amounts of land and water, which could have negative impacts on food production and water availability in certain regions.

Apart from above discussion **Table 3** describes briefly the advantages and disadvantages of bioplastics compare to conventional plastics that as found from detailed literature survey [12, 34-38].

Table 3: Advantages and disadvantages of bioplastics compare to conventional plastics

Types	Advantages	Disadvantages
Bioplastics	• Biodegradable • Eco-friendly • Sustainable • Reduced Carbon footprint • Lower greenhouse gas emissions	• Expensive • Less Availability • Limited Biodegradability • Recycling Challenges • Brittleness
Conventional Plastics	• Low Cost • Durability • Versatility • Ease of Manufacturing • Can save energy and resources	• Mostly Non-biodegrdable • Environmental Impact • Based on petrochemical • Difficult to recycle • Toxicity

11. Conclusion

In conclusion, the review article highlights the significance of bioplastics as a sustainable and environmentally friendly alternative to conventional plastics. It emphasizes the need to address the environmental concerns associated with plastic pollution and the depletion of fossil fuel resources. The article discusses various types of bioplastics, including those derived from renewable resources such as plant-based feedstocks and those produced using microbial fermentation processes.

The review article emphasizes the potential benefits of bioplastics, such as reduced greenhouse gas emissions, decreased reliance on fossil fuels, and the ability to biodegrade under appropriate conditions. It acknowledges that bioplastics offer a range of properties and applications comparable to traditional plastics, making them a viable option for industries such as packaging, agriculture, and biomedical fields.

However, the article also highlights the importance of considering the complete life cycle of bioplastics, including feedstock production, manufacturing processes, use, and end-of-life options. It emphasizes the need for sustainable feedstock sourcing, efficient production methods, proper waste management infrastructure, and advancements in recycling and composting technologies to maximize the environmental benefits of bioplastics.

Overall, the review article recognizes the potential of bioplastics as a sustainable and environmentally friendly solution to address the plastic waste crisis. It calls for continued research and development efforts to improve the performance, scalability, and end-of-life considerations of bioplastics. It concludes that with careful consideration and holistic approaches, bioplastics can contribute to a more sustainable and circular economy, reducing the environmental impact of plastics and fostering a greener future.

References

[1] W F Bartoe and D S Frederick, Characteristics of Plastics as Engineering Materials, SAE Trans., 52, 54-61 (1944).

[2] A L Andrady, Plastics and the Environment, John Wiley & Sons, (2003).

[3] N Laskar and U Kumar, Plastics and microplastics: A threat to environment, Environ. Technol. Innov., 14, 100352 (2019).

[4] M Sigler, The effects of plastic pollution on aquatic wildlife: current situations and future solutions, Water Air Soil Pollut. 225, 1-9 (2014).

[5] S A Ashter, Introduction to bioplastics engineering, William Andrew, (2016).

[6] S Thakur, J Chaudhary, B Sharma, A Verma, S Tamulevicius and V K Thakur, Sustainability of bioplastics: Opportunities and challenges, Curr. Opin. Green Sustain. Chem., 13, 68-75 (2018).

[7] J C Huang, A S Shetty and M S Wang, Biodegradable plastics: a review, Adv. Polym. Technol., 10(1), 23-30 (1990).

[8] T M Aminabhavi, R H Balundgi and P E Cassidy, A review on biodegradable plastics. Polym. Plast. Technol. Eng., 29(3), 235-262 (1990).

[9] M Flury and R Narayan, Biodegradable plastic as an integral part of the solution to plastic waste pollution of the environment, Curr. Opin. Green Sustain. Chem., 30, 100490 (2021).

[10] E B Arikan and H D Ozsoy, A review: investigation of bioplastics, J. Civ. Eng. Arch., 9(1), 188-92 (2015).

[11] G Atiwesh, A Mikhael, C C Parrish, J Banoub and T A Le, Environmental impact of bioplastic use: A review, Heliyon, 7(9), e07918 (2021).

[12] I S Sidek, S F Draman, S R Abdullah and N Anuar, Current development on bioplastics and its future prospects: an introductory review, i TECH MAG, 1, 03-8 (2019).

[13] S Pathak, C L Sneha and B B Mathew, Bioplastics: its timeline based scenario & challenges, J. Polym. Biopolym. Phys. Chem., 2(4), 84-90 (2014).

[14] M H Rahman and P R Bhoi, An overview of non-biodegradable bioplastics, J. Clean. Prod., 294, 126218 (2021).

[15] B R Mose and S M Maranga, A review on starch based nanocomposites for bioplastic materials, J. Mater. Sci. Eng., B, 1(2B), 239 (2011).

[16] M M Abe, M C Branciforti and M Brienzo, Biodegradation of hemicellulose-cellulose-starch-based bioplastics and microbial polyesters, Recycling, 6(1), 22 (2021).

[17] M Karamanlioglu, R Preziosi and G D Robson, Abiotic and biotic environmental degradation of the bioplastic polymer poly (lactic acid): A review, Polym. Degrad. Stab., 137, 122-130 (2017).

[18] N A Taib, M R Rahman, D Huda, K K Kuok, S Hamdan, M K Bakri, M R Julaihi and A Khan, A review on poly lactic acid (PLA) as a biodegradable polymer, Polym. Bull., 80(2), 1179-1213 (2023).

[19] K W Meereboer, M Misra and A K Mohanty, Review of recent advances in the biodegradability of polyhydroxyalkanoate (PHA) bioplastics and their composites, Green Chemistry, 22(17), 5519-5558 (2020).

[20] M Brodin, M Vallejos, M T Opedal, M C Area and G Chinga-Carrasco, Lignocellulosics as sustainable resources for production of bioplastics–A review, J. Clean. Prod., 162, 646-664 (2017).

[21] R Reshmy, D Thomas, E Philip, S A Paul, A Madhavan, R Sindhu, R Sirohi, S Varjani, A Pugazhendhi, A Pandey and P Binod, Bioplastic production from renewable lignocellulosic feedstocks: a review, Rev. Environ. Sci. Biotechnol., 20, 167-187 (2021).

[22] H M Park, M Misra, L T Drzal and A K Mohanty, "Green" nanocomposites from cellulose acetate bioplastic and clay: effect of eco-friendly triethyl citrate plasticizer, Biomacromolecules, 5(6), 2281-2288 (2004).

[23] A Butu, S Rodino, B Miu and M Butu, Mycelium-based materials for the ecodesign of

bioeconomy, Dig. J. Nanomater. Biostructures, 15(4), 1129-1140 (2020).
[24] C Lim, S Yusoff, C G Ng, P E Lim and Y C Ching, Bioplastic made from seaweed polysaccharides with green production methods. J. Environ. Chem. Eng., 9(5), 105895 (2021).
[25] C S Onen, Z K Chong, M A Kucuker, N Wieczorek, U Cengiz and K Kuchta, Bioplastic production from microalgae: a review, Int. J. Environ. Res. Public Health, 17(11), 3842 (2020).
[26] J Y Boey, C K Lee and G S Tay, Factors Affecting Mechanical Properties of Reinforced Bioplastics: A Review, Polymers, 14(18), 3737 (2022).
[27] J G Rosenboom, R Langer and G Traverso, Bioplastics for a circular economy, Nat. Rev. Mater., 7(2), 117-137 (2022).
[28] W A Ahsan, A Hussain, C Lin and M K Nguyen, Biodegradation of Different Types of Bioplastics through Composting—A Recent Trend in Green Recycling, Catalysts, 13(2), 294 (2023).
[29] S Nanda, B R Patra, R Patel, J Bakos and A K Dalai, Innovations in applications and prospects of bioplastics and biopolymers: a review, Environ. Chem. Lett., 20(1), 379-395 (2022).
[30] N Jabeen, I Majid and G A Nayik, Bioplastics and food packaging: A review, Cogent Food Agric., 1(1), 1117749 (2015).
[31] T Narancic, F Cerrone, N Beagan and K E O'Connor, Recent advances in bioplastics: application and biodegradation, Polymers, 12(4), 920 (2020).
[32] G Gadaleta, C Ferrara, S De Gisi, M Notarnicola and G De Feo, Life cycle assessment of end-of-life options for cellulose-based bioplastics when introduced into a municipal solid waste management system, Sci. Total Environ., 871, 161958 (2023).
[33] M I R Morris and A L Hicks, A human-centered review of life cycle assessments of bioplastics, Int. J. Life Cycle Assess., 27, 157-172, (2022).
[34] M M Abe, J R Martins, P B Sanvezzo, J V Macedo, M C Branciforti, P Halley, V R Botaro and M Brienzo, Advantages and disadvantages of bioplastics production from starch and lignocellulosic components, Polymers, 13(15), 2484, (2021).
[35] M Rujnić-Sokele and A Pilipović, Challenges and opportunities of biodegradable plastics: A mini review, Waste Manag. Res., 35(2), 132-140 (2017).
[36] Y J Chen, Advantages of bioplastics and global sustainability. Appl. Mech. Mater., 420, 209-214 (2013).
[37] M Gill, Bioplastic: a better alternative to plastics, Int. J. Res. Appl. Nat. Soc. Sci., 2, 115-120 (2014).
[38] M S Muthusamy and S Pramasivam, Bioplastics–an eco-friendly alternative to petrochemical plastics, Curr. World Environ., 14(1), 49 (2019).
[39] T Walker, D Gramlich and A D Bergeron, The case for a plastic tax: a review of its benefits and disadvantages within a circular economy, Sustainability, 4, 185-211 (2020).
[40] J Brizga, K Hubacek and K Feng, The unintended side effects of bioplastics: carbon, land, and water footprints, One Earth, 3(1), 45-53 (2020).