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Corn Starch Plastic: An Overview

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ABSTRACT

Purpose: *The production and use of traditional petroleum-based plastics have caused significant environmental problems, such as non-biodegradable waste and pollution. This environmental concern can be overcome using biotechnological tools and techniques to develop bio-plastic as a sustainable alternative to daily use plastic and ensuring a smooth transition from fossil-based to bio-based plastics. Various industrial biotechnology methods such as microbial fermentation, enzymatic catalysis are used as primary methods for bio-plastic production. The microbes are genetically modified, harvested and engineered for this purpose of fermentation for high quality and quantity production.This article provides an in-depth overview of bio-plastic such as corn- starch plastic as an alternative to traditional petroleum-based plastics and to mitigate environmental concerns arising from them. Corn starch plastic, also known as polylactic acid (PLA), is a biodegradable polymer made from corn starch that is gaining popularity due to its properties and biodegradability. It includes its properties, production, applications, challenges, and future directions.*

Research method: *It involves a number of biotechnological processes. Starting with extraction of corn starch from corn kernels and separation of starch from mixture. It is followed by gelatinization of starch and plasticization with plasticizers like glycerol to enhance flexibility. Further, the starch is processed using injection molding, and ultimately cooling and solidification are carried out.*

Findings: *Findings reveal that a number of by-products are retrieved during the extraction process of corn starch plastic that can be further mixed with corn starch plastic to enhance its properties and produce plastics of different kinds and applications. For example, polyhydroxyalkanoates (PHA) is a complex polymer that, when added to corn starch plastic, enhances its strength and flexibility. Cellulose acetate (CA) is another renewable polymer that produces a transparent bio-plastic that is also chemically resistant and durable. Many such polymers have been identified and described further.*

Research limitations: *Process is energy consuming and water intensive inputs are required. Microorganisms can cause unwanted contamination, hindering the process.*

Originality/ value: *Production of bio-plastics that is biodegradable.*

Keywords: *Biodegradable plastic, Biotechnology, Corn Starch, Glycerol.*

INTRODUCTION

Corn starch plastic, also known as bio-plastic or biodegradable plastic, has gained significant attention as an eco-friendly alternative to traditional petroleum-based plastics. Starch from corn kernels must first be extracted before it can be altered using various biotechnological techniques to create corn starch plastic. The mechanical and thermal characteristics of corn starch plastic may be improved using a variety of techniques, including enzymatic hydrolysis, chemical modification, and

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mixing with other biopolymers.

Plastic made of corn starch possesses a number of advantageous qualities, including biodegradability, composability, and renewability. It has potential uses in the biomedical, agricultural, and packaging industries. The potential to be used in single-use items due to maize starch plastic's biodegradability helps reduce the amount of non-biodegradable trash that ends up in the environment. It may also be utilized in mulches, controlled-release systems, and agricultural films, all of which support sustainable farming techniques. Corn starch plastic might be used in tissue engineering, medication delivery devices, and other medicinal fields (Prachayawarakorn *et al.,* 2012).

A key factor to take into account is the effect corn starch plastic has on the environment. While the capacity to degrade through biodegradation has benefits, suitable disposal procedures and facilities for industrial or composting decomposition are required for efficient waste management. For corn starch plastic to be widely used and to be commercially viable, issues with its mechanical characteristics, susceptibility to moisture and cost-effectiveness must be resolved (Rafiqah *et al.,* 2021).

Enhancing the corn starch plastic's cost-effectiveness, mechanical strength, and barrier qualities as well as putting in place efficient waste management mechanisms for its disposal are required, which can be obtained through further research and studies. This review article presents a comprehensive overview of the biotechnological aspects of corn starch plastic, highlighting its production processes, properties, applications, and environmental considerations.

PROPERTIES OF CORN STARCH PLASTICS

Corn starch plastic has several properties that make it an attractive alternative to traditional plastics. Firstly, it is transparent, making it suitable for applications in packaging and other consumer goods. Secondly, it has good mechanical properties, such as strength and stiffness, making it suitable for use in products that require durability.

Thirdly, it is biodegradable and compostable, meaning it can break down in the environment and contribute to a circular economy (Rafiqah *et al.,* 2021). Due to their accessibility and lack of toxicity, biodegradable composites are becoming more and more popular. However, due to the composite's non-biodegradable matrix, the production of totally biodegradable composites is currently at a limited level. As a result, this is a detailed description of the mechanical and physical characteristics of cornstarch (CS) mixtures with various glycerol weight percentages as a thermoplastic corn starch (TPCS) matrix. According to Zakaria *et al.,* (2021), the following data has been analyzed. The glycerol contents that were chosen were 30, 35, and 40% by weight. The TPCS samples were created via hot compression molding at 165°C for 15 minutes using mixtures of CS and various weight percentages of glycerol. Tensile testing, hardness testing, water absorption testing, moisture content testing, and microstructure analysis were done for the mechanical and physical properties.

In order to create a mixture of corn starch and glycerol, the samples were manufactured using a high-speed mechanical stirrer model. Glycerol is used for preparation as it acts as a plasticizer that makes the material more flexible and easier to mold. It also tends to reduce the brittleness of the plastic. Various weight percentage (%) loadings of glycerol were introduced into the corn starch in order to obtain the optimal qualities from the mixture of CS and glycerol. As shown in Table 1, loadings of 20, 25, 30, 35, 40, 45, and 50% weight% glycerol were added to CS. The mixes, however, for the 20 and 25 weight (%) loadings of glycerol remained in powder form and were extremely fragile. The glycerol loadings of 45 and 50 weight percent, however, were created as a liquid. It is acknowledged that neither powder nor liquid forms are appropriate to be turned into sheets of steel for testing purposes such as tensile strength, hardness, etc.

GLYCEROL AS PLASTICIZER

Glycerol or commercially known as glycerin is a triglyceride majorly produced by -product in the refining and production of biofuels and diesels. Usually released as waste this glycerol is actively utilized for the synthesis of biopolymers that are environment friendly and add value to the products. It acts as a common plasticizer for certain class of hydrophilic polymers. It acts by providing thermoplasticity to the polymer making is moldable and facilitates film casting. It acts by breaking down the hydrogen bonds present in the polymer chain reducing the crystalline nature. Apart from this it adds more strength to the bioplastic, absorbs more water and is suitable for packaging purposes. Glycerol plasticized films are capable of maintaining flexibility along with transparency that is essential feature of packaging materials.

TENSILE STRENGTH

There are two key causes behind the thermoplastic CS's increased tensile strength. The impact on the maize starch's amylase concentration comes into play first, followed by the addition of plasticizer (glycerol) to the combination. Corn starch (28%) has higher amylose content than other starches, including potato (20 to 25%), rice (20%), cassava (17%), and waxy rice (5%). The mixture's increased amylose content led to a higher degree of polymerization (Prachayawarakorn *et al.,* 2012). They discovered that waxy rice has a lower tensile strength than rice starch with a higher amylose concentration. In addition, Prachayawarakorn *et al.,* (2012) came to the conclusion that the tensile strength was influenced by the plasticizer content. This conclusion was reached by contrasting other research that used various plasticizer/starch ratios, including 50:50, 65:35, and 70:30. Greater strength and stiffness, along with low ductility, are produced through TPS development with reduced loading (wt. %) of glycerol (Fig.l).

The stronger intermolecular bonds in the starch chains are reduced by the plasticizing effect, which occurs when more plasticizer is used. Another aspect that may affect the disparity of the mechanical features as well as the results obtained is the employment of various manufacturing techniques and specifications. The increase in elongation is due to an increase in plasticizers (glycerol), which decrease the intermolecular bonds between amylose-amylopectin in the starch and thus, substitute them with hydrogen bonds (Figure 2). Such disruption and reconstruction of starch molecular chains reduce rigidity and enhance flexibility. Hardness is related to the strength

Table 1: Appearance of mixtures of corn starch and glycerol in different weight percentages (wt. %).

Corn Starch (%)	Glycerol (%)	Appearance
50	50	Liquid
55	45	Liquid
60	40	Sheets Plate
65	35	Sheets Plate
70	30	Sheets Plate
75	25	Powder
80	20	Powder

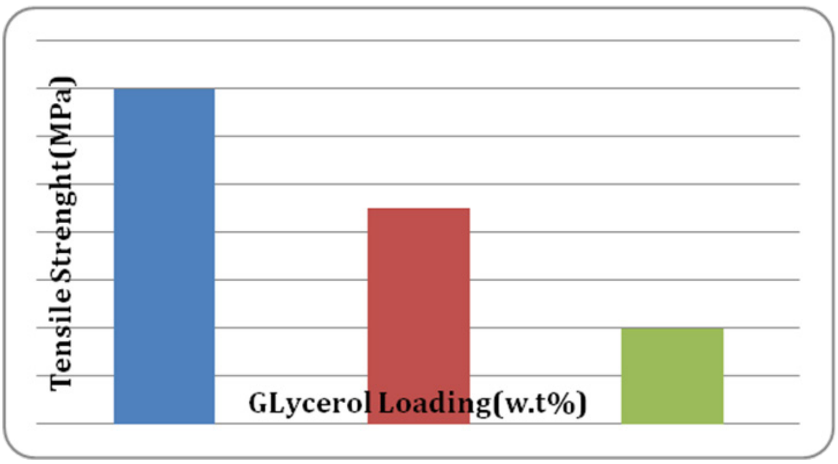

Figure 1: Tensile strength of corn starch blended with glycerol

and toughness of the composite. The increase in glycerol content will decrease its hardness (Table 2).

The concentration of amylose and amylopectin rises when maize starch content does as well. The density value increases as the amount of maize starch increases. It can be argued that the density of the combination may be impacted by the larger loading (wt. %) of maize starch (Table 3). It is observed that a decrease in glycerol results in a gradual decrease in moisture content, which insists on their directly proportional relationship (Table 4). As this is a bio-based product, one of its key features is water absorption. Studies show that a longer period of immersion leads to excellent water absorption for all mixtures due to the higher amount of water that the materials can absorb. The following graph indicates the water absorption potential of the mixture after 0.5 hours and 2 hours of immersion (Fig. 3).

CORN STARCH PRODUCTION

The production of corn starch plastic involves several biotechnological processes. Here are the brief steps that generalize the process. Firstly, corn starch is extracted from corn kernels and then converted into glucose by enzymes. The glucose is then fermented by microorganisms such as Lactobacillus, which convert it into lactic

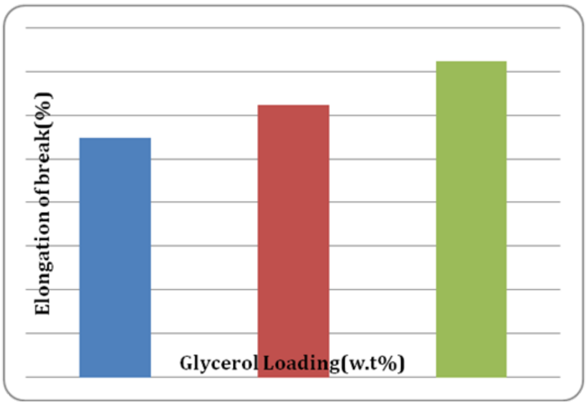

Figure 2: Elongation of break of corn starch blended with glycerol.

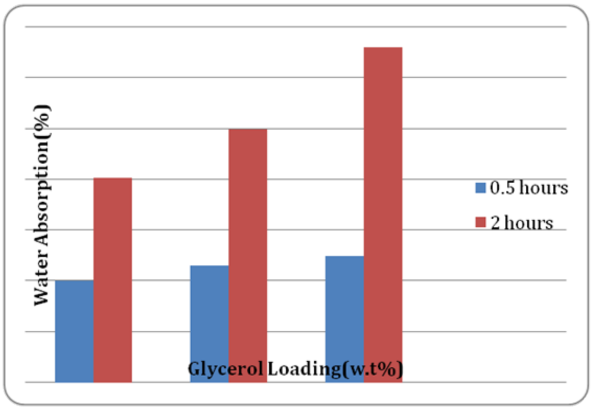

Figure 3: Water Absorption for corn starch/glycerol.

Table 2: Hardness test for the mixture of CS and glycerol based on the ratio of CS and glycerol.

Sample	70/30	65/35	60/40
1	6.1726	4.8747	2.0715
2	6.0392	4.6877	2.4445
3	5.2577	4.6997	2.177
4	6.013	4.991	2.8068
5	5.91	4.9131	2.523
Average	5.8785	4.8332	2.4046

Table 3: Density of corn starch/glycerol.

Thermoplastics CS	Density(g/cm^3)
70/30	1.404
65/35	1.396
60/40	1.375

Table 4: Moisture content of corn starch/glycerol.

Thermoplastics CS	Moisture content (%)
70/30	24.60
65/35	27.22
60/40	28.77

acid. The lactic acid is then polymerized to form PLA. The process of producing PLA from corn starch is known as the PLA production process. This process is energy-intensive and requires a significant amount of water. Several researchers have proposed modifications to this process to make it more sustainable and efficient.

General Stages for the Production of Corn Starch Plastic

Extraction of Corn Starch: Corn kernels are processed to extract the starch. This is typically done by milling the corn kernels, followed by separating the starch from other components such as proteins, fibers, and oils.

Gelatinization: The extracted corn starch is mixed with water and heated to form a gel-like substance through a process called gelatinization. This involves breaking down the starch granules and swelling them with water.

Plasticization: Plasticizers, such as glycerol or sorbitol, are added to the gelatinized corn starch. These plasticizers help improve the flexibility and processability of the material, making it easier to shape into various forms.

Processing: The plasticized corn starch is then processed using methods such as extrusion or injection molding. Extrusion involves melting the plasticized starch and forcing it through a die to obtain the desired shape, while injection molding injects the molten starch into a mold under high pressure.

Cooling and Solidification: The shaped corn starch plastic is cooled and allowed to solidify, which helps the material retain its shape and structural integrity.

The process of making corn starch plastic at home is relatively simple and requires only a few ingredients. The primary ingredients required are corn starch, vinegar, and glycerin (Marichelvan *et al.,* 2019). The corn starch provides the base for the plastic, while the vinegar acts as a plasticizer, and the glycerin improves the flexibility of the plastic.

The following is a step-by-step guide for making corn starch plastic at home:

1. Mix 1/4 cup of corn starch and 2 tablespoons of water in a bowl to make slurry.

2. In a separate container, mix 1 tablespoon of vinegar and 1 tablespoon of glycerin.

3. Add the vinegar-glycerin mixture to the corn starch slurry and stir well.

4. Transfer the mixture to a saucepan and heat over low heat, stirring constantly.

5. Continue heating and stirring until the mixture thickens and turns into a gel-like consistency.

6. Remove the saucepan from the heat and let the mixture cool to room temperature.

7. Once cooled, the mixture can be molded into various shapes and sizes.

8. Allow the molded plastic to dry for 24–48 hours.

Corn starch plastic is made from polylactic acid (PLA), which is a biodegradable polymer produced from lactic acid. Lactic acid is derived from renewable sources, such as corn starch, cassava, tapioca, and sugarcane, through a fermentation process that involves microorganisms such as *Lactobacillus* and *Rhizopus*. The fermentation process converts the sugar in these renewable sources into lactic acid, which is then purified and polymerized into PLA. The addition of vinegar to the corn starch slurry helps to lower the pH, which initiates the hydrolysis of the starch molecules into shorter chains. The hydrolyzed starch chains can then crosslink with each other to form a gel-like structure. The addition of glycerin to the mixture improves the flexibility and durability of the plastic. Some examples of bio-products mixed with corn starch to make bio-plastics of different kinds, along with their properties and usages, have been discussed below.

Bio-Products mixed with corn starch

Polyhydroxyalkanoates (PHA): PHA is a family of biodegradable polymers produced by bacteria. When mixed with corn starch, it produces a bioplastic that is flexible, strong, and has good barrier properties. PHA corn starch bioplastics are commonly used in food packaging, agricultural films, and medical implants.

Cellulose acetate (CA): CA is a biodegradable polymer made from cellulose, a renewable resource. When mixed with corn starch, it produces a bio-plastic that is transparent, tough, and has good chemical resistance. CA corn starch bioplastics are commonly used in food packaging, cigarette filters, and photographic film.

Polybutylene succinate (PBS): PBS is a biodegradable polyester made from succinic acid and 1,4-butanediol. When mixed with corn starch, it produces a bio-plastic that is tough, flexible, and has good gas barrier properties. PBS corn starch bioplastics are commonly used in food packaging, disposable tableware, and agricultural films (Rafiqah *et al.,* 2021).

Polyhydroxy Urethane (PHU): PHU is a biodegradable polymer made from isocyanates and hydroxyl-containing compounds. When mixed with cornstarch, it produces a bio-plastic that is flexible, strong, and has good water resistance. PHU corn starch bioplastics are commonly used in food packaging, biomedical devices, and coatings.

Poly (lactic-co-glycolic acid) (PLGA): PLGA is a biodegradable copolymer made from lactic acid and glycolic acid. When mixed with cornstarch, it produces a bioplastic that is flexible, biocompatible, and has good mechanical properties. PLGA corn starch bioplastics are commonly used in biomedical devices, drug delivery systems, and tissue engineering (Zhang *et al.,* 2019).

All of these biodegradable bioplastics offer unique properties and have potential applications in various industries. However, it is important to note that the biodegradability of these materials can vary depending on the specific formulation, processing conditions, and disposal method. Therefore, it is important to consider the end-of-life options and environmental impact of these bio-plastics when designing and using them.

Some examples of bio-products that can be mixed with corn starch to produce partially biodegradable or non-biodegradable bioplastics are:

Polyethylene (PE): PE is a non-biodegradable polymer made from ethylene. When mixed with natural fibers like corn starch, it produces a bio-plastic that has improved mechanical properties, including tensile modulus and tensile strength (Khanam and AlMaadeed*,* 2015). Polyethylene corn starch bioplastics are commonly used in film packaging, shopping bags, and disposable containers.

Polypropylene (PP): PP is a non-biodegradable polymer made from propylene. When mixed with corn starch, it produces a bio-plastic that has improved mechanical properties and reduced carbon footprint compared to traditional Polypropylene. Polypropylene corn starch bioplastics are commonly used in automotive parts, household appliances, and packaging films.

Polyethylene terephthalate (PET): PET is a non-biodegradable polymer made from ethylene glycol and terephthalic acid. When mixed with corn starch, it produces a bio-plastic that has improved biodegradability and reduced carbon footprint compared to traditional Polyethylene terephthalate. Polyethylene terephthalate corn starch bioplastics are commonly used in beverage bottles, food containers, and textile fiber.

While these partially biodegradable or non-biodegradable bioplastics are not fully sustainable, they can still offer some environmental benefits compared to traditional plastics. It is important to note, however, that the end-of-life options for these materials may vary depending on their specific composition and recycling infrastructure in different regions.

APPLICATIONS OF CORN STARCH PLASTICS

Corn starch plastic has a wide range of applications in various industries, including food packaging, medical devices, agriculture foils, building and construction, and consumer goods (Izathul *et al.,*2019). In food packaging, it is used as a sustainable alternative to traditional plastic packaging, which is often non-biodegradable and contributes to plastic pollution. In medical devices, it is used as a biodegradable and biocompatible material for implants and drug delivery systems. In consumer goods, it is used in products such as disposable cutlery, cups, and bags. PLA has also shown potential for use in the automotive and construction industries.

Methods of composting and degradation

There are several methods of composting and degrading corn starch plastic, which is also known as biodegradable or compostable plastic. Here are some common methods used for composting and degrading corn starch plastic.

Industrial Composting: Corn starch plastic can be composted in industrial composting facilities that provide controlled conditions of temperature, moisture, and aeration. These facilities create an optimal environment for microorganisms to break down the corn starch plastic efficiently. The composting process typically takes a few weeks to several months, depending on the specific conditions.

Home Composting: Corn starch plastic can also be composted at home, provided that you have a compost pile or bin. It is important to ensure that the compost pile maintains the right balance of organic materials, including nitrogen-rich (green) and carbon-rich (brown) materials. Shredded corn starch plastic can be added to the compost pile along with other compostable materials. The microorganisms in the compost pile will gradually break down the cornstarch plastic (Erickson *et al*.,2012).

Aerobic Degradation: Corn starch plastic can undergo aerobic degradation, which occurs in the presence of oxygen. This process involves the action of microorganisms, such as bacteria and fungi that produce enzymes capable of breaking down the corn starch polymer chains. The degradation process results in the conversion of corn starch plastic into simpler organic compounds. The compounds so produced are used as source of food by the microbes. The process takes place in the presence of oxygen and results in release of carbon dioxide and water along with other byproducts. The entire process can go up to 45 days at temperature ranging from 55 to 57 degree Celsius under aerobic conditions.

Microbial Biodegradation: Microbes play a crucial role in the biodegradation of corn starch plastic. Certain bacteria and fungi have the ability to produce specific enzymes, such as amylases and celluloses that can degrade the corn starch polymer structure. They are able to cleave the glycosidic bonds of the polymer holding the starch molecule together. The smaller molecules produced are utilized by the plant as a source of food that gets absorbed and metabolized. These microbes are most active under pH ranging from 7 to 8.The type of starch also affects the degradation rate along with other environmental factors. The microbes attach to the outer surface of corn plastic and release enzymes that break down the corn starch plastic into smaller fragments that can be further metabolized by microorganisms, ultimately resulting in the complete degradation of the plastic (Yahia *et al*.,2024).The further breakdown of molecules into byproducts such as carbon dioxide, water , methane is known as mineralization.Both the aerobic and microbial degradation depends on the starch contend present in the plastic. More the starch contend faster is the degradation process.Mostly fungal and bacterial strains such as Psuedomonas, bacillus are associated with this type of degradation.

Soil Degradation: When corn starch plastic is placed in soil, it can undergo degradation over time. Soil microorganisms, such as bacteria, fungi, and earthworms, contribute to the breakdown of the corn starch polymer chains. The process of degradation in soil is influenced by factors such as temperature, moisture content, and the presence of other organic matter (Ahsan *et al.,* 2023).

Hydrolysis: Hydrolysis is a chemical process in which water molecules break the bonds between the corn starch polymer chains, resulting in the degradation of corn starch plastic. This process occurs naturally over time, but it can be accelerated under certain conditions, such as high temperatures or exposure to specific enzymes.

The specific conditions and time required for the composting and degradation of corn starch plastic may vary depending on factors such as temperature, moisture, oxygen availability, and the presence of appropriate microorganisms.

Challenges

Despite its many benefits, there are also several challenges associated with the production and use of corn starch plastic. Firstly, the production process is energy-intensive and requires a significant amount of water. Secondly, the biodegradability of PLA is dependent on specific conditions, such as temperature, humidity, and the presence of microorganisms, which can limit its effectiveness in certain environments (Yahia *et al*.,2024). Thirdly, there are currently limited facilities for the collection and composting of corn starch plastic waste (Izathul *et al.,*2019).

To overcome these challenges, researchers are exploring new biotechnological processes for the production of PLA that are more energy-efficient and use fewer resources. They are also investigating new materials and technologies that can enhance the biodegradability and compostability of corn starch plastic. For example, blending PLA with other biodegradable polymers or adding nanoparticles can improve its mechanical and thermal properties.

FUTURE IN INDIA AND WORLDWIDE

In India, there is a growing demand for bioplastics, driven by environmental concerns and government regulations. The Indian government has set a target to eliminate single-use plastics by 2022, creating opportunities for the development and use of bio-plastics. Several Indian companies, such as Bio-based Industries Consortium (BIC), Plasto-bags, and Bio-lutions, are working on the development and production of bioplastics, including corn starch plastic.

Globally, the market for bio-plastics is also growing, with a predicted compound annual growth rate of 18.8% from 2023 to 2030, according to a report by Grand View Research. The report also states that the packaging industry is the largest end-user of bio-plastics, followed by agriculture and the automotive industries. The increasing demand for sustainable materials, coupled with government initiatives and regulations, is driving the growth of the bioplastics market (Wei *et al*.,2024)**.**

CONCLUSION

Corn starch plastic, also known as polylactic acid (PLA), is a biodegradable polymer made from corn starch that has several properties, making it an attractive alternative to traditional plastics. The production of corn starch plastic involves several biotechnological processes and has several applications in various industries, including food packaging, medical devices, and consumer goods. Despite its many benefits, there are also several challenges associated with the production and use of corn starch plastic, such as energy and water requirements, limited facilities for waste collection and composting, and limited biodegradability under certain conditions. However, researchers are exploring new biotechnological processes and materials to overcome these challenges and enhance the properties and biodegradability of corn starch plastic. With the growing demand for sustainable materials and government initiatives and regulations, the market for bio-plastics is expected to continue to grow globally, including in India.

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