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Bioplastics – An Eco-Friendly Alternative to Petrochemical Plastics

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Abstract

Plastics have varied application and have become an essential part of our daily lives. The use of the plastics has increased twenty-fold in the past half-century and is expected to double again in the next 20 years. As a global estimate, around 330 million tonnes of the plastics are produced per annum. The production, use, and disposal of the plastics emerged as a persistent and potential environmental nuisance. The improper disposal of the plastics ends up in our environment, resulting in the deaths of millions of animals annually and the reduction in fertility status of the soil. The bioplastics products are manufactured to be biodegradable with similar functionality to that of conventional plastics, which has the potential to reduce the dependence on petrochemicals based plastics and related environmental problems. The expansion and development of the bioplastics and their products would lead to an increase in the sustainability of environment and reduction in the emission of greenhouse gases. The bioplastics innovation would be a key to a long-term solution for plastic pollution. However, a widespread public awareness is essential in effecting longer-term change against plastic pollution.

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Introduction

Plastics are used in varied applications and have become an integral part of our society. The global cumulative production of plastics for the past 13 years is half the plastics produced from 1950 onwards.[1] The global plastic production is also expected to increase in the future. The increasing rate of global plastic consumption for the next 20 years is anticipated to reach the production levels of more than 600 metric tonnes.[2] It is an undeniable reality that our mother earth is fully surrounded by overwhelming amounts of plastic wastes. Despite the fact that it has been an issue as long as the plastic has been an integral part of our society, the

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concept of plastic pollution is arising among the peoples across the world. Today's conventional plastics are produced from the petrochemicals such as polyethylene, polyvinyl chloride and polystyrene, and the production of such plastics accountable to consume more fossil fuels and thereby emit more amounts of greenhouse gases. The conventional petrochemical plastics are persistent in the environment and thus the production and disposal of these plastics would become a major problem in many metropolitan cities throughout the world.[3] Improper disposal of these hazardous plastic wastes is a significant source of environmental pollution and it will be harmful to the lives.[4] The conventional plastic wastes would prevent the penetration and dissipation of water and air into the earth and thus the reduction in the soil fertility, inhibition of other organic wastes degradation and hazard to animal life. In the marine environment, disposal of the plastic wastes would cause the choking and entanglement to marine mammals.[5,6] The conventional plastics have also a costly impact on waste management. Burning of plastics can also emit toxic chemicals such as dioxins.[7] Nowadays, several kinds of plastics are being used for several purposes and recycling of that plastic wastes also carried out by different processes and hence the collection and recycling of plastic wastes are also more difficult. Understanding this precarious situation, the several nations across world commemorated World Environment Day 2018 with a theme of "Beat Plastic Pollution". The newly imposed environmental regulations, societal concerns, and growing environmental awareness have triggered the search for new products that are compatible with the environment. Under these circumstances, replacement of the non-degradable petrochemical plastics by biodegradable and/or renewable resource-based plastics is of major interest for both to decision-makers and the plastic industry. In this context, creation of public awareness about bioplastics is an enviable goal. Therefore, this paper traces the different types of bioplastics and provides an overview of its development and waste management. This paper also makes out a case for an accelerated shift from traditional petrochemical plastics to bioplastics.

Bioplastics

The bioplastics are biodegradable plastics and/or bio-based origin of plastics, which are derived from plant and/or microorganisms, instead of fossil fuels. Similar to conventional plastics, the bioplastics also can be used in several ways under ordinary conditions. The only difference is that the bioplastics are biodegradable or biobased polymers. Both the biodegradable and biobased plastics incorporate the phrase "bio", but they are different from each other. The biodegradable plastics are made of either natural or fossil sources, and are biodegradable or mineralizable into water and carbon dioxide by the action of microorganisms, in a reasonable period of time. The term "Biodegradability" is defined as the characteristics of the material that can be microbiologically degraded to the final products of carbon dioxide and water, and therefore is unlikely to persist in the environment. The biodegradable plastics are defined as materials whose physical and chemical properties undergo deterioration and completely degrade when exposed to microorganisms, into carbon dioxide as in aerobic processes, methane as in anaerobic processes with a specific time limit.[8,9,10] The time required to decompose completely depends on the material, environmental conditions such as temperature and moisture, and location of decomposition. Compostable plastics are a group of plastics that can be degraded by microbes into humus, with an absence of toxic metals. The compostable polymers should be in accordance with the defined standards. There are three international standards *viz.*, EN 13432:2000, ISO 17088:2012 and ASTM D6400-12 outlined the criterion of compostable polymers. Under European standard EN 13432:2000, at least 90% of the compostable polymers must be converted into carbon dioxide in industrial composting plants within 6 months period. Furthermore, particles have to be disintegrated into residues with dimensions below 2 mm during this period.[11] Not all biodegradable plastics are compostable. The other group of bioplastics, biobased plastics are produced from a wide range of plant-based raw materials, which are not necessarily biodegradable. In general, the bioplastics are produced from the natural polymers occurring in microorganisms, plants, and animals, etc. Further, monomers like sugar, disaccharides and fatty acids are also used as the basic raw materials in the production of bioplastics, where the renewable resources are modified and processed into biobased plastics.[12]

Therefore, the bioplastics are produced by biological systems *viz*., microorganisms, plants, and animals or chemically synthesized from biological starting materials like starch, cellulose and lactic acid. The large-scale production and utilization of the bioplastics would preserve the non-renewable fossil fuel resources and the related environmental problems. Moreover, it would offer advantages such as a reduction in carbon footprint and additional waste management options through chemical and organic recycling.[13] The global plastic pollution problems would be solved through biodegradability.[14] In general, the bioplastics are compostable and hence it would be applied to the soil without any harmful effects, where the bioplastics will degrade and decompose easily. Unfortunately, some types of bioplastics may leave toxic residues as plastic fragments behind in soil, for example, some group of bioplastics will be degraded only at high temperatures in a specialized composter. The indiscriminate disposal of the biodegradable plastics in the ocean may cause the death of several marine organisms,[15] because the marine environment would not offer a suitable environment for the degradation. However, the implementations of collection, sorting and recycling practices effectively would offer the benefit of improved resource recovery during the disposal of bioplastics. Moreover, the products of bioplastics exhibit higher mechanical strength and thermal stability which are very similar to conventional virgin plastics. The bioplastics are also available in many grades with a wide variety of properties.[16] In general, products of bioplastics are used as carry bags, super-absorbent for diapers, and wastewater treatment, various packaging applications, medical and dental implants, catering and hygiene products, and mulching in agriculture.[17] Even though the bioplastics are a viable alternative to conventional plastics, they are not cost-effective[18] and hence the potential of the bioplastics have not been yet realized. However, the growing interest in sustainable development, desire to reduce dependence on fossil fuels and changing policies and attitudes in waste management are improved the utility and availability of bioplastics.[19] Further, the behavior and awareness among the consumers and research institutions are also escalating the commercialization of new applications for bioplastics in worldwide.[20]

Advantages and Disadvantages of Bioplastics

Advantages

The environmental problems arising due to improper disposal of the plastic wastes would be solved through the bioplastics. The main advantage of bioplastic products is that they are produced from renewable resources rather than fossil resources.[21] The usage of renewable resources would contribute to a reduction of greenhouse gases emission through the reduced carbon footprint.[12,22] Compared to petrochemical plastics, the bioplastics production can emit about 80% less carbon dioxide.[23] The production of bioplastics also consumes 65% less energy than the production of petrochemical plastics.[24] After any possible reuse and recycling options, the renewable biomass of bioplastics would be recycled and utilized for energy recovery through cascades recycling[25] and thus it offers the advantage of the improved resource recovery. Further, the bioplastics can avoid some of the environmental problems like uncontrolled dumping on land and disposal at sea, and the related emission of toxic substances. However, effective implementations of collection, sorting and recycling practices and public awareness are also essential to reward the benefits of bioplastics.

Disadvantages

It is an undeniable reality that the bioplastics are offering many significant advantages over petrochemical plastics. However, they are also having a number of disadvantages that need to be taken into account. Uncontrolled and improper disposal of the bioplastic wastes also contributing to the problems like littering and, soil and water pollution. Similar to conventional plastics, the bioplastic wastes littering also harmful to wildlife. The disposal of bioplastic wastes into a landfill may contribute to the greenhouse gases emission. The higher manufacturing cost of bioplastics is also limiting the use of these plastics. At last, the cultivation of crops for manufacturing bioplastics can create competition on cultivable land for food production.[25]

Types of Bioplastics

The bioplastics are a group of products each varied with its properties, and the applications also varied with the raw materials and manufacturing processes involved in the bioplastics products. Currently, the bioplastics are coming under the following categories.

Starch Based Bioplastics

The first bioplastic was invented with maize starch substituted plastics and sold under names such as EverCorn™ and NatureWorks. These plastics were manufactured by the blending of petrochemical plastic polymer with biodegradable starch polymeric compounds.[26] Currently, the starch-based polymer can be produced from potato, corn, wheat, tapioca.[10] During the disposal of this bioplastics, the starch molecules occurring in the polymer will be degraded by the microorganisms and thereby the plastic polymer will be disintegrated. However, the physical and chemical properties of this starch substituted bioplastics are not suitable for practical usage. Further, the accumulation of non-degradable plastic residue in soil and water may cause environmental pollution. This type of bioplastics manufactured directly from the starch, which will affect the stability of the products during the exposure to moisture.[27,28] Further, these bioplastics also produced from the starch through the microbial fermentation processes. For example, the bioplastics such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA) are producing through the process of microbial fermentation of starch.[21] Moreover, the starch and other carbohydrates are acts as the raw materials for the manufacturing of new generation bioplastics such as the biobased polyolefins polyethylene (PE) and polyvinyl chloride (PVC), and the partially biobased polyethylene terephthalate (PET).

Cellulose Based Bioplastics

Cellulose is a polymer of glucose in which the glucose units are linked by β-1,4-glucosidic bonds.[29] The cellulose is found in the cell wall of all major plants and green algae and in the membranes of most fungi. In general, the cellulosic polymers are produced by the extraction or chemical modification of natural cellulose. The most predominant source of cellulosic plastic is cotton fibres and wood pulp. The organic cellulose esters and regenerated cellulose are the two types of cellulosic plastics. Currently, around 20% of the global total chemical grade pulp is utilized for the production of organic cellulose esters.[30] The organic cellulose esters are produced through the process of esterification of cellulose with organic acids. The industrially important organic cellulose esters are cellulose acetate (CA), cellulose acetate propionate (CAP) and cellulose acetate butyrate (CAB). The organic cellulose esters are being used in packaging film, cigarette filters, textile fibers, pharmaceutical, and other specialty industrial applications. Cellulose regenerate is produced from cellulose through dissolving by chemicals and then newly restructured in the form of fibers or film.[21] At present, more than 60% of the global total chemical grade pulp is used for the production of cellulose regenerates.[30] The examples of this regenerated cellulose are viscose, viscose silk, lyocell and rayon.

Polylactic Acid Based Bioplastics

Polylactic acid (PLA), polylactide plastics are today's most important bioplastics on the market.[31] PLA is based on lactic acid and is mainly produced by the process of microbial fermentation of starch obtained from the maize, cassava, potato, sugarcane and sugar beet. The problems identified in the starch substituted bioplastics can be overcome through these PLA bioplastics. In this process first, the plant starch is transformed into lactic acid as a monomer through microorganisms and then the lactic acid is chemically treated to link up the molecules into long chains or polymers. This PLA plastic looks like conventional petrochemical plastics and it is a truly biodegradable plastic. The major advantages of the PLA plastics are the high level of rigidity, stability, transparency, thermoplasticity and superior performance in the existing equipment of conventional plastics manufacturing industry. Applications of the PLA plastics are mainly in food packaging because of its properties similar to polyethylene and polypropylene. Moreover, making of this PLA plastic saves two-thirds of the energy required for manufacturing of the fossil fuel-based plastics. The PLA plastics also emit almost 70% less greenhouse gases than conventional plastics during the degradation in a landfill. At present, PLA and PLA-blends are available in granulated form as different grades for manufacturing of film, moulded parts, drinks containers, cups, bottles and other everyday items.[32] The application of the PLA based plastics is also expanding to a wide range of fields like medical, textile, cosmetic and household applications. Moreover, the automobile industries also producing the dashboards, door tread plates, etc. from the PLA based plastics.[33]

Polyhydroxyalkanoates Based Bioplastics

Polyhydroxyalkanoates (PHA) based plastics are produced from the plant based starch by the processes of microbial fermentation. These PHA based plastics are having the physical and chemical properties very similar to polyesters, polyethylene and polypropylene.[34] In the presence of excessive carbon sources, several natural microorganisms form PHAs granules intercellularly.[31] The different groups of polyhydroxyalkanoates normally using for the manufacturing of plastics are polyhydroxy butyric acid (PHB) and polyhydroxybutyrate, polyhydroxyvalerate (PHV), poly-3-hydroxybutyrate-co-valerate (PHBV).[31] Several companies producing PHA based plastics in a large scale. The well-known examples are Biopol and Bionelle. The Biopol is a copolymer of Polyhydroxy butyrate (PHB) called poly 3-hydroxybutyrate-co-valerate (PHBV) and the Bionelle is a chemically synthesized PHA based biodegradable plastic. There are more than 75 genera of prokaryotes and archaea are having a capacity to produce PHA intracellularly.[35,36,37] The bacteria such as *Alcaligens* spp., *Pseudomonas* spp. and a number of filamentous genera *viz*., *Nocardia* spp. are also able to produce these PHAs during nutrient-limited conditions.[38] The phaC gene is responsible for the synthesis and accumulation of PHA in microorganisms.[39]

In general, specific microorganisms can accumulate 80% of their body weight as PHA polymer granules in the cytoplasm of cells under limited nutrient conditions through novel transgenic fermentation of carbohydrates.[36] The PHA polymer is purified by breaking of the cell wall and then harvested through an aqueous based extraction method with organic solvents. After that, the PHA biopolymer is purified and converted into the form of lattices for plastic manufacturing. Through genetic engineering, scientists developed several genetically modified plants for producing PHA from the phaC gene. Switchgrass, *Panicum virgatum*, has used as a host received for producing PHA through genetic engineering.[40] Later, scientists developed genetically modified maize for producing PHA and the plants also being cultivated effectively as a crop of plastic. Recently, a European-based bioscience engineering company, Metabolix®, has successfully launched a biobased PHA production program through optimization of multi-gene expression techniques in crops like switchgrass, camelina and sugarcane.[41,42] In recent years, the biopolymers such as polyhydroxyalkanoates and alginates are also produced from the digestate of the anaerobic digester and sludge produced from aerobic wastewater treatment. The production of biopolymers from the sludge will offer advantages like low production costs since it is produced from the inexpensive waste sludge.[43,44]

The PHAs based plastics are truly biodegradable, which can be completely biodegraded within a period of 1 year by many different genera and species of bacteria and fungi under aerobic and anaerobic conditions.[45,46] Biodegradation of the PHA's under aerobic conditions yields carbon dioxide and water. It is a non-toxic and natural polymer[47] and hence, it can be used in a wide range of applications like food packaging, medical implants and agriculture.[45] In a global market, the PHAs are available as film and injection moulding grades as well as extrusion and blow moulding grades. A man-made particle foam board is also manufactured from poly-3-hydroxybutyrate-co-3-hydroxyhexanoate (PHBH), which has very similar properties to Styropor.[48]

Drop-in Bioplastics

Drop-ins are a group of bioplastics that are made up of completely or partially biobased materials[49] however, these plastics are non-biodegradable. These plastics are commonly made from corn, sugarcane and sugar beets. These plastics are a hybrid version of conventional petrochemical plastics. The presence of complete or partial renewable biobased raw material base is the only difference in the drop-ins over conventional plastics. At present, the production and utilization of drop-in bio-based materials are tremendously increasing. The examples of these bioplastics are bio-polyethylene (PE), bio-polypropylene (PP) and bio-polyethylene terephthalate (PET). The renewable resource like bioethanol is using to manufacture the conventional plastic types such as polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC). The drop-in bio-based plastics are chemically identical to conventional plastics and hence they can be used in exactly the same applications. According to Van den Oever *et al.*,[50] the bio-PE and bio-PET are mainly using in packaging applications. The bio-PET plastics are mainly using in the manufacturing of bottles and the bio-LDPE are using in film manufacturing. Biobased succinic acid is suitable for several applications in sports and footwear, automotive, packaging, agriculture, non-wovens, and fibres applications. The main advantage of these bioplastics is reduced carbon footprint since it is made up of renewable biomass. It is also possible to process, manufacture and recycle these drop-ins in the existing facilities of conventional plastics, which will reduce the production cost.

Fossil Fuel-based Bioplastics

The biodegradable plastics can be manufactured not only from bio-based feedstock but also from the petrochemical raw materials. Petrochemical products such as polybutyrate adipate terephthalate (PBAT) also using for manufacturing of the bioplastics. The PBAT is a new group of a polymer of petrochemicals but is still biodegradable, and commonly known as polybutyrate.[49] It is mainly used in conjunction with starch and other bioplastic materials for improving the application-specific performance, because of its biodegradability and rigidity. The development of new bio-based or partly bio-based versions of PBAT has increased in recent years. This PBAT plastic has also been produced from renewable resources.[51] For example, poly(butylene adipate-co-terephthalate) (PBAT) is commercially synthesized from adipic acid, terephthalic acid, and 1,4-butane diol. This PBAT is a random copolymer made up of butylene adipate and terephthalate. It is biodegradable and it having the properties *viz.*, high elasticity, fracture resilience, and flexibility, and hence, it is used as a preferred alternative for use in products such as bags, wraps and other packaging materials. It is also used to produce rubbish bags and disposable packaging, because of its fastest rate of decomposition. It has also been used as the additives in manufacturing of bioplastics for giving rigidity and flexibility.

Waste Management Options for Bioplastics

The bioplastics are suitable for a wide range of end-of-life options *viz.*, reuse, mechanical recycling, chemical recycling, organic recycling and energy recovery. A 'waste hierarchy' proposed by the several nations also recognizes the options like reduction, reuse and recycle for the sustainable treatment and disposal of the wastes.[52,53,54,55,56,57] However, the bioplastics that enter into the municipal waste stream makes some complications for existing plastic recycling systems, since it having the variation in the base materials over conventional plastics.[58,59] The bioplastic wastes also act as potential substrates for composting since it is biodegradable in nature where the valuable organic materials are recovered as an end product.[60]

Recycling Options

Recycling is the preferred and viable options for the sustainable management of bioplastics, and then incineration with energy recovery is the most suitable method over land-filling. All the recycling methods including material, chemical, and organic recycling are viable for bioplastics management. Material recycling is defined as the reprocessing of waste material into a new product. This type of recycling is also called mechanical recycling. The mechanical recycling is suitable for all types of bioplastics, however, the unreliable supply of bioplastic waste in a large quantity would make this recycling as a less economically attractive than for the conventional plastics. The mechanical recycling companies convert these sorted products into recyclates using processes like washing, density separation and compounding. Currently, the produced bioplastics are being recycled easily along with conventional plastics depending upon the base materials. For examples, the biobased polyethylene (PE) is being recycled in the PE-stream, and the biobased polyethylene terephthalate (PET) is being recycled in the PET -stream. In this way, the bioplastics contribute to higher recycling proportions. The PLA polymers wastes can be recycled efficiently without any alterations in chemical and physical properties through mechanical recycling for a few times and the recyclates being converted into the products *viz.*, plastic lumber, piping, garden furniture and pallets.[61]

Another option for recycling of the bioplastics is chemical recycling, in which the biopolymer wastes will be remelted and regranulated for the development of a new product. In certain cases, the biopolymer wastes also converted into the chemical building blocks i.e., monomers which can be used again for the production of the biopolymer. This type of recycling is also called as feedstock recycling. This recycling is the feasible option for PLA based bioplastics. At present, the PLA based bioplastics are recycled effectively into the lactic acid and converted into a new PLA based products in countries like Belgium and The United States of America. The Loopla process is also one of the chemical recycling processes, in which the PLA is hydrolyzed into lactic acid.[62]

Composting has the potential for recycling the biodegradable plastic wastes into a nutrient-rich soil amendment and it is being implemented in many parts of the world.[60] The natural microorganisms can convert these biodegradable polymers wastes into simpler compounds and then the simpler compounds are decomposed into carbon dioxide and water under the aerobic condition and decomposed into methane and carbon dioxide under anaerobic conditions. The composting is also considered as one kind of material recycling, which is referred to as organic recycling.[63] The composting is also equivalent to the material recycling[64] and hence it is considered as a sustainable and environment-friendly option for bioplastic wastes management. Van der Zee 65 conducted the study for tunnel composting of PLA based foam at 10x10 cm sized blocks with a temperature of more than 60 °C and he observed that the complete disintegration of PLA foam with 3 days in a composting period of 2 weeks. According to ISWA,[25] the bioplastics would not produce any toxic substances during the composting period. The biodegradable plastic wastes compost also improved the soil quality and enhanced the plant growth parameters like other organic manures.[66]

Energy Generation

The energy is generated from the bioplastic wastes through different processes *viz*., anaerobic digestion, pyrolysis, incineration. But it would be carried out after complete recovery of all the recyclable materials from the bioplastic wastes.[60] Since, the bioplastics having a high caloric value, it can be used to generate energy in general conventional plastic waste incineration facilities.[67,68,69] Even though some of the bioplastics such as natural cellulose fibre and starch having the property of lower gross calorific values (GCV), they are a resemblance to wood, and hence the energy recovery is feasible and viable from these bioplastic wastes through incineration.[67,70] The incineration of the bioplastic wastes will emit large quantities of carbon dioxide which will be captured and may be used to develop new biobased products.[50] This will make the practice of incineration of bioplastic wastes as a sustainable practice.

Anaerobic digestion is also being used to manage the bioplastic wastes effectively from separate waste collection schemes, and mechanical treatment of mixed municipal solid waste. In anaerobic digestion, the bioplastic wastes are decomposed into methane and carbon dioxide under anaerobic conditions.[71] The anaerobic digestion producing the biogas and digestate, in which the biogas can be used as a renewable source of energy and the digestate can be utilized as organic manure. Song *et al.*[60] reported that the biodegradable plastic wastes are suitable for anaerobic digestion where the waste biopolymers are converted into methane. Moreover, the methane-containing landfill gases also may be utilized for the generation of energy.

Market Demand for Bioplastics

The importance of the bioplastics was not known for the past two decades. However, recently the bioplastics have become an integral part of our society. The continuous research and developmental activities towards bioplastics and growing awareness towards environmental conservation have led to a remarkable growth of the overall bioplastics market.[72] Further, the stringent regulatory reforms by the several governments towards the reduction of plastic usage have augmented the demand for bioplastics. At present, the contribution of bioplastics products in the total plastics market is around only 1 per cent. However, the results of European Bioplastics' annual market data update, presented at 12th European Bioplastics Conference held on 29 November 2017 in Berlin, confirmed that steady growth of the global bioplastics industry. The capacity of the global bioplastics production is 2.05 million tonnes in 2017 and it is expected to be increased to 2.44 million tonnes in 2022. [73] The growth rate of bioplastics is around 20-25 per cent per year but the growth rate for conventional plastics is only 4-9 per cent per year.[74] The European bio-plastics market reported that the global bioplastics market is to be growing at more than 20% per year.[75] The only disadvantage of the global bioplastics market is high production cost over conventional plastics,[76] however, it can be overcome by the technology advancement. Moreover, the increasing price of crude oil has also boosted the manufacturer towards the production of bioplastics over petroleum based plastics.[20,60] The developing countries like India, China, etc., also promoting the bioplastics by providing incentives coupled with contract manufacturing which is also further expected to contribute to the growth of the bioplastics market. At present, the drop-ins bioplastics are dominant in the bioplastics market. Around 56 per cent of the global bioplastics production is only the drop-in bio-based plastics *viz*., bio-PET, bio-PA and bio-PE.[67] While considering the individual types, the drop-in bio-based PET is dominating in the bioplastics market over other types of bioplastics, which is followed by the starch-based bioplastics. However, the PLA and PHA based plastics production are expected to increase in the bioplastics market due to its superior quality and valid end-of-life options. In terms of application, the global biodegradable plastics market is segmented into packaging, textile, agriculture, electronic, medical, building construction, injection moulding and a number of other segments. Among them, the packaging industry is the largest field which contributes to 60 per cent of global bioplastics production.

Conclusion

Bioplastic is an important innovation and it would offer sustainable and eco-friendly alternatives to avoid the plastic pollution. Further, the intensification of research through industrial tie-ups and promotion of the large-scale production and commercialization of the bioplastic products are also inevitable to solve the plastic pollution in our environment. The bioplastics are still in its infancy, and hence a great innovation would be developed by the intensification of research through the government and industrial funding. The continuing intensified research in this field would facilitate further breakthroughs and improvements. However, bioplastics are not the only solution to the problem of plastic pollution. The changes in consumer behaviour in buying, consuming and disposing of plastics, and widespread public awareness of the bioplastics are also essential in effecting the control of plastic pollution.

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Conflict of Interest

The Author(s) declare no conflict of interest.

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