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(Review Article)

Journey from plastic to bioplastic

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Abstract

In the present era, overuse of plastics has increased alarmingly because of advantages like their less dense nature, transparency, toughness to withstand weight, low cost, ease of production, and impermeability to fluids. But, due to their non-biodegradable nature, they are causing severe environmental pollution, such as the emission of greenhouse gases that lead to global warming and pose a threat to humans, animals living in terrestrial as well as aquatic habitats. In this article, we are focusing on the journey of bioplastic from plastics, where bioplastics have wide benefits over conventional plastics due to their biodegradable nature, less toxic effects, and ease of production from natural sources.

Keywords: Bioplastics; Conventional Plastics; Environmental Sustainability; Starch-Based Bioplastics; Solvent Casting; Compression Molding

1. Introduction

Plastics are made of a wide range of synthetic or semisynthetic organic molecules, which are essentially derivatives of petrochemicals [1]. The word "plastic" comes from the Greek word "plastikos," which means "able to change into different shapes" [2]. In 1846, Christian Schonbein, a German chemist, discovered plastic. Coal, natural gas, and crude oil are examples of fossil fuels that contain hydrogen and carbon compounds that serve as building blocks for long polymer molecules. These molecules are joined to form long carbon chains known as polymers. Plastics are utilized extensively in many different applications, including carry bags, drink bottles, toys, food packaging, electronic equipment parts, containers, furniture, etc [3]. Due to their molecular structure, molecular weight, and the physical and chemical makeup of polymers, which enable plastics to resist a wide range of temperatures, solvents, heat, and other conditions, as well as their convenience for packaging, the demand for plastic products is rising [4]. Plastics' widespread use and ease of access have resulted in concerning risks such as their non-biodegradability, the creation of dangerous compounds when disposed of in landfills, and a decline in drinking water quality [5], Large amounts of greenhouse gases are released during the burning of land-filled plastic waste, which damages the human reproductive system and causes genital deformities in people [6]. Development of biodegradable plastics is the most effective means of reducing plastic waste [7]. Therefore, plant-based extracts have been used to create environmentally beneficial techniques for a variety of uses [8].

2. Bioplastics

In contrast to conventional plastics, which are manufactured from petroleum chemicals, bioplastics are renewable, environmentally benign polymers or monomers that can be utilized to create materials with similar qualities [9]. Because they are inexpensive, plentiful, easily accessible, and form continuous matrices, sources such as potato, rice, maize, etc., are used to create bioplastics [10]. Bioplastic comprises a broad class of polymers. They are growing due to new inventions and efforts to enhance existing attributes. Some of its varieties are

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- Starch-based - basic bioplastics made from corn starch
- Cellulose-based - made using cellulose derivatives and cellulose esters
- Protein-based - made of proteins, including milk, casein, and wheat gluten.
- Aliphatic polyesters - such as polylactic acid (PLA), polyhydroxy valerate (PHV), and polyhydroxy hexanoate (PHH), are biobased polyesters.
- Organic polyethylene - produced by fermenting unprocessed crops like corn and sugar cane [11]

2.1. Advantages of bioplastics over conventional plastics

Bioplastics are eco-friendly. Traditional plastics are made from petroleum. It is detrimental to the environment to acquire and use materials derived from oil to make plastics. Bioplastics typically come from renewable resources, which lessens environmental pollution [12]. Bioplastics are biodegradable. In contrast to how traditional plastics pollute the environment, bioplastics are quickly broken down by bacteria into end products, including water, carbon dioxide, methane, biomass, and inorganic chemicals in a matter of days. It takes a few years for some bioplastics to fully decompose because they are robust [13]. Bioplastics are compostable. Under regulated circumstances, bacteria in a lab, business, or household composting facility can decompose bioplastics. One type of bioplastic that is biodegradable and utilized in single-use packaging is Parable, PLA [14]. Bioplastics are recyclable with mechanical recycling [15]. Bioplastics are burned, which causes a sluggish rate of biodegradation. This has less of an impact on the environment than burning traditional plastics [15]. The monomer of bioplastics can be recovered. After the PLA products' life, PARABLE, PLA can be utilized to recover 99% of the lactic acid [16]. The bioplastics economy offers more job prospects [16]. There is a decreased dependence on fossil fuels with the use of bioplastics. As oil is becoming extinct, the production of plastics must look for alternate renewable plant sources [13, 17].

2.2. What are bioplastics made from, and their comparison to conventional plastics?

The majority of conventional plastics are made of petrochemicals, which have several drawbacks, including pollution, non-biodegradability, and exhaustibility [18]. Conventional plastics that are frequently used include polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), and polyurethane (PU) [19]. A more sustainable substitute for traditional plastics, bioplastics have gained popularity as awareness of the environmental issues they cause has grown. Petroleum is one of the primary non-renewable resources used to make traditional polymers. These materials, sometimes referred to as polymers derived from fossil fuels, are incredibly resilient and long-lasting. However, because of the exploitation of resources and the resulting greenhouse gas emissions, their manufacture has a substantial negative environmental impact. There are two types of bioplastics: those derived from fossil fuels and those derived from renewable resources. These materials can be made from sugar cane, sugar beet, biomass, and starch. The manufacturing of bioplastics from renewable resources lessens reliance on fossil fuels and lowers greenhouse gas emissions [20].

The following are some sources of bioplastics. Food scraps are a source of bioplastics. An estimated 1.3 billion meals of food are wasted annually, which leads to unfavourable outcomes like water and environmental damage, greenhouse gas emissions, and conflicts. As a result, current research aims to create bioplastic from food waste. Bioplastics are made from food waste that has been valued. Waste materials such as potato peels, tomato waste, carrot waste, tea leaves, and spinach waste are utilized as a substrate for microbial fermentation, which leads to the subsequent extraction of biopolymers. Animals, plants, and vegetables were all renewable resources that could be readily used to extract the proteins and polysaccharides needed to make polymers. Polymers, including starch, gluten, soy, cellulose, pectin, albumin, and others, can be produced by them. Additionally, under specific conditions, microorganisms (such as fungi, bacteria, E. coli, and microalgae) are cultivated to provide bioplastics such as polylactic acid and polyhydroxyalkanoates [18, 21].

2.3. Formation of conventional plastics and bioplastics

Traditional plastics are made of bio-derived monomers like polylactides and polylactic acid, as well as synthetic monomers such as petrochemical products like polycaprolactones and polyesteramide [22] [Figure 1]. Agro-polymers, which include proteins, lipids, polysaccharides, and polyhydroxyalkanoates, are biomass products that are used to make bioplastics [23] [Figure 2].

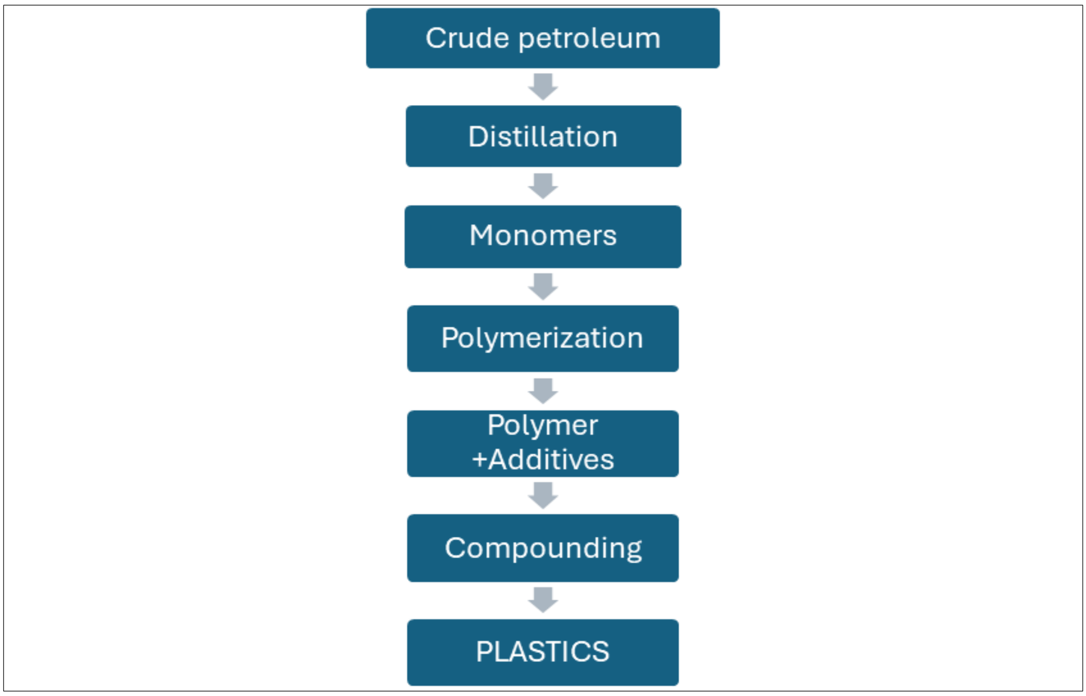

Figure 1 Formation of conventional plastics

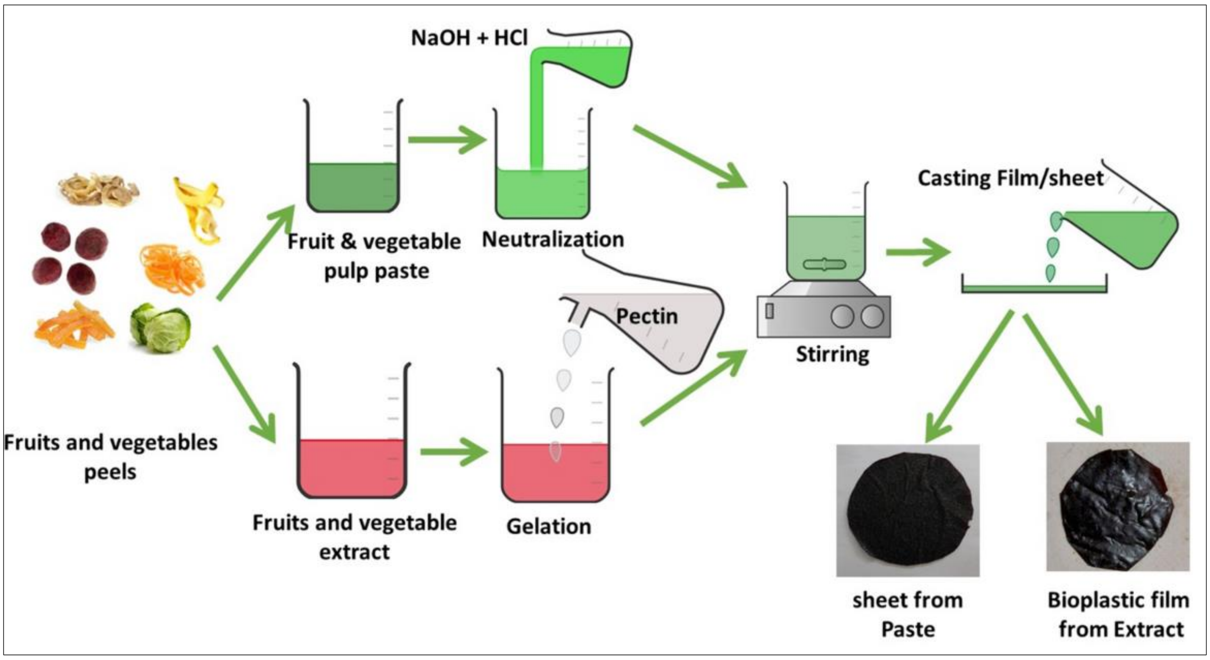

Figure 2 Formation of bioplastics

2.4. Production of bioplastics

Solvent casting: For creating composite films, the solvent casting process is a commonly used technique. For the prepared film-forming solution to have the appropriate dispersion and homogeneity, the polymer composites and nanomaterials must be vigorously stirred or ultrasonically sonicated in water or an organic solvent. The film-forming solution can then be poured onto the glass sheets or petri plates. The plates containing the solution are dried in a hot air oven for a minimum of 12 to 24 hours, depending on the components of the solution. Thin layers of composite materials made up of nanomaterials and a polymer matrix are what remain when the solvent evaporates (Figure 3) [24]. Solvent casting is a low-cost method of creating films with optimal optical purity, homogeneous thickness distribution, and minimal haze [25].

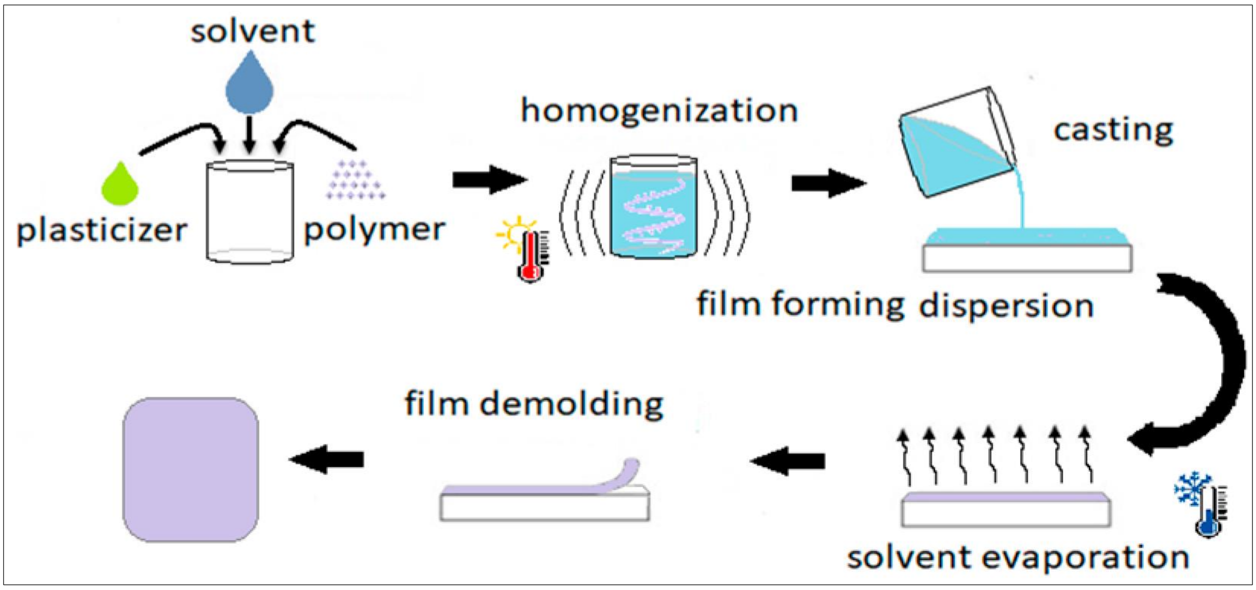

Figure 3 Solvent casting

Compression molding: One manufacturing technique for creating composite materials is compression molding. This process involves inserting a heated material into an open heated mold cavity, sealing the mold with a top plug, and applying consistent pressure to compress the material such that the polymer contacts every part of the mold. After that, the molding material is taken out of the system after curing at a specific temperature and pressure (Figure 4) [26].

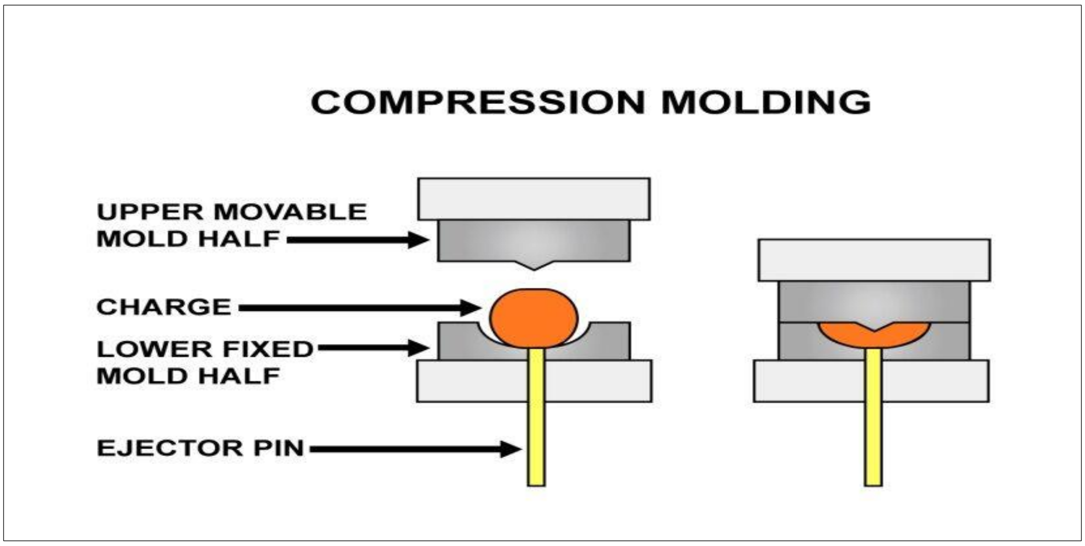

Figure 4 Compression molding

2.5. Market share of bioplastics

Until recently, the public was unaware of the significance of bioplastics. This had an impact on the market for bioplastics' supply and demand. According to earlier statistics, bioplastics only made up around 1% of the market for plastics overall. According to 2017 research, the bioplastics business is expanding steadily. While the production of conventional plastics grew at a pace of just 4–9% yearly, that of bioplastics increased to 2.05 million tons in 2017 and is predicted to reach 2.44 million tons in 2022 at a growth rate of 20–25% annually. The high cost of production is one barrier to bioplastics, although this might be reduced with government incentives and innovations. Petroleum prices may also have the power to influence the market in one of two ways [27].

2.6. Comparing the properties of bioplastics and conventional plastics

While conventional and bioplastics have different effects on the environment and living things, they should ideally provide customers with the same uses or advantages.

According to this, bioplastics are generally thought to be less detrimental to the environment than traditional plastics. The following are some characteristics that set plastics apart. Most plastics that are made wind up in landfills. What is most concerning, though, is that traditional plastics are not easily broken down by microorganisms.

The microbes that break down bioplastics include bacteria, fungi, and algae, producing byproducts including CO_2, methane, and H_2O biomass. Biodegradable bioplastics that are widely accessible include thermoplastic starch (TPS), polyhydroxyalkanoate (PHA), PLA, and starch blends. Therefore, bioplastics aim to reduce plastic pollution from solid waste [22]. Fossil fuels are used to make traditional polymers. Every stage of the plastics lifecycle is described there, along with the pollution (emission) implications. Since most bioplastics are derived from plants, they lower greenhouse gas emissions. Moreover, bioplastics require less energy to produce than traditional plastics. However, because bioplastics consume a lot of chemicals and fertilizers in agriculture, they lead to high levels of eutrophication and acidification (Figure 5) [28].

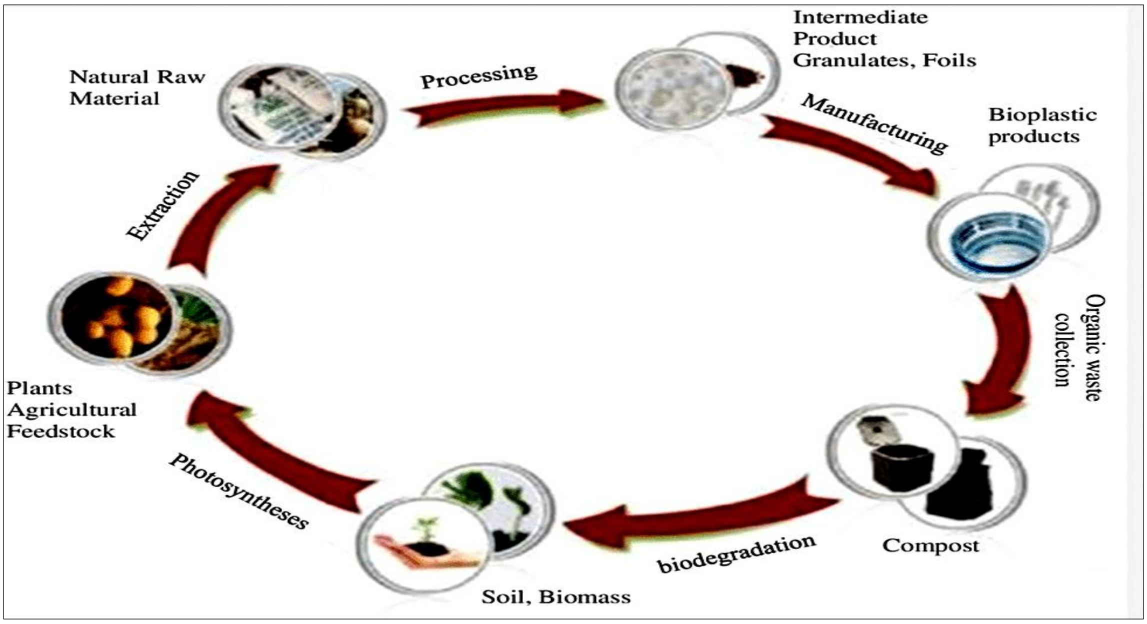

Figure 5 Lifecycle of bioplastics

2.7. Applications of biopolymers

Biopolymers can be utilized to enhance the performance of other biologically active compounds in a product since they are biocompatible and biodegradable. Additionally, they can be altered to accommodate a number of possible uses, such as the following:

Synthesis of nanomaterials: The study of nanoparticles, including their synthesis, characterization, and uses, is known as nanotechnology. Currently, scientists are working to create more environmentally friendly methods for creating nanoparticles. The synthesis protocol now primarily focuses on "green" chemistry and bioprocesses rather than physical and chemical processes. Because of their quantum size effects, metal nanoparticles have several unique characteristics. However, the majority of their synthesis procedure poses a serious environmental risk [29]. The reducing agents employed in typical synthetic processes, such as organic solvents and toxic-reducing agents like sodium borohydride, hydrazine, and N-dimethylformamide, are thought to be extremely harmful to the environment [30]. These substances are all extremely reactive and could be harmful to the environment and human health. The development of green chemistry methodologies is desirable due to the growing interest in waste minimization/elimination and the adoption of sustainable procedures. The manufacture of different nanoparticles has made considerable use of biopolymers as reducing and capping agents. When creating diverse nanoparticles, biopolymers such as chitosan, heparin, soluble starch, cellulose, gelatin, PVA, PVP, and others can be utilized in place of a variety of hazardous substances. [31-33].

Biomedical applications: Because of their biological uses in tissue engineering, medication delivery, and medical devices, biopolymer materials have garnered a lot of attention recently. Gelatin is a typical biopolymer that has been used extensively in medicine as an adhesive, for wound dressings, and other applications. Solvents or gasses, which are simple porogens, were used to create porous gelatin scaffolds and films. These scaffolds allow the delivery of drugs or nutrients to the wound for healing. Scaffolds made of electrospun polylactic acid (PLA) have found widespread use in biomedical engineering, including drug delivery and tissue engineering systems [34 - 36]. Additionally, electrospun nanofibers containing MWCNT that have a high surface area-to-volume ratio and porous properties have demonstrated potential uses in a variety of tissue engineering applications [37, 38]. Although proteins, polysaccharides, and synthetic biopolymers are the preferred sources of biomaterials, they do not have the mechanical qualities or stability in aquatic settings required for medicinal applications. Although most cross-linkers either result in cytotoxicity or unfavourable alterations to the biopolymers' functionality, cross-linking enhances the qualities of the biomaterials. Contradictory opinions regarding the cytotoxicity of glutaraldehyde-cross-linked materials have been expressed, and glutaraldehyde, the most common cross-linking agent, is challenging to work with [39].

Food industry: Using biobased films and containers instead of oil-based packaging materials could provide improved technical qualities in addition to a competitive edge because of their more environmentally friendly and sustainable image. Food coatings, food packaging materials, and encapsulation matrices for functional foods are currently made with biopolymers. Along with lowering the overall carbon footprint associated with food packaging, they provide innovative solutions to extend product shelf life. The three primary areas of food-related applications where these biobased materials are especially helpful are food packaging, food coating, edible food films, and encapsulation. Thermoplastics and some biodegradable polyesters are the most commercially viable materials for food packaging.

Industry: Textiles- The textile industry is one of the largest contributors to pollution due to synthetic fibers like polyester and nylon. Biopolymers are being used to create sustainable fibers, coatings, and textile materials.

Electronics- The electronics industry generates massive e-waste, and biopolymers help develop biodegradable components to reduce environmental impact.

Cosmetics- The cosmetics industry relies heavily on packaging, stabilizers, and formulations, and biopolymers play a crucial role in making beauty products sustainable.

Food packaging- The food packaging industry is a major consumer of plastics, and biopolymers provide biodegradable and compostable solutions.

Health and pharmaceuticals: Biopolymers provide sustainable and innovative solutions in the health and pharmaceutical industries. Their adaptability makes them invaluable for UV protection, controlled drug delivery, bone regeneration, and medical implants, contributing to improved patient outcomes and reduced environmental impact [40].

Agriculture: Because biopolymer-based agricultural products improve soil health, increase crop production, and reduce plastic pollution, they play a major role in sustainable farming. A greener and more sustainable agricultural industry is ensured by biopolymer-based fertilizer bags, mulching films, and agricultural nets that offer environmentally suitable substitutes for conventional plastics [41- 43].

Architecture and construction Industry: Mechanical strength of bioplastics could be enhanced through the addition of reinforcing materials, which enable the application of reinforced bioplastics in the industry. Bioplastics reinforced with different structural materials provide benefits, such as being water resistant, being lightweight, having high stability in load resistant, having a low cost, having durability, and having ease of processing as construction materials in the industry [44, 45]. Reinforced bioplastics are commercially available to be used as stabilizers for earthen construction materials, which previously used cement, and reinforced bioplastics can improve strength, durability, recyclability, and water resistance [45].

3. Conclusion

The replacement of plastic with bioplastic is a better alternative to the environment that imparts beneficial effects on humans and animals that live in terrestrial and aquatic habitats, and protects the environment by preventing the emission of hazardous greenhouse gases, which leads to increased global warming. There are wide applications of bioplastics in packaging, crockery, and cutlery. Expecting an increase in the bioplastic industries in the coming years to protect our Mother Earth with healthier lives.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest.

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