Bioplastic, Biodegradability of Bioplastic and its Applications: A Review

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Article Info

ISSN (online): 3049-0588
Volume: 02
Issue: 04
July - August 2025
Received: 22-05-2025
Accepted: 24-06-2025
Published: 05-07-2025
Page No: 51-60

Abstract
Bioplastics offer a promising solution, made from renewable materials that reduce our reliance on fossil fuels and decrease carbon emissions. They're also less toxic and free from harmful chemicals like Bisphenol A (BPA). Biodegradable plastics can be fully broken down by microorganisms into water, carbon dioxide, and compost, while compostable plastics biodegrade in specific conditions. The article covers various types of bioplastics and their sources, including bio-based monomers, biopolymers, and additives. The environmental impact of bioplastics is assessed, including their implications for end-of-life management and the potential for turning food waste into biodegradable bioplastics. The article includes an in-depth analysis of the biodegradation of bioplastics While bioplastics offer many benefits, their biodegradation can have both positive and negative effects on the environment. To ensure bioplastics are a sustainable solution, we must understand their eco-toxicological impact and manage their production and disposal carefully. In conclusion, bioplastics offer a promising alternative to traditional plastics, but require careful management to ensure their biodegradability and eco-toxicological impact are minimized.

DOI: https://doi.org/10.54660/GARJ.2025.2.4.51-60

Keywords: Plastics, Biopolymers, Fossil fuels, feedstock, PLA

1. Introduction

The demand for plastic products have seen unprecedented growth and this trend keeps on accelerating as the Organization for economic cooperation and development (OECD) statistic shows that yearly production of the plastic annual production by 2060 will reach a total of 1.2 billion tons. During the 1950s, production of plastic reached a record figure of 8.3 million tons. Plastic is not easy to recycle and is typically sent to landfills, burnt, or directly poured into rivers or oceans, making up 79 % of all mismanaged plastic waste. Although this issue is related to environmental impacts in general, plastic-containing water waste will represent about a day of about 25 million tons discharged to the marine environment. Water reserve pollution due to plastics and micro-plastics is an additional well-known case of a new challenge that legal frameworks are finding complex to address (Yasin *et al*., 2024) [43]. The indications of the these materials in the water excipient the easy waste-water remedy, but also others giving the chance environmental pollution and threat of human health (Saleh, 2021) [38]. Plastics are not safe substances; rather, they are made of a number of harmful compounds that can leak out into the atmosphere as microplastics pollutants (Sajid *et al*., 2024) [37]. Endlessly, now, when polymers are functionalized with different nanoparticles may have the potential to release into soil as well and water. Moreover, a great amount of plastics, mainly non-degradable contaminants, reach the soil, lakes and rivers. Additionally, the pandemic has motivated an excessive amount of disposable plastic as their use as personal protective equipment by means of an over-use of PPE. Healthcare plastics in this period did not receive the necessary bans and the amount of medical waste plastic grew from 3-10 times (Rosenboom, Langer, & Traverso, 2022) [36]. Plastics are a quite large family of polymers (organic compounds composed of molecules with repeating structure), which have traditionally been derived from fossil resources such as petroleum, natural gas, or coal we commonly call them as having a wide range of properties and characteristics. In reality, carbon-based fossil fuels are extracted from water, to be converted into a polymer that is then added to plastics; this process is called "pyrolysis" (MacArthur, Waughray, & Stuchtey, 2016) [26].

Plastics are constantly used in the modern age in a variety of areas. Is it still astonishing that there hardly exists anything we use or interact with on a daily basis (from cosmetics to cars, from computers to construction), that is not, in some form or shape, made of or contained at least one type of plastic. Overall, the total of plastics that the world produces yearly. if we compare the cases of 1950s and now, we can see that they increased the concentrations of greenhouse gases by more than 230000% to 350 million tons annually (Okoffo *et al*., 2021) [34]. Considering that fact that nowadays plastic production consumes about 4-8% of global oil products and that forecast predicts to increase to 20% by 2050 (Pascaris & Pearce, 2020) [35]. The massive production of plastics during the 1950s has made plastics spread virtually across the entire society by being employed in many areas of life (Geyer, Jambeck, & Lavender, 2017) [12]. Plastic's extraordinary growth can, as reasons, have two sides: their low prices, extremely durable and strong properties and easy life (Andrady & Neal, 2009) [5]. The low cost of global plastics production combined with the fact that the properties which makes them attractive has made plastic production steady in the past 56 years increasing from 15 million metric tons in 1964 to the projected 2-fold increase in the next 20 years.

The polymer industry is a necessary part of the European labor market, as plastics reportedly employed over 1 million and more people, while having a €360 billion turnover in 2018 (Leal Filho *et al*., 2021) [24]. Moreover, plastics have the odd strength to weight ratio that can cut down the transportation cost of these items substantially. For example, the substitution of PET bottles by glass in Europe is a practice that has decreased the energy required for transport by 52%. Coming from a global economy phenomenon which succeeded in improving the population standers and in line with the rise in buying powers by individual all have had to lead to more increase in the plastic production. On the one hand, petrochemical plastics have become indispensable in human daily life due to their increased quality as compared to the previous succession, however, they are mainly single use and durable and recalcitrant, which leads to a very wearing the fraction of municipal solid waste.

It is important to create a balance between plastics and the environment. On the other hand, the release of poison gases to carbon dioxide and methane into the air as well. occurs as a result of the incineration of plastic. These greenhouse gases (GHGs) are warming the whole planet now change negatively (Netz, Davidson, Bosch, Dave, & Meyer, 2007) [33]. Today, biomaterials are believed to be the alternative to be the promising solution to this challenge. Plastic mostly because it is a replacement of imported finished products and preferential use of recycled materials will be the major reasons. Fossil fuels with carrying and then the environmental problem.

1.1. Historical development in Bioplastic

Plastics biodegradable, a growing category of macromolecules, are known as greener replacement of petroleum-inspired plastics, which hold promise in the environmental benefits they cause. Firstly, fossil plastics were reported by Robert Bacon almost a century ago. Then people started widely using these plastics in the industry and revealed the facts about plastic pollution and the urgency of the eco-friendly technologies of biodegradable plastics. Generally, the manufacture of traditional petroleum-type synthesized plastics has been linked with environment-related issues like greenhouse gas emission, contamination of nature and releasing of harmful substances to the environment. Contrary to normal plastics, bioplastics are manufactured to produce lower carbon footprint, dependency on natural resources and have higher 'green' safety measure and sustainability. Natural polymers have scientific prospects to replace the so-called petro-plastics, which generate worries about consumption of non-renewable resources and slowness of plastic degradation.

The early studies on the subject have now started to indicate that greening of plastics usage needs thorough evaluation to get the right results. Nevertheless, the greenhouse gas emissions and water usage systemic of bioplastics compromise the limited portability of these material substitute. That means, therefore, that all life cycle and land use change evaluations need to be comprehensive in order to know the real environmental impact of new bioplastics generation. Moreover, it must highlight the assessment of bioplastics on an extensive level encompassing both positive and negative environmental impacts. Through examination of various available and coming bioplastics, assessment of their impact on the environment, and unraveling the much debated environmental effects of bioplastics, can establish a better knowledge base about the production of bioplastics.

Plastic production is another number that has gone up a lot and compared to the 1950s, production has increased by 400%. In 1950, only two million tons were being produced; now. It now proves 450 million tons. Plastic has added much value to our lives: the material is a low-cost or multi-purpose option that is widely used as such as piping, equipment parts, medical instruments, and product packaging. On the other hand, a not properly managed waste plastic, which is not recycled, incinerated or kept in closed landfills, is the largest environmental polluter.

2. Importance of Biodegradability In Plastic

Plastics are products of plastic industry also known as petrochemical industry, which is light, strong, durable, and inexpensive synthetic or semi-synthetic organic polymers, wherein 99% of plastic polymer is made from non-renewable resources such as charcoal, petroleum, and natural gas (Censi *et al*., 2022; Van den Oever, Molenveld, van der Zee, & Bos, 2017) [7, 41]. The use of plastics is about 20% to the petroleum consumption total and they are mainly used in packaging, construction, textile, and automobiles. Nevertheless, the functionalities of durability that is primarily what makes plastic attractive in different applications, ironically provides the environmental problem of plastic pollution; plastic waste ends up in landfills and oceans. Biodegradable plastics have been advocated as the killer problem from this and they turn it into water, carbon dioxide and biomass by microorganisms. One can categorize biodegradable plastics into two: those that are biodegradable, and those which are bio-based, or both. With this, still there are those that are composed of compostable polymers. Aqueous biodegradable bioplastics are decomposed under the influence of bacterial activity which eventually leads to CO_2 and H_2O formation in aerobic degradation that takes place in presence of oxygen and CO_2

and CH_4 formation occurs in anaerobic degradation that happens in the absence of oxygen. Biomass-based synthesis leads to the production of bioplastics from bio-based bioplastics, where by way of examples are poly (3-hydroxybutyrate) (PHB), poly (ε-caprolactone) (PCL), and poly (butylene succinate) (PBS). Biodegradable plastics can be adopted in the packaging of food, in the utensils used during food service, in the bags used for shopping, in the fibers and nonwovens, as well as in agricultural applications.

2.1. Bioplastic

Bioplastics are the materials they are derived from the resources that are renewable and are ingredient like potato, corn and sugar released into atmosphere by all sorts of microbes (Karana, 2012) [21]. Bio-based bioplastics are someone got into starch, derived from renewable resources protein, and cellulose. The most known bio-based PLA is polylactic acid, which is totally derived from renewable sources. Bioplastics are ecofriendly materials made from renewable biological sources including plants, microorganisms and biological wastes. They have functional applications compatible to the petroleum based polymers and have great promise in food, medical, cosmetics, electrical engineering, automobiles, construction, agriculture, and gardening. Estimates show that the global bioplastics market will grow by $20 billion to accomplish (Jayakumar, Radoor, Siengchin, Shin, & Kim, 2023) [17].

2.2 Types of Bioplastic

The types of bioplastic as categorized as:

2.2.1 Starch-Based Bioplastic

Starches which can be sourced in great abundance, are biopolymers that are seeing growing levels of popularity because of their renewable and available sources, economic nature together with their biodegradable properties. Also, starch is being viewed as a good resource for the bio-based production of polymers. In other words, polylactic acid (PLA) is after starch-based plastics and is the subsequent one with 35% for the bioplastics production total (Agarwal, Singhal, Godiya, & Kumar, 2023) [2]. There are two types of polymers involved in its composition: alpha amylose and branched nature of amylopectin (Hernandez-Carmona, Morales-Matos, Lambis-Miranda, & Pasqualino, 2017) [15]. Another key quality of bioplastics is their elasticity due to linear amylose and the crosslinking provided by amylopectin- which is amylopectin with a branched structure that controls the tensile strength and elongation (Dang & Yoksan, 2015) [8].

2.2.2 PLA-Based Bioplastic

Polylactic acid is a so-called green polymer because of its origin from natural or renewable raw materials. The first and most popular PLA, which is a well-known thermoplastic, involves aliphatic polyester. PLA is non-cyclic, non-aromatic and from the lactic acid and lactase that formed by polymerizing the sugars which comes from various agricultural biomass sources (also known as PLA) (Helanto, Matikainen, Talja, & Rojas, 2019) [14]. Biopolymer polylactides are designed to make packing materials that would degraded under the three weeks' process in industrial composting facilities. PLA emerges as the first synthetic polymer ever derived from renewable materials from organic origin (Giordano, 2018). Polylactic acid has great advantages to be fabricated easily, biocompatible, biodegradable, non-toxic than others and above all has breathable thermal properties (Jiménez-Rosado *et al*., 2019) [18]. What polylactic acid degrades into are water, carbon dioxide and of organic matter, which are the nutrients plants use for photosynthesis. This consequently reduces greenhouse gas emissions, meaning better air quality as a whole. In addition, unlike the case with other complements, when oxygen is added to PLA there are no toxic intermediates and compounds. Polylactic acid is less emissive of the greenhouse gas compares with traditional synthetic polymers (Karamanlioglu, Preziosi, & Robson, 2017) [20]. The main sources of starch which can be used in the first step are as follows: the ingredients include primarily whole grain corn (maize), straw, tapioca (cassava), potatoes, and the other raw materials which, after the hydrolysis, are converted into mono- and disaccharides and which are of course used as food. The hydrolysis of starch was at first performed with the direct use of chemicals, however, nowadays the enzymatic methods go always hand in hand with the process. Nevertheless, quite a number of bacteria forms are inefficient for fermentation as maltose brings about the primary substance in the enzymatic hydrolysis.

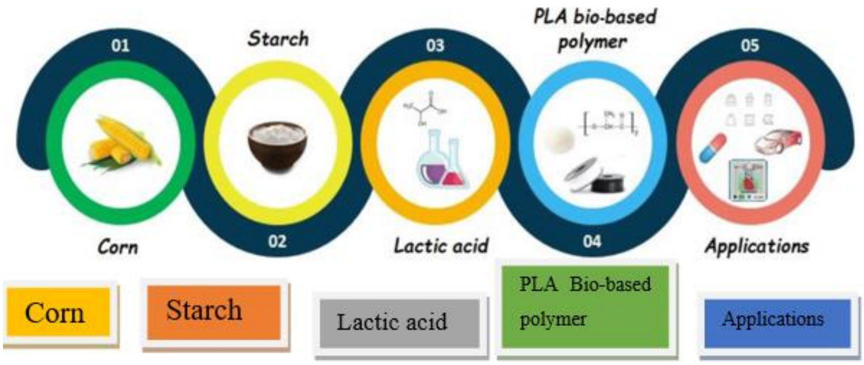

Fig 1: PLA to feedstock to final product.

2.2.3 PHAs-Based Bioplastic

Two types of microalgae synthesis polyhydroxyalkanoate, which is a biodegradable and biopolymer bioplastics (Geueke, 2014; Kim, Chang, & Kim, 2021) [11, 22]. Immediately after nutrients become limited, more and more diverse prokaryotic microorganisms start accumulating PHAs for carbon storage. In PHA, fatty acids with 3 hydroxyl acids engage in condensation reactions, yielding biopolymers (Mal, Satpati, Raghunathan, & Davoodbasha, 2022) [27]. With respect to the physical attributes, PHAs stands in relation to petro-chemical polymers, which enables its suitability as a replacement for the expanding global market of bioplastics. The bioplastic applications that exploit PHAs are few and this is partly because the expenses involved in these processes are costlier. Scientists are selected low cost as well as renewable sources that would be as good as PHA. Close to 90% of PHAs degraders also break down starch and catalyze the starch breakdown only using a variant of a similar biodegradation pathway (Imam *et al*., 1999) [16].

2.3 Implication of Bioplastic In Environment

The environmental advantages of bioplastic have been distinguished:

2.3.1 Reduction in Fossil Fuel Dependence

Starch-based plastics, by-products from agriculture and fermentation of microorganisms are sources of the renewable materials used to manufacture bioplastics. Considering that Bioplastics are generated from renewable resources, unlike those conventional plastics which are imported from the fossil fuels, all of us as individuals will use less non-renewable resources. For example, the biomass fermentation of corn starch using microorganism leads to the generation of polylactic acid (PLA).Although there are different injuries which is often generated through extraction and processing of the conventional fuel (petroleum), the utilization of renewable sources will reduce these damages (Kumar *et al*., 2023) [23].

2.3.2 Lowered emissions of greenhouse gases

Among various attributions of the emission of greenhouse gases and production of conventional plastic are of great concerns, The capability of bioplastics to capture CO2 during the growth of their source materials is usually related to being much more carbon neat than other plastics (Joo, 2024) [19]. For instance, growing plants to generate bioplastics will facilitate to reach carbon net-zero by locking in the carbon dioxide gas. The discharge of greenhouse gases for the production of bioplastics is substantially lesser compared to the production of conventional plastics like polyethylene.

2.3.3 Reduced accumulation of plastic wastes

The fact that bioplastics - one of the biggest benefits - can reduce the accumulation of plastic refuse in landfills and other waste streams is very appealing. In the scenarios of commercial composting facilities and soil environments, bioplastics are made that quite naturally breakdown. This characteristic empowers them to decay into organic materials faster, so they become less persistent and, consequently, plastic waste can be reduced. A biodegradable bioplastic that can degrade in a specific environment is polycarpic-lactone (PCL). In this case, PCL can break down either in the marine environment or in the soil (Kumar *et al*., 2023) [23]

2.3.4 Better end-of-life care management

Composting, anaerobic digestion, and recycling are, among others, very significant solutions at the end of life procedures implemented for bioplastic products. Green plastic performed as it is meant to be can be easily incorporated into the existing waste management system, based on eco-friendly disposal methods. Another well-known example is polyhydroxyalkanoates (PHAs), a kind of biodegradable bioplastics, which can be converted into biogas, a renewable energy source. The process is called anaerobic digestion, and is done biologically (Kumar *et al*., 2023) [23].

2.3.5 Preservation of marine ecosystems

Biodiversity would be better off if sustainable bioplastics are made use of. Traditional plastics sitting in the world's oceans already cause destruction of ecosystems and kills marine life. The biodegradable fibers called bioplastics could be creating an avenue through which the effects of plastic pollution could be biologically diminished in aquatic environment. One of the sample, PBS which is marine degradable plastics, has the potential to halt the degradation of marine plastics (Kumar *et al*., 2023) [23].

2.3.6 Eco-toxicological impact of Bioplastics biodegradation

The Eco-toxicological effect of bioplastic biodegradation is crucial study part of environment sustainability consideration. Bioplastics, along with being an alternative to the environmental polluter of conventional petrochemical plastics, could still have a few challenges such as being biodegradable and the type of impact on the ecosystem it could have. It is true that while some of the bioplastics will decompose efficiently, there are others types which may also not be fully biodegradable which can therefore contribute to the plastic pollution rates. It is discovered that the biodegradation of bioplastics finds the way to soil nutrient changes, and therefore might cause eutrophication or adversely influence the growth of plants. Secondly, the cytotoxicity, oxidative stress, baseline toxicity, and antiandrogencity of bioplastics that originate from natural sources have sparked concerns about the implications for the ecosystem (Ali, Isha, & Chang, 2023; Ammar, 2023) [3, 4].

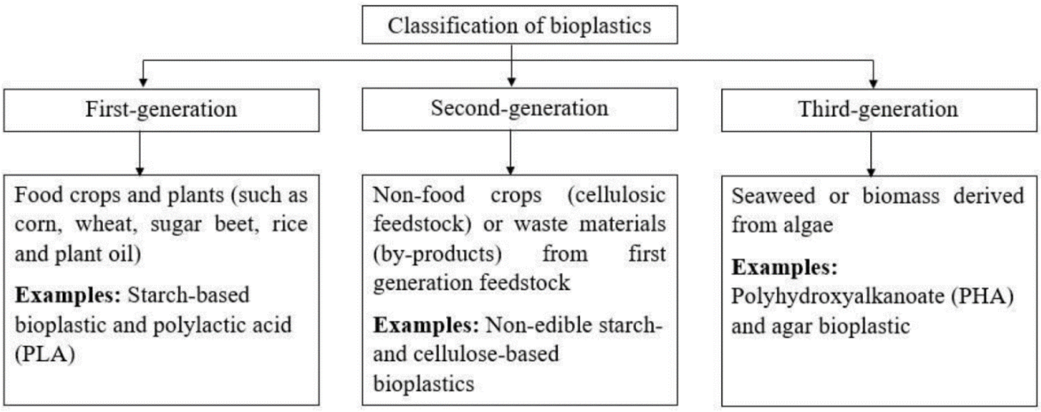

Fig 2: Classification of bioplastic based on sources (Tan *et al*., 2022).

2.4 Bioplastic production
The bio plastic industry has gone through a rapid growth and a major transformation. The global bioplastics and biopolymers market size is predicted to reach around 27.9 billion USD by the year 2025. Such as growth are prompted by growing interest in environmental problem and environment-friendly solution, in which starch-based bioplastic accounted for about 38% of the market in 2018. The world production capacity of bioplastics is estimated to grow from around 2.1 million metric tons in 2020 to 2027 where PLA will be the main contributor forecasting a larger revenue up to 16.3% from 2020 to 2027. Bio based and non-biodegradable plastic making up almost 36% (i.e. Biodegradable polymers, which are materials formed from natural products and arranged in such a way that they can be broken down completely into their basic components, are a good substitute for traditional plastics. Bios-base plastics, which emit 70 % less greenhouse gas than petrochemical versions, are one of the most important options.

2.5 Impact of bio-based plastic and end of life management of bio-based plastic
Plastics can biodegrade under specific conditions during which bio-based plastics can shrink plastic waste accumulation (Mierzwa-Hersztek, Gondek, & Kopeć, 2019) [28]. On the positive side, biodegradation can result in the emission of the greenhouse gases, methane and carbon dioxide (Yang *et al.*, 2019) [42]. Bio-based plastics also can pronounced to increase micro plastic burden in the water environment that in turn may threaten the habitats of aquatic ecosystems (Liu *et al.*, 2018) [25]. Bio plastics are able to be composted, recycled or incinerated afterwards for energy recovery (Abrha *et al.*, 2022) [1]. Nevertheless, one may point out to a need of standardized recycling system and adequate education of the consumers that prevent the proper disposal of bio-based plastics (Moshood *et al.*, 2021) [31]. Research efforts are continuously investing in reliable recycling techniques such as chemical recycling and natural biodegradation.

2.6 Turning food waste into Bio-degradation bioplastic
Unlike conventional plastics, biodegradable bioplastics can be produced from the food waste transforming them into a type of matter that bacteria know how to break down and the bioplastics gets made when that matter is utilized through one of the processes that turns it into a biodegradable material. This innovative approach involves the following steps: This innovative approach involves the following steps:

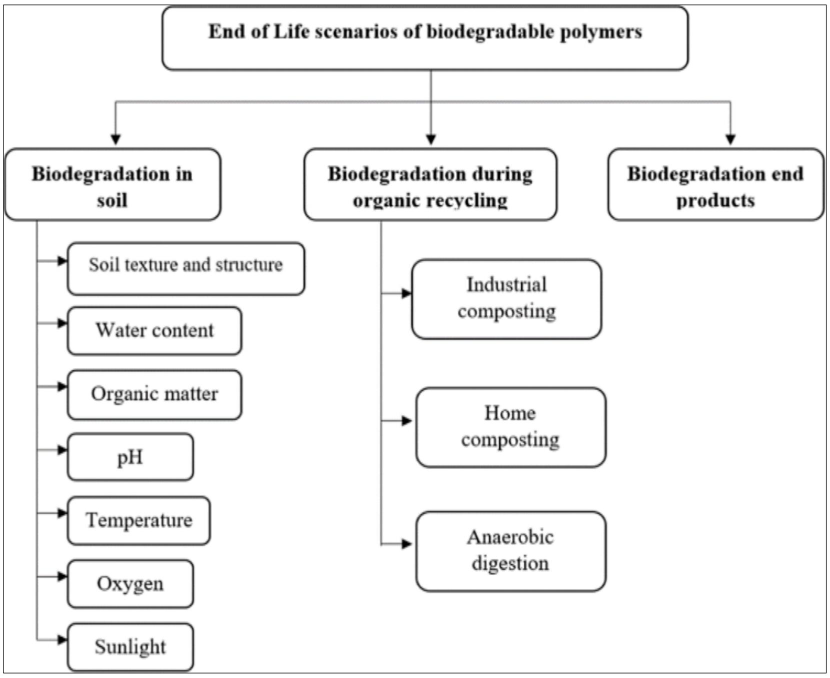

Fig 3: End-of-Life scenarios of Biodegradable Polymers (Samir, Ashour, Hakim, & Bassyouni, 2022) [39].

Microorganisms in food waste which are usually from sugars, starches and proteins are preserved for bioplastics. The bacteria in that case, feed on the organic matter in food waste and produce polyhydroxyalkanoates (PHAs), also known as bioplastic which is a non-toxic and environmentally friendly type of the polymer.

2.7 PHA Production
Bacteria produce PHAs which are isolated from the waste stream and further processed to forms of bioplastic that can be blown into different shapes, such as injection-molded food packaging, plastic bags, bottles, straws, food wrappers, and other appropriate packaging materials.

2.7.1 Industrial Transformation
Companies such as PepsiCo, Unilever, Proctor & Gamble and Cova have been the most active mostly via experimental programs which show their great future demand from the market. The transformation process which in no way gives rise to such kind of food wastes in landfills and instead supports in mitigation of greenhouse gas emissions as organic waste naturally decomposes.

2.8 Degradation Challenges of biodegradable plastic
The use of biodegradable plastics may not meet the expectation of findings as diverse environments like marine habitats and compost piles at home, may not have the same

level of degradation. As a result, it is possible that micro plastics will be getting accumulated which in turn can seem dangerous to the wildlife and the environment as well.

2.9 Toxicity Challenges of biodegradable plastic

Biodegradable plastics may break down quickly; however, their process can release toxic substances into the environment which may affect soil, water, and other animals. The toxicity of these chemicals differs according to the type of plastic and the environmental factors which may influence degradation.

2.10 Bioplastic innovation that might save the Environment

The biodegradable plastics serve as a highly probable solution to the environmental problems arising from the conventional plastics because they are made from the renewable sources, biodegradable, and also they emit carbon-dioxide in lower volumes compared to traditional plastics. Bio transition will help to implement bioplastics in several industries such as an automotive or packaging, as well as to eliminate plastic pollution in the oceans and landslides. Bioplastics may act as a driver to rural healthier economic systems and help in bringing more job opportunities too. Nonetheless, the transition to bioplastics from conventional plastics is limited by a couple of concerns. Consumption of bioplastics increase environmental burden, because they contain materials originated from land, which is already used for food production. To overcome this problem, there is a need to use safe and stable renewable feedstock's.

3. Raw Material Selection

Bio plastics utilize the variety of materials such as corn starch, sugarcane, soybean, and the cellulose which is extracted from the wood or agricultural waste. Corn starch, which is the most common feedstock for bioplastics in existent due to the fact it is high output and cost-effective compared to other starches, especially in those areas with large amounts of corn production. It consists of the primary component amylose and amylopectin, that can be easily hydrolyzed and further metabolized to form another sort of biopolymer, like PLA.

Sugarcane is another sugar-rich crop which is not only suitable but also competitive with crops that can be grown in tropical climates. The bio-PE, which is a type of polyethylene, made from organic ethanol from sugarcane's central parts, is now showing high promise, owing to its smaller carbon footprint than the traditional plastics. Soy bean oil can be converted into the material for production of bioplastics. Vegetable oils also contains the triglyceride compounds which can give rise to biodiesel by triglyceride transesterification. These fatty acids are left aside and can be converted to the biopolymer production. The features of soy-based biodegradable bioplastics are biodegradability and versatility in fields of usage.

Cellulose is the most ubiquitous natural polymer on the planet. It can be extracted from all kinds of lignocellulose biomass including wood, agricultural waste such as straw and maize cobs, and dedicated energy crops like switch grass and miscanthus. It is an exhaust cell pellet that has great ability as a bioplastic feedstock because of its renewal nature and natural biodegradability features. Cellulose-based bioplastics are strong mechanically and are suitable for film, fiber, or even structure processing.

Biopolymers can be made from polysaccharides (e.g. starch, cellulose, chitosan/chitin), proteins (e.g. casein, gluten), and other carbon sources with the help of feedstock or air (Nachwachsende, 2020) [32]. And currently, the method to produce bioplastic is the thermoplastic starch, which is made by enzymatic saccharification and microbial fermentation (Mojibayo & Samson, 2020) [29].

In spite of this, however, the stability of the starch-based bioplastics which have been plasticised and stored for a long time is also not immune to recrystallization followed by mechanical property degradation. This issue can be fixed by Nano-enhancing the starch-based bioplastics to obtain the nanocomposite bioplastics that can be used in the automobile industry, packaging materials and drug delivery, among others (Mose & Maranga, 2011) [30].

Synthetic biopolymer are a class of materials which are created artificially but have similar properties of the ones produced by plants as well as incorporating many functional advantages. They are most times synthesized and can be adapted to various uses by changing their chemical or biological formula. Some examples included PLA is a polymer that constitutes of renewable sources of corn starch or sugarcane, which are biodegradable as well. It holds various tasks such as packaging, textiles and medical devices as the main ones. PHA is a biodegrable polymer class process by microorganisms under some conditions. Such materials are considered green substitutes for conventionally produced kind which can lead to waste of resources and contamination. Peptide-based polymers is a class of polymers derived from the same sub build as proteins that are artificially composed of amino acids just like proteins. They can be created in any order as need stumbles and able to show those properties focused in mind just by having self-assembly or biocompatibility.

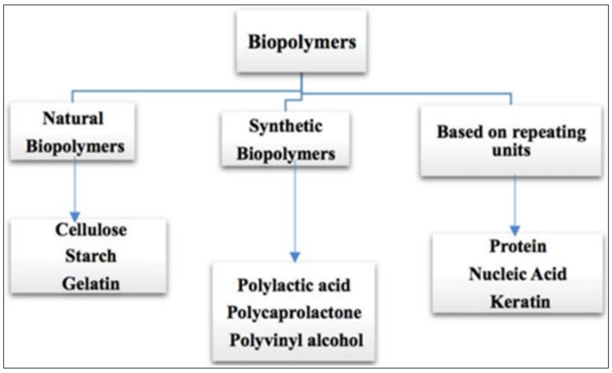

Fig 4: Classification of biopolymer based upon their origin (Baranwal, Barse, Fais, Delogu, & Kumar, 2022) [6].

Feedstock's of the first generation such as sugar cane, soybeans and corn, are very efficient when producing biopolymers, as they need less land and produce more yield than others. Of the technical maturity of these ingredients the level is very high it is though not free from food chain sources disconnection which creates ethical issues (Ferrari *et al*., 2022) [10].

The second generation of feed stocks covers non-edible crops, e.g., cellulose or bagasse which is an end product of sugarcane. The above mentioned materials are derived from both- edible and non-edible crops of the first-generation. Generated material, however, is ready for a large-scale application albeit the high expenses. The very last but one kind of feedstock is the 3rd generation feedstock which it can be classified the most innovative, as food leftovers, algal biomass, and industrial or municipal waste are its sources, therefore, it can cope with the problem of consuming sources of biomass from the food chain. Diversified research is in motion for the distinctive biopolymers production from disgusting fooastes (Esposito Corcione *et al*., 2020) [9].

3.1 Polymerization of Bio-Based Monomers

This method involves a combination of degradation and re-construction of a bio-based polymer chain formed from bio-based monomers derived from renewable resources such as plant sugars, vegetable oils, or microorganism fermentation products. The most widespread polymers are lactic acid (PLA) that comes from fermented sugars (e.g., sugarcane and corn starch), and polyhydroxyalkanoates (PHA) based on organic substrates (including waste materials).

3.2 Blending of Biopolymers with Additives

Above all, mixing biopolymers with fillers or other additives is a common method used to change and improve eco-friendly plastic options. This includes the addition of additives like plasticizers, fillers, rein forcers, e.g. fibers, stabilizers, and compatibilizers like additives to improve the mechanical properties, flexibility, thermal stability and processing properties of biopolymer matrices. Mixing achieves the process of distinct customization of bioplastics for different fields, including packaging, agriculture, lorries, and medical equipment.

3.3 Modification of Biopolymers

Biopolymers can be chemically or physically modified by being reacted with chemicals or stretched, twisted, etc. to give them the properties desired for a particular application. Chemical modification techniques fall into the category of grafting, cross-links, or copolymerizations to introduce functional groups or intensify the interactions in the polymers. Physical modification techniques are the means of blending of the polymers with other components in order to modify the crystallinity, molecular weight distribution or the affinity among the parts.

3.4 Innovative Techniques and Advancements

One of the emerging advanced bioplastic formulation features is the introduction of enzymes as the assisting catalysts and bio catalysis for the purpose of controlled polymerizing reaction which permits the designers to carry out precision operation on the polymer structure and properties. There is also a focus on using Nano technology to improve bioplastic performance by doing things like add nanoparticles (e.g. cellulose nanocrystals, clay nanoparticles) which are used to make bioplastic stronger in terms of mechanical strength, barrier properties and thermal stability. Innovative line-by-line solutions comprise bio-inspired polymer synthesis which is analogous to natural procedures, as well as the genetically engineered microorganisms which are in possession of more specified properties.

4. Bioplastic production process

Renewable biomass sources like corn starch, sugarcane or cellulose are preferred among others due to their abundance and the fact that such compounds have the potential to be used as a basis for the manufacture of bioplastics.

Biomass goes through various pretreatments such as conversion process to simpler sugars and breaking it down to simpler molecules; a sample may be the fermentation phase in order to get the best possible outcome. Promptness of this action is vital as it enhances the yield and efficiency of the general process. Rapid multiplication of these bacteria or yeast turn the biomass into bioethanol that can be used in automobiles. By using microorganisms to produce enzymes, the carbohydrate complexes are eventually changed into lactic acid, succinic acid, or 3-hydroxy bacteria.

5. Testing of Biodegradability of Materials

At the beginning tap examples of the material to analyze from among the sample represent intents in the full-scale scenario. In addition, for example, if the assessment to be performed is on a bioplastic meant for food packaging, the objects should be tested to yield a product of the same thickness, texture, and additives. Varying conditions of the scenarios which could be expected further lead to testing in different environments. Compute manifolds include soil, compost, marine settings, or lab environments that look like them. Samples are exposed to specific adjustable factors (such ones as temperature, humidity, and oxygen levels) which in turn ensure the simulation of actual decaying processes.

The whole monitoring process involves measuring multiple variables, which an indicator of degradation speed progression. There are several parameters to consider such as weight changes, visible destruction such as visible break-up of satellites, subsequently the chemical composition can be analyzed by techniques like spectrometry or chromatography and lastly assessing microbial activity through counts and genes. These measurements provide both quantitative and qualitative evidence related to the degree of degradation and the actual process of its happening.

Biodegradation effects are often ascertained within pre-specified time frames, from just several weeks to years of exposure. This duration will be dispersed according to the forecasted service life and how the waste is anticipated to be handled in the final disposal phase. The longer-term testing for degradation gives a more comprehensive understanding of the kinetic mechanism, and the possibility of long term Eco toxicological consequences. Data obtained during testing is tested thoroughly and qualitatively to measure biodegradation level and identify any bio-products of degradation. The use of discharge rate and scale invariance to Classical test theory can help in determining the rates of degradation and assessing the levels at which change is significant. Specific techniques like microscopy, spectroscopy, and chromatography that unravel the mechanisms of physical and chemical transformations that accompany biodegradation are used too.

By evaluating degradation capabilities, we compare the characteristics of our sample material with those of standard plastics or other biodegradable shreds. This comparison examines criteria like degradation factor, weight loss percentage, or formation of degradation byproducts.

6. Potential Applications

The potential applications are as follow:

1. **Packaging:** The use of bioplastics in packaging operations extends to production of bags, containers, and films. They can be dissolved completely without harmful leftovers under some circumstances, representing their main advantage. The feature is addressing such areas as single-use items where traditionally plastic packaging has a prominent indication. When making their packaging choices and purchasing decisions, businesses and consumers can decrease their environmental impact by opting for bioplastics which also digresses plastic waste generation in landfills and the ocean.
2. **Textiles:** Biodegrading plastics can be transformed into fibers competing with the generally used synthetic fibers based on polyester. The bioplastic fibers can be blended with other fibers, such as cotton or polyester, to achieve the desired textile characteristics required by the clothing, upholstery or any other textile application. With bioplastics integration into textiles manufacturers will be able to reduce their use of fossil fuel enrichment and mitigate the environmental consequences that are to be linked to traditional textile production techniques. Moreover, bioplastic textiles are comparable to traditional textiles in terms of their performance and aesthetic features but go a step further as one of the achievements in the more sustainable textile industry.
3. **Medical Devices:** Compatible with both flesh and blood bioplastics become very popular in the field of medicine and medical equipment's. These bioplastics are meant to work with body such that they, by and large, avoid adverse reactions or mechanistic complexities while inside the body. Furthermore, their biodegradability in the body itself lessens their need for repeated surgeries to remove implants; therefore, by considering both patient's safety and comfort, such devices are helping to enhance the delivery of such treatments. Bioplastics of medical devices take place in the forefront of the progress of the healthcare technology because manufacturing of them is characterized by sustainability and ecological awareness.
4. **Consumer Goods:** Consumable bioplastics already enter the market to the degree of cutlery, utensils and disposable tableware service. Such bioplastics alternatives are the perfect solution to sustainability problems associated with traditional plastic items and exist as an eco-friendly option. Herein directing the attention to pollution and depletion of resources. Bioplastic consumer goods are eco-friendly substitutes to their conventional counterparts with similar convenience of use and biodegradable or compostable properties that help to dispose them at the end of their life-cycle wisely. Such type of consumer products which promote sustainable practice are bioplastics. They increase their chances of joining the circle of recyclables and becoming a part of the transition towards circular economy.

7. Limitation and Advantages compared to conventional plastic

The advantages compared to conventional plastics are:

Biodegradable Plastics tend to disintegrate into their raw materials at a much faster pace than the regular plastics which remain in the environment for several hundred years or more. That feature helps to reduce the risk of that ecosystem being destroyed by long-term pollution or hurting wildlife. A lot are biodegradable plastics contain the renewable sources such as corn starch, sugar cake, or cellulose. Fossil fuels are endlessly consumable. So, ultimately, biodegradable plastics become better for environment. Biodegradable plastics might be a solution to this problem because they inhabit more space in landfills than regular ones and they threaten the marine life. They also facilitate the process of putting waste to a good use for the purpose of producing compost which is soil amendments' substitutes. Rising environmental knowledge gives the consumers empowerment and motor for demand for green products. Biodegradable plastics are now out on the market to fulfill the rising consumers' expectations and can be utilized as an eco-friendly alternative.

8. Future Directions

Future development in bioplastics industry will work on different fronts, such as sustainability enhancement and circles economy implementation. Here are some suggestions:

8.1 Exploration of Novel Feedstock's

Comparing various nonfood-base feedstock's such as waste byproducts or faecal sludge can supplant competition for food sources and diminish the environmental impact. Algae, bacteria, and dead (non-living) material streams are some of the most likely places for bioplastics precursors.

8.2 Optimization of Production Processes

Efficient bioplastic production methods, which are underscored by minimized power use and generation of very little waste, are what needs to be focused on. Techniques invention like fermentation, enzymatic catalysis, and metabolic engineering can be redesigned to make the production maximum while reducing the cost within manufacturing procedures.

8.3 Biodegradation Studies

Identification of the further conversion pathways of bioplastics in various environments is crucial for evaluation of the total ecological effect of the materials and the creation of such products having the extended life cycles. Recherché on micro hydras capable of effectively destroying bioplastics can be exploited in the design of biodegradables that have better performance and biocompatibility.

8.4 Life Cycle Assessment (LCA)

Performing truly elaborated life cycle assessments on the production of bioplastic from taking it from the cradle to the grave is vital for addressing the considerations into decision making and for reaching sustainability. Monitoring should factor in consumption of resources and GHG emissions, together with potentially undesirable effects on the ecosystems to give a view of the full impact, both negative or positive.

Conclusion and Recommendations

Bioplastics, are not only an alternative but they also join the fight towards environmental issues that are being addressed by traditional plastics. Bioplastics are a bit different from the traditional plastics which are produced using fossil fuels. Rather, they are made from renewable resources like plants, algae or even waste items. Resource depletion is cut thereby while emissions due to production process decreases too. Therefore, bioplastics also possess the capacity to decompose quickly and thus lower the drawbacks on the ecosystems, particularly on marine organisms. The bioplastics adoption can actively bring the circular approach to production into being and clean the plastic waste so as to form healthy and sustainable future environment for our coming generations. Materials commonly used in bioplastic production include: Similar to PET (Polyethylene terephthalate) or PE (Polyethylene), PLA is one of the widely employed family of bioplastics. Firstly, PHA bioplastics are manufacturers by bacterial fermentation of sugars or lipids. Through the use of these raw materials bioplastic manufacture is directed at decreasing the dependence on the fossil fuels, minimizing the nurturing of the environment and promoting sustainable approach to manufacture. The research of biodegradability is mostly carried out in conditions of the laboratory by conducting experiments that measure the rate and size of the degradation of the bioplastic materials with the use of different environmental conditions. Over a determined time period periodic assays for mass, mechanical strength, and chemical composition of bioplastic samples are undertaken to detect any changes. Results might be subject to fluctuations because of factors such as composition and substitution of polymers, admixtures, environmental conditions and microbial activity. In the end, like assessing biodegradability, the environmental sustainability of bioplastic material is actually estimated, and then it can be used as a hint for developing eco-friendlier options that can substitute for classic plastic material.

Further study

Further study on bioplastic colud investigate several key areas. Research should focus on developing sustainable production methods of bioplastic. There is also need of enhanced biodegradation mechanisms that can help to reduce environmental impact. Further exploration of policy frameworks can support to promote sustainable bioplastic use. Scalable production techniques are important for making bioplastics commercially practicable.

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