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Biodegradable plastics-advantages and challenges: An update

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Abstract

Plastic litter pollution in the oceans, the land and freshwater rivers is increasingly emerging as a serious global environmental concern. Conventional plastics are fossil-based, made from non-renewable natural resources. A novel way out of the increasing rate of demand for plastic packaging is to adopt biodegradable plastics. *Cannabis sativa* (Hemp), sugarcane, cassava, and corn are some of the most popular plants utilized to produce bioplastics. Some biobased polymers are biodegradable. However, not all biobased plastics are biodegradable. It should be understood that similar to petroleum-based plastics, some bio-based plastics cannot be recycled. Consequently, many biodegradable bioplastics end up in landfills, which decompose gradually and produce methane gas. Biodegradable plastic that is commercially available has its own advantages and limitations respectively upon degradation in both freshwater and marine environments. The Indian bio plastics market is still in its early stages, with only a handful of companies currently operating in this segment. India has shown increasing interest in bio-plastics due to growing environmental concerns and a focus on sustainability. In terms of revenue, the biodegradable plastics market in India is likely to grow at a significant CAGR of 12.5% over the forecast period. India's significant agricultural sector provides a rich source of bio-based feed stocks for the production of bioplastics. Crops such as hemp, sugarcane, corn, and other biomass materials are utilized in Bio Plastics manufacture, contributing to the growth of the industry.

Keywords: Bioplastic; Biodegradable; Ecobharat; Fossil-Fuel; India; Plastic; Pollution; Polymers; Toxicity

1. Introduction

Traditional fossil-fuel based plastic production emits massive levels of greenhouse gasses, and the material can take hundreds of years to break down [1-44]. Atiwesh et al., (2021) [1] reported that plastics are versatile, corrosion-resistant, well-insulated, and have a low heat conductivity [1-18-44]. Traditionally, plastics are made from petroleum-

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based compounds, which release toxic gases into the atmosphere. Petroleum-based plastics and its by-product have a devastating effect on the land, water, and wildlife [1-18-26-44]. The global consumption of plastics has increased over the years, particularly because they are lightweight, resilient, relatively low-priced, and long-lasting [1-18-26]. Biodegradable plastics are produced using petro-chemicals just like conventional plastics except some additives are included in their manufacturing which helps them in there fast degradation. Discarded plastic waste, owing to the durability and low degradability of these polymers, may take hundreds to thousands of years to decompose [1-44]. Consequently, oceans and landmass are infested with plastics [1-18-26]. The vast accumulation of end-of-life plastic has put the ecosystem under unprecedented strain. In terms of environmental consciousness, plastic waste has become one of the main global challenges [1-18]. However, the ocean is being harmed by plastic, the land and freshwater are not immune to the effects of plastic contamination [1-18-26-44]. In fact, more than 10 million tons of plastic waste is dumped in the oceans alone, so that the majority of anthropogenic debris littering the oceans is composed of human-made plastics [1-44]. This anthropogenic debris threatens ocean safety, integrity, and sustainability [1-18-26]. Plastic litter pollution in the oceans is increasingly emerging as a serious global environmental concern [1-18]. Since 1950, approximately 8.3 billion tons of plastic have been produced, with an estimated 6.3 billion tons disposed of as waste [1-18]. Notably, ocean plastic litter stemming from discarded plastic containers washed into the sea has gradually deteriorated, fragmenting into microplastics [1-18-44]. This process causes ecological and marine environmental degradation, garnering widespread attention. Plastics, which take a long time to decompose and are immune to natural processes, account for a large portion of household and industrial waste (10–30%) [1-18-26]. They contain chemicals that can pose a risk to the atmosphere, and they need more resources to manufacture. The accumulation of plastic waste obstructs water and oxygen flow, causing harm to the atmosphere and all living things [1-18-26-44]. Overall, plastic waste contributes to a pressing environmental problem is as yet unsolved. The production of synthetic plastics, particularly non-degradable ones, is an environmental burden. This is because 'non-degradable' plastics take decades or centuries to break down [1-18-26]. The traditional way of disposing of plastic waste was to dump it in landfills [1-18-26]. Because of environmental issues and insufficient garbage capacity, the emphasis is now on recycling waste materials [1-44]. Recycling also has a number of issues, including difficulties in recycling due to a complicated polymer composition, lack of specific beneficial properties, and the need for advanced technologies or more resources [1-18-44]. Dust and toxic gases (CO_2, NO_x, and SO_x) are released into the atmosphere as traditional plastic composites are recycled. Non-biodegradability of certain plastics suggests that their chemical structure cannot be adequately modified by naturally occurring microorganisms, water, carbon dioxide or methane to degrade them [1-18-26]. Meanwhile, 'biodegradable' plastics are truly compostable materials that can almost entirely be converted into benign trash after a matter of months in a composter [1-18-44]. A novel way out of the increasing rate of demand for plastic packaging is to adopt biodegradable plastics [1-18-26-44].

Plastics have become commonplace manufacturing materials that find applications in a variety of industries, from packaging to the production of toys, from grocery bags to plastic cutlery, from straws to 3D printed rocket nozzles [1-18]. Chemically, plastics are high molecular weight polymers typically comprising between 1000 to 10000 monomeric repeating units [1-18-26]. Conventional petroleum-based synthetic plastics are produced in a series of steps, the first of which is the distillation of crude oil in an oil refinery [1-18]. This process separates and fractionates the heavy crude oil into groups of lighter components, called segments [1-18]. Each segment is a mixture of polymeric hydrocarbon chains, which differ in terms of size and structure [1-18]. One of these fractions, naphtha, is the crucial component needed to generate monomers such as ethylene, propylene, and styrene to produce plastics [1-18-26]. These monomers form plastics through poly-addition and/or polycondensation aided by specific catalysts [1-26]. However, this conversion produces pollutants and greenhouse gases such as carbon dioxide (CO_2), thus contributing to environmental pollution and global warming [1-18-26-44]. Moreover, several petroleum-based plastics are non-biodegradable, which leads to their persistence at the site of disposal and harms the environment [1-18-26-44]. Over two recent decades, several studies have suggested alternatives to the conventional petroleum-based plastics [1-18-26]. One such alternative is bioplastics, which are polymeric compounds that are both functionally like synthetic plastics and largely environmentally sustainable [1-26]. However, bioplastics are surrounded by myths, for example, all bioplastics are biodegradable and good for the environment. The truth is that some bio-plastics may contribute significantly to global warming pollution, and drastic land use change [1-18-44].

According to **Atiwesh** et al., (2021) [1], not all petroleum-based plastics are non-biodegradable [1-18]. For example, polycaprolactone (PCL) and poly(butylene succinate) (PBS) are both petroleum-based plastics which can undergo microbial degradation [1-18-26-44]. However, the biodegradability of these polymers is affected by their physicochemical properties such as degree of cross-linking, degree of crystallinity, molecular weight and the species of microorganisms used [1-18-26]. Indeed, studies have revealed that cross-linked polymers have the lowest rate of degradation, followed by crystalline and then amorphous polymers [1-18-26-44]. Therefore, this review is intended to highlight the biodegradable plastic,identified the limitations and advantages of these biodegradable plastics [1-18-26].

2. Bioplastics

The environmental problems caused by discarded synthetic plastics have paved the way for the search for substitutes [1-18-44]. Therefore, it is vital to state that bio-based plastics are not constantly recyclable and that recyclable plastics are not constantly bio-based [1-18-26]. There is a mixed-up between biodegradable plastics and plastics that are bio-based. Both are considered eco-friendly plastics; both are not similar concerning the original concept [1-18-26]. Biodegradable plastics production is from the biodegradability perspective, while biomass is adopted as the raw material in place of oil in bio-based plastics production [1-18]. Bioplastics, which are both functionally similar to synthetic plastics and environmentally sustainable, are touted as promising new materials to address these problems [1-18]. Bioplastics is a term used to refer to plastics that (1) are biodegradable, such as PCL or PBS; or (2) may or may not be degradable but are produced from biological materials or renewable feedstock, such as starch, cellulose, vegetable oils, and vegetable fats [1-18-44]. Like any other polymeric material, the degradability of bio-plastics is also a factor of their composition, degree of crystallinity and environmental factors, leading to degradation times ranging from several days to several years [1-18]. For these reasons, the development of biodegradable bioplastics has gained attention in recent years [1-18]. The term "biobased" refers to the origin of the substance, which might be partly or completely biobased [1-18]. Conventional plastics are fossil-based, made from non-renewable natural resources [1-18]. Renewable biomass, or plants, is used to make biobased polymers [1-18]. Sugarcane, cassava, and corn are some of the most popular plants utilized to produce bioplastics [1-18]. Some biobased polymers are biodegradable. However, not all biobased plastics are biodegradable [1-18]. The term "biobased" solely refers to the material's manufacturing process biodegradable [1-18]. Furthermore, producing bioplastics from plants such as corn and maize requires repurposing of land for producing plastic instead of fulfilling food requirements [1-18]. A recent statistical study revealed that almost a quarter of the agricultural land producing grains is used to produce biofuels and bioplastics [1-18]. As more agricultural land gets used to produce biofuels and bioplastics, there may be a significant rise in food prices, affecting the economically weaker sections of the society [1-18].

A variety of bioplastics have been developed to address environmental issues associated with conventional petroleum-derived plastics – from well-known and well-studied biodegradable and/or bio-based plastics like PHB, PCL and PLA to recent additions such as mycelium based and chitin-based biopolymers [1-18]. It should be understood that similar to petroleum-based plastics, some bio-based plastics cannot be recycled [1-18]. Consequently, many biodegradable bioplastics end up in landfills, which decompose gradually and produce methane gas [1-18]. For these reasons, people are starting to believe that bioplastics should be used only when needed, with tailor-made properties [1-18]. However, the harms associated with bioplastics are still less severe when compared to conventional plastics [1-18].

The most considered bio-based and eco-friendly plastic resources examined currently are PLA and polyhydroxyalkanoates (PHAs) [1-18]. The starting material for PLA and PHA production is extracted from annually renewable plant materials [1-18]. This ensures that all aliphatic polyesters will, in theory, be processed sustainably. These bio-based plastics may be restored to CO_2 and then be photosynthesized by plants because they are biodegradable The development of PLA and PHA can thus be considered carbon-neutral and null pollution processes [1-18]. Bio-based and biodegradable plastics, including PLA and PHA, are commonly called eco-friendly and renewable, decreasing fossil fuels [1-18].

Embracing bioplastics in the food packaging industry offers several advantages [1-44]. Firstly, the manufacturing process of bioplastics emits fewer greenhouse gases compared to their conventional counterparts, which is a considerable step towards mitigating climate change [1-44]. The base materials for bioplastics, such as corn, food waste, and other plant-based raw materials, are renewable, offering both sustainability and the possibility of a more circular economy [1-44]. Some bioplastics are also biodegradable under certain conditions, potentially reducing the volume of waste destined for landfills [1-44].

As the consequential environmental impact of traditional plastics becomes increasingly apparent, the introduction of bioplastics has ignited a beacon of change [1-44]. Among the most alluring attributes is the capacity of some bioplastics to degrade, thereby potentially reducing the magnitude of non-biodegradable waste plaguing our lands and seas [1-44]. Furthermore, feeding into the cycle of a circular economy, the raw materials for bioplastics are renewable, which provides an advantage over non-renewable petroleum-based plastics. Even during their production, bioplastics contribute significantly less to greenhouse gas emissions than traditional plastics, a decisive factor in the current struggle against climate change [1-44]. Yet, despite these perceivable benefits, the environmental contribution of bioplastics is not wholly positive [1-44]. A balanced interpretation of the environmental impact demands a more nuanced understanding of the bioplastics pros and cons [1-44]. There exist considerable problems associated with biodegradable plastics, from the land required for their biomass production to the complex and specific composting conditions needed for them to degrade. The consequences of these challenges should be understood and factored into

any decisions about the transition towards bioplastics in food packaging [1-44]. As consumers become increasingly environmentally conscious, the use of bioplastics can also offer businesses a competitive advantage, meeting consumers' demands for more sustainable packaging options [1-44]. However, it is important to remember that while the pros of plastic can not be disregarded, the cons of plastic—particularly concerning environmental impacts—often outweigh them [1-44].

3. Advantages of Bioplastics

1. Reducing Carbon Emissions with Bioplastics: A key advantage of bioplastics lies in their potential to reduce carbon emissions [1-44]. Traditional plastic production is a highly energy-intensive process involving petroleum extraction and refining, both of which contribute significantly to greenhouse gas emissions. On the flip side, bioplastics, derived from plant raw materials, have a double effect on carbon sequestration. Firstly, the plants absorb carbon dioxide during their growing phase, which counteracts greenhouse gas emissions [1-44]. Secondly, the use of these plant-based materials in place of petroleum not only reduces our reliance on finite fossil fuels but also reduces the carbon emissions associated with the production process. Some studies suggest that replacing traditional plastics with bioplastics could result in a 25% reduction in carbon dioxide emissions, supporting the fight against climate change. However, it's crucial to remember these potential benefits need to be balanced against the cons about plastic, primarily their ability to fully degrade without leaving toxic leftovers [1-44]. **2**.Enhancing Food Safety with Bioplastics: Food safety forms another crucial context in the bioplastic discussion. Bioplastic products, being generated from natural materials, pose less of a threat in terms of chemical pollution. Certain petroleum-based packaging materials could potentially leach harmful chemicals into food, particularly under high temperatures. Bioplastics present an alternative with a lesser risk of such chemical leaching, making them a safer choice for food packaging in many cases [1-44]. **3**. Embracing Environmental Responsibility: By shifting to bioplastic packaging, companies can lower their environmental footprint, contributing positively to global sustainability efforts. This shift signals a commitment to environmental responsibility, aligning the brand with the values of environmentally-conscious consumers [1-44]. 4**.** Enhancing Brand Image and Reputation: As consumers become increasingly aware of environmental issues, companies using bioplastic packaging could boost their brand image and reputation. Showcasing a commitment to sustainability can differentiate a brand from its competitors and foster a stronger emotional connection with consumers. **5**. Potential Cost Reductions: The price of petroleum-based plastics is tied to the volatile oil market. In comparison, the costs of producing bioplastics, especially those made from food and industrial waste, are likely to decrease in the future as technology improves and economies of scale come into play. **6**. Reaping Regulatory Benefits: As legislation becomes increasingly environment-focused, companies using bioplastics might benefit from regulatory incentives or avoid future penalties associated with traditional plastic use [1-44]. **7**. Moreover, being derived from renewable resources like corn or sugar cane, there's the argument that bioplastics could indirectly support food safety by lessening the soil and water pollution associated with oil drilling and petroleum refining. **8**. When comparing the manufacturing processes of bioplastics and traditional plastics, significant differences emerge, largely stemming from the materials used [1-44]. However, it's essential to note that the sustainability of both processes heavily depends on factors such as source material production, energy use in manufacturing, and final product disposal [1-44].

Traditional plastics are manufactured from petroleum, a non-renewable resource [1-44]. The petroleum is processed and converted into polymers, forming the basis for different types of plastics [1-44]. This production process is energy-intensive and contributes substantially to greenhouse gas emissions [1-44]. Bioplastics, on the other hand, are derived from renewable plant resources such as corn, sugarcane, or cassava. The process typically involves fermenting sugars from these crops to produce polylactic acid (PLA), a common type of bioplastic [1-44]. Other bioplastics, like Polyhydroxyalkanoates (PHA), are produced from microorganisms that consume plant sugars. Although the production process also requires energy, it's generally considered more sustainable due to the renewable nature of the inputs and the lower carbon emissions [1-44].

Bioplastics, also known as biodegradable plastic, are creating a buzz in the world of materials [1-44]. Derived from renewable resources, these substances stand as promising alternatives to traditional plastics, which pose significant environmental challenges [1-44]. As definitions go, bioplastics are a form of plastic derived from renewable biomass sources such as corn starch, and food waste, among others, as opposed to conventional plastic derived from petroleum [1-44]. Bioplastics bear their origins in an array of plant-based raw materials, signifying a significant shift away from fossil fuel-based traditional plastics [1-44]. Several types of bioplastics have emerged, each derived from unique plant sources and used for different applications [1-44].

However, it is worth noting that not all bioplastic categories are biodegradable, and even within the biodegradable category, some require specific disposal procedures to decompose completely [1-44]. On the other hand, some non-degradable bioplastics represent a significant step forward due to the renewable nature of their raw materials, therefore

offering a smaller carbon footprint than petroleum-based products [1-44]. As with every material, assessing bioplastics pros and cons is imperative to understanding their potential usability and impact [1-44].

4. Biodegradable Plastic

Biodegradable plastics are being the substitute for synthetic plastics and widely been used in order to combat plastic pollution [1-18]. Yet not all biodegradable plastics are degradable especially when it does not meet its favorable conditions, and also when it comes to aquatic environments [1-18]. Biodegradable plastic that is commercially available has its own advantages and limitations respectively upon degradation in both freshwater and marine environments [1-18-44]. There is a growing demand for bioplastic as an alternative to synthetic plastic which causes plastic waste pollution [1-18]. Biodegradable polymers were seen as the solution to replace synthetic plastic in combating plastic pollution [1-18]. Production of bioplastics are dramatically increasing over the years and expected to continue increasing by 2026 as the biodegradable plastic was seen as a solution to combat plastic pollution [1-18]. Commercialised biodegradable plastic is said to be 100% biodegradable in the environment, yet the fact is a myth. Not all biodegradable plastics are compostable [1-18-44]. Studies have shown that biodegradable plastic does biodegrade, yet it biodegrades into smaller particles forming microparticles [1-18]. In general, microparticles might degrade or might not degrade in the environment where there is no evidence to prove the consequences of it [1-18]. There are possible risks in the wide usage of biodegradable plastics in terms of accumulation in the open environment due to improper usage or disposal and management, and shift between environments that need to be considered [1-18-44]. Despite all the uncertainty of the possible negative impacts of biodegradable plastics, there are advantages or mileage that biodegradable plastic could offer. Biodegradable plastics that are bio-based could reduce the carbon footprint during the plastic production phase as well as could save the non-renewable natural resources as the plastics were derived from renewable natural resources [1-18-44]. Besides, byproducts from biodegradation result in zero waste accumulation and improve the environment without disrupting the biogeochemical cycle [1-18]. In fact, biodegradable plastic has been said to metaphorically take and giving back to the environment without any additional elements added that may cause undesirable consequences [1-18]. Basically, understanding on biodegradable plastics is still shallow that require more evidence and prove that shows the behaviour of biodegradable plastic [1-44].

Biodegradable plastics can be classified based on the different types of biodegradable plastics manufactured and commercialized according to the properties that can fit different industries that have specific needs and requirements [1-44]. According to their source, biodegradable plastic can be divided into two categories, biobased and petroleum-based [1-44]. Basically, biobased plastics are produced of renewable resources as the main component of the polyester such as polysaccharides, proteins, and microbial polyesters while petroleum-based plastic are formed of synthetic polymers such as aliphatic polyester and aromatic polyester. In regard to application, biodegradable plastics are commonly and widely used in different sectors to replace synthetic plastics.

Bio-based biodegradable plastics are made from biomass feedstock material that has the property to biodegrade [1-18-44]. It is also an enzymatically degradable plastic [1-18]. PLA is the biodegradable aliphatic polyester used extensively around the globe [1-18]. The monomer that results from the fermentation of glucose such as cane sugar, corn, potatoes, and tapioca is used to create degradable PLA plastic [1-18]. It has properties such as high strength, stiffness, strength, and biocompatibility, eco-friendly, processability, and energy-saving [1-18-44]. Polysaccharide used in the making of biodegradable plastic includes plants, animals, fungi, and bacteria [1-18]. Meanwhile, fossil-based biodegradable plastics are made from the combination of fossil resources and bio-based biodegradable plastic that improves its properties and biodegradability [1-18]. Biodegradable plastic can be degraded in various ways according to the environment that it ends up in [1-18]. Degradation can be varied according to the factors and conditions that are present in certain environments. As a result, most plastics firms will not be interested in economic research to help select biodegradable plastics that are economically cost-effective [1-18]. Despite the fact that some biodegradable plastics have demonstrated excellent mechanical, degradable properties and physicochemical in various industrial use, it is widely acknowledged that biodegradable plastics are not yet a viable replacement for synthetics plastics [1-18]. With the rise of biodegradable plastics, there is a need to address a knowledge gap in this field [1-18-44]. As a result, it is still debatable whether biodegradable plastics can be a viable long-term option for achieving sustainable development goals for plastics manufacturing and reducing global plastic pollution [1-18]. The opportunities and challenges of solving environmental plastic pollution and factors driving the uptake of biodegradable plastics perspectives are also raised [1-18-44].

Biodegradable plastics are plastics that degrade under specific conditions after use. They can be handled similarly to general plastic products, but after use, they degrade at the molecular level through the action of microorganisms present in the natural environment, ultimately transforming into carbon dioxide (CO_2) and water (H_2O) [1-18]. Biodegradable plastics can be categorized into three groups based on raw materials and manufacturing methods [1-18]. Microbially

produced: Biodegradable plastics are manufactured utilizing microorganisms [1-18-44]. Natural extracted: Derived from cellulose found in plants, corn, other grains, potatoes, and similar sources [1-18].

Chemically synthesized: Produced through chemosynthetic reactions [1-18]. Biodegradable plastics offer significant environmental benefits due to their ability to decompose naturally through the action of microorganisms, ultimately breaking down into water and carbon dioxide [1-18-44]. This decomposition is especially effective in compost systems, where these plastics contribute to the production of high-quality organic fertilizer without negatively impacting its quality [1-18]. Additionally, when incinerated, biodegradable plastics have a low calorific value, which prevents damage to incinerators and minimizes atmospheric pollution [1-18]. These characteristics make biodegradable plastics ideal for products used in natural settings or in applications where recycling is challenging [1-18-44]. Biodegradable plastic bags are made from all-natural plant-based raw materials that enable the natural decomposition process which is achieved when the bacteria and fungi present in the surrounding environment naturally metabolizes the plastics and helps to further breakdown the structure of a biodegradable plastic [1-18]. The end result of which is less harmful to the environment as compared to regular plastic bags [1-18-44].

Biodegradable bag products are made from non-hazard and harmless substances that produce just 32% of greenhouse gases compared to traditional plastic products. Biodegradable plastic takes 35% less energy to manufacture than non-biodegradable plastic [1-44]. The use of biodegradable goods reduces reliance on fossil fuels and non-renewable resources [1-44]. These are made of organic materials, which helps reduce waste, a significant source of land, water, and air pollution. These goods are reusable and recyclable, which helps to reduce waste. Biodegradable plastic has the potential to create an entirely new industry. The products represent an innovative approach to lowering carbon and waste footprints [1-44]. Switching to this product helps to reduce the environmental effect of pollution. They are goods that promote long-term business [1-44].

5. Types of Biodegradable Plastic and Uses

Biodegradable plastic (or biodegradable polymer) is a synthetic compound that can decompose over time through living organisms, eventually breaking down into water, carbon dioxide, and leftover material called biomass [1-44]. Biodegradable plastic's ability to naturally degrade within an organic time frame makes it unique from other plastics, which can take hundreds or thousands of years to break down. There are several recognized types of biodegradable plastics, including Polyhydroxyalkanoates (PHAs), Polylactic acid (PLAs), plant starch blends (like corn starch), and cellulose-based plastics [1-44]. There are a few notable differences between biodegradable plastic, bioplastic, and compostable plastic: **Biodegradable plastic** refers to any plastic that can degrade naturally through living organisms, regardless of the original material from which it derives. Plastic can be biodegradable without being a bioplastic or being considered "compostable plastic [1-44]. **Bioplastic** is a term that describes any plastic made from renewable raw natural materials. While some bioplastics are biodegradable or compostable, many of them are not, meaning they won't break down even though they're made of natural materials [1-44]. **Compostable plastic** is a term that describes plastics that need specific conditions to break down, rather than the less complex conditions of biodegradable plastics. While biodegradable plastics can break down in a more natural environment, compostable plastics usually require industrial composting facilities. In general, biodegradable plastics take between three and six months to decompose when left exposed to oxygen or light [1-44]. Regular plastics can take up to 1,000 years to reach the same levels of decomposition [1-44]. Biodegradable plastic's ability to break down within a year means it has several advantages over traditional plastics: I**t decreases the waste sent to landfills or incinerators** [1-44]. When you toss traditional plastic into the trash, it has a negative environmental impact because it can wind up in landfills, where it can potentially sit for hundreds of years, or incinerators, where it will be burned and release harmful chemicals into the natural environment. Conversely, biodegradable plastic has an environmental benefit: it will break down in a landfill and doesn't need to be burned. **It takes less energy to manufacture**. The manufacture of biodegradable plastics often takes less energy than traditional plastics, meaning that it takes fewer fossil fuels and produces fewer greenhouse gas emissions that harm the planet. I**t releases fewer harmful substances when breaking down**. While traditional plastics can leach toxic chemicals into the environment as they sit, well-made biodegradable plastics should break down with few harmful byproducts. Instead, biodegradable plastics release a combination of water, carbon dioxide, and biomass (which is often simply leftover plant materials) [1-44]. 1. **Food packaging**: Manufacturers can make biodegradable food packaging out of a range of items, from cheese byproducts to almond shells. Common biodegradable plastic products include takeout containers, carry-out bags, and coffee cups. 2. **Disposable tableware**: Biodegradable plastic plates, cups, and utensils are easy to find on the market—some have the texture of paper or cardboard while others feel smoother like traditional plastic. 3. **Plastic bags**: There are many biodegradable plastic bags in circulation, including shopping bags, produce bags, and other single-use bags. 4. **Packing peanuts**: While traditional packaging peanuts were made from non-biodegradable polystyrene, there are now many starch-based packaging peanuts available that are biodegradable [1-44]. 5. **Plant pots**: Many companies now package their plants in biodegradable containers, meaning the packaging can

be planted straight into the ground and will decompose naturally in the soil. 6. **Medical products**: Many medical materials like surgical sutures and wound dressings are made from biodegradable material, so they naturally break down without needing an invasive technique to remove the material [1-44].

Bio-based and compostable plastics such as polylactic acid (PLA), polyhydroxyalkanoates (PHA), polybutylene succinate adipate (PBSA), and polybutylene succinate (PBS) have emerged as alternatives to existing commodity plastics [45-57]. Additionally, studies have demonstrated that thin biodegradable plastic films can attain outstanding barrier properties, but they often required the application of additives such as cellulose or nanoclay or specialized techniques such as electron beam-mediated cross-linking [45-57]. Researchers have evaluated a range of biopolymers for their usefulness as bio-plastic materials, e.g., cellulose, starch, collagen, casein, plant proteins [47-57]. Rutin induced Chitosan/Poly (vinyl alcohol) bioactive films were developed by using solvent casting technique [45].

In recent years, biodegradable polymers have garnered attention because of their ability to degrade into nontoxic and environmentally friendly materials [58]. Bioactive films showed strong antimicrobial activity against *E. coli* and *S. aureus* bacteria [45]. The overall migration of components of bioactive films in different food simulants were within the permitted limits of 10 mg/dm2 [45]. Hence, rutin induced CS/PVA bioactive films have potential to be used for improving food quality and extending the shelf life of food [45]. Rutin (3,3 ,4 ,5,7-pentahydroxyflavone-3-rhamnoglucoside) is a flavonol, abundantly found in plants, such as passion flower, buckwheat, tea and apple [45]. Tea leaves, apples and many more possess rutin as one of the active constituents [45]. Conventionally, rutin is used as an antimicrobial, antifungal, and anti-allergic agent [45]. The exploration of bioactive compounds in food packaging has received increasing attention in recent years due to consumer concerns about the use of synthetic preservatives [45]. The bioactive compounds used for the development of food packaging are mainly nontoxic, used as protective materials to maintain the quality and extend shelf life of food [45-57]. Organic acids, essential oils, fatty acids, fruit and plant extracts such as *Spathodea campanulata* extracts [46], *Phyllanthus reticulatus* anthocyanin [47], *Piper betel* leaves extract [48], *Solanum nigrum* L. leaf extract [51], *Piper nigrum* leaves extract [52], *Basella alba* stem extract [53], turmeric rhizomes (*Curcuma zedoaria*) [55], and *Syzygium cumini* leaves extract [56], and agricultural waste products etc. are all bioactive compounds with effective antimicrobial and/or antioxidant properties useful for preparation of active food packaging films [45-57]. Biopolymers have been widely used for the development of food packaging films as they are excellent vehicles for incorporating a wide variety of additives such as antioxidant, antifungal and antimicrobial agents [45-58]. Among the biopolymers, chitosan (CS) is the most interesting for food packaging as it is non toxic, biodegradable and biocompatible [45-57]. Wheat gluten is one of the most important biopolymers due to its low cost and high content of hydrogen bonds in the film [45-57].

6. Advantages of Biodegradable Plastics

1. Reduction in Carbon Emission: One of the main advantages of using biodegradable polymers to make plastic bags is the significant reduction in the carbon emissions that happen during the manufacturing process as compared to that of regular plastic. Not just that, since the materials used to create biodegradable plastics are plant based, minimal carbon is emitted during the composting processes [1-44]. **2**. Lesser Energy Consumption: While the initial investment might be slightly higher, in the long run biodegradable plastics require lesser amounts of energy and require fossil fuels to be reprocessed in order to create polymers. What's more – lesser the energy requirements, lesser the pollution and environmental impact [1-44]. **3**. Eco-Friendly Disposable Solution: Biodegradable plastics require composting or recycling to ensure proper breakdown of the plastic pieces to enable the natural composting process. The requirement to properly dispose/process biodegradable plastic products automatically reduces the amount of waste that would otherwise be sent to landfills. **4**. Recyclable Material: Apart from taking a significantly lesser time to breakdown as compared to regular plastic, biodegradable plastic can also be further recycled to create more plastic by products [1-44]. The use of plant based oils to make biodegradable plastics also ensure its integrity (they contain no chemicals or toxins compared to other types of plastics). **5**. Sustainable Raw Materials: Bioplastics are derived from renewable resources like corn, sugarcane, and food waste, reducing dependency on fossil fuels [1-44]. **6**. Lower Carbon Footprint: The production of bioplastics generally releases fewer greenhouse gas emissions compared to traditional plastics, contributing positively to climate action efforts. **7**. Potential for Biodegradability: Certain types of bioplastics can degrade in suitable environments, lessening the burden of plastic waste in landfills. **8**. Confusion in Disposal: Not all bioplastics are biodegradable, which can lead to confusion in waste management and improper disposal. **9**. Land Use Conflicts: The production of biomass for bioplastics could potentially conflict with agricultural land for food production. **10.** Industrial Composting Required: Some bioplastics need specific industrial composting conditions to decompose properly, which may not be widely available [1-44].

Another benefit lies in the sector of waste management: when biodegradable plastics are disposed of under appropriate conditions, they can break down without leaving harmful toxins behind, unlike traditional plastics 1-44]. Biodegradable

plastics possess the ability to decompose in the natural environment, reverting to soil and seawater. Conversely, biomass plastics utilize renewable organic resources like plants as raw materials, reducing reliance on fossil fuels such as petroleum [1-44]. Moreover, the adoption of "mono-materials" facilitates efficient material recycling, contributing to the realization of a circular economy [1-44].

7. Disadvantages of Biodegradable Plastics

While biodegradable plastics have numerous advantages, they do have some drawbacks as well [1-44]. As mentioned earlier, biodegradable plastics need specific conditions to decompose, meaning the natural breakdown of this plastic will not occur if it is sent to the landfill along with other waste [1-44]. A special composting system is required to ensure proper recycling/processing of biodegradable plastic bags. The other drawback to biodegradable plastics is that if they are not disposed properly and mix with regular plastics, they become contaminated and cannot be used anymore [1-44]. But, in spite of the minimal drawbacks of biodegradable plastic, it is still becoming a popular alternative to regular plastic, especially due to the growing awareness for environmental safety. Plus, the advantages of biodegradable plastics totally outweigh the disadvantages making it a better choice as compared to plastic polymers that have been used traditionally [1-44].

7.1. Cost of Production to limit the India Bio Plastics Market growth

Bio-plastics are more expensive to produce compared to traditional petroleum-based plastics [1-44]. The higher production costs are a significant barrier to widespread adoption, especially in price-sensitive markets. The availability of feedstock, such as crops and biomass, is constrained by factors like climate conditions, land use, and competition with food production [1-44]. Dependence on specific feed stocks create challenges in ensuring a stable and sustainable supply chain, which significantly restrains the India Bio Plastics Market growth [1-44]. While bio-plastics are often marketed as biodegradable, the conditions required for effective biodegradation are present in all environments. Improper disposal practices, including sending bio-plastics to landfills without the right conditions for degradation, undermine their environmental benefits. Evolving and uncertain regulatory frameworks impact the Indian bio-plastics market [1-44]. The lack of clear standards and regulations creates uncertainties for businesses and investors [1-44].

8. Biodegradable Plastics: Consumer Demand and challenges

These days, biodegradable plastics manufactured from renewable biomass are a hot topic. Plastics manufactured from renewable raw ingredients such as cellulose, bioethanol, starch, and lignin are commonly used in biodegradable products 1-44]. Polylactic acid (PLA), poly (hydroxy alkenoates) (PHA), poly (hydroxybutyrate) (PHB), poly (hydroxybutyrate-co-valerate) (PHBV), and poly (hydroxy valerate) (PHV) already exist on the market as the most common biodegradable and commercially available natural polymers. Biodegradable plastics can be biodegraded without causing any negative consequences due to their perseverance [1-44]. Biodegradable plastics are now being used effectively in several industrial and environmental initiatives [1-44]. Consumers and manufacturers are trying to discover alternative materials to replace plastics and microplastics, and biodegradable plastics have emerged as a viable option 1-44]. Theoretically, investments in biodegradable plastics, better than traditional plastic composition, were undertaken by a more extensive range of plastic producers, and therefore two concerns were created [1-44]. The big concern is adoption and how it can be handled globally. Due to the cost of biodegradable plastics, most consumers are stopped from patronizing them. This may seem to be because most people do not know enough about biodegradable plastics' utility and protection [1-44].

Biodegradable plastics decompose, and the volume of rubbish created decreases significantly, resulting in less landfill waste. There is less total waste to manage since less junk takes up space in landfills [1-44]. In addition, several biodegradable plastic bag manufacturers in India have their capabilities and product offerings. By examining these factors and selecting a reliable manufacturer, you can ensure that you get quality biodegradable plastic bags that meet your needs while having the lowest possible environmental impact [1-44].

Biodegradable plastics decompose in environments such as soil or water, or in compost [1-44]. In other words, creating an environment conducive to microbial activity is crucial for plastics to decompose effectively [1-44]. However, biodegradable plastic agricultural mulch film typically takes several months or longer to decompose, while biodegradable plastic garbage bags break down into smaller pieces more quickly [1-44].

The rate of degradation of biodegradable plastics is highly reliant on microbial activity and the surrounding environment. Biodegradable plastics generally incur higher production costs compared to conventional plastics. This is due to the labour-intensive development and production processes [1-44]. Additionally, the utilization of plant-derived

raw materials increases raw material costs in contrast to fossil fuels (e.g., petroleum). While biodegradable plastics naturally degrade, the recycling process to reuse them as recycled resin may become challenging [1-44]. In particular, if marine biodegradable plastics* become predominant in the future, reusing them may become challenging, leading to a higher proportion being sent to landfills or incinerated, potentially impacting the recycling system.*Marine biodegradable plastics: Plastics that are degraded in the ocean by the action of enzymes produced by microorganisms. Biodegradable plastic snack food packaging labeled as "compostable" has sparked consumer complaints [1-44]. The "100% compostable package" faced criticism from users due to the bag wrinkling and emitting a loud noise when snacks were removed. Eventually, the manufacturer introduced a different biodegradable product that was "quieter," resolving the issue [1-44]. These early efforts in using biodegradable plastics underscore the importance of "anticipating and addressing new challenges proactively from the consumer's perspective. "Addressing environmental concerns in plastic waste involves promoting biodegradable plastics, biomass plastics, and material recycling with mono-materials [1-44].

There are four major challenges to the widespread use of biodegradable plastics: 1. Technical issues in biodegradable plastics manufacturing 2. Establishment of evaluation and certification systems for manufactured products 3. Development of composting facilities 4. Reduction of production costs. Biomass plastic" refers to plastic derived from plant-based materials. Originally, it was categorized as carbon-neutral because it utilizes plant-derived materials (plants absorb CO_2 and water for growth), thereby not contributing to the increase in CO_2 concentration in the atmosphere. The following four issues need to be addressed to promote the use of biomass plastics: 1. Higher price compared to materials derived from fossil fuels (e.g., petroleum). 2. Some biomass plastics do not biodegrade [1-44]. 3. Certain biodegradable biomass plastics, assumed to degrade on the ground by microorganisms, do not easily degrade in the ocean. 4. The raw materials for biomass plastics are crops such as sugarcane and corn, so increasing production for bioplastics will impact sales of food crops. While biodegradable may aid in the environment conflict against traditional plastics, it does have some drawbacks: It may not break down completely. While scientists have yet to determine the effects of biodegradable plastic, there is evidence that certain types do not break down completely [1-44]. When biodegradable plastics only partially break down, it can be even more harmful to the environment than if it had stayed whole since the smaller pieces (called microplastics) become harder to clean up or identify. **It can release harmful substances when breaking down**. While biodegradable plastic releases fewer harmful chemicals when breaking down, that doesn't mean it's harm-free—certain types of biodegradable plastics can release harmful substances like metals and methane [1-44]. It reinforces a single-use mindset. Biodegradable plastic reinforces the idea of single-use materials, encouraging excess waste production as a sustainable practice [1-44]. This mindset can have negative consequences because consumers may turn to biodegradable plastics as the best solution for environmental issues, passing up more environmentally friendly practices such as low- waste living, recycling, prioritizing organic materials, and composting food waste. It's expensive to produce. Biodegradable plastic is more expensive to produce than traditional plastic, making it challenging to encourage plastic manufacturers (without incentives) to switch to biodegradable plastic for their products and packaging [1-44].

9. Biodegradable Plastics Manufactures in India

Bioplastics are a type of plastic derived from renewable biomass sources, such as plants, rather than traditional petrochemical sources like oil and natural gas [27-44]. These plastics are considered more environmentally friendly compared to conventional plastics because they often have a smaller carbon footprint and are derived from renewable resources [27-44]. Many bio-plastics companies in India are incorporating sustainability into their business strategies, including the adoption of bio-plastics to reduce their environmental footprint [27-44]. Corporate social responsibility (CSR) initiatives often involve the use of eco-friendly materials, further boosting the demand for bioplastics [27-44]. Bio-plastics are finding applications in various industries, such as packaging, agriculture, automotive, and textiles [27-44]. The versatility of bio-plastics and their suitability for different uses contribute to their adoption in diverse sectors. Commitment by large companies (both Indian and MNCs) is expected to move towards 100% recyclable plastic packaging by 2025 [27-44].

The Indian bio plastics market is still in its early stages, with only a handful of companies currently operating in this segment [27-44]. The support from environmental awareness programs, the ready availability of feedstock, and government backing are crucial factors bolstering bioplastics manufacturers in India, which is expected to boost the Indian Bio Plastics Market growth. However, there is a need for more initiatives to enhance production, develop raw materials, and advance technology [27-44]. Initiating environmental awareness campaigns and emphasizing the long-term benefits of bio-plastics are essential steps toward instigating this change. The National Green Tribunal's state-level committee set a deadline of August 31, 2019, for the government to enforce the ban on conventional plastic, adding urgency to the need for sustainable alternatives [27-44]. Scientists across India are actively involved in bioplastic development, with a recent breakthrough from IIT-Guwahati leading to the commercial production of a new bioplastic. Following are the few bioplastic manufactures in India [27-44].

- The 'SKYi -FKuR Biopolymers Pvt Ltd' based in Pune, Maharashtra state, India is the first dedicated manufacturer of compostable biopolymer compound resins in India. The product portfolio of the FKuR group comprises the FKuR Kunststoff GmbH product groups marketed as Bio-Flex®, Biograde®, Fibrolon®, Terralene®, Terraprene® as well as the FKuR Polymers brands Macoprene®, Macolen® PE and Macolen® PP [27-44]. They produce the Bio-Flex® product range in India which are sophisticated and innovative resins comprising of renewability, biodegradability and compostability [27-44]. Bio-Flex resins are the most effective environment friendly alternative to single use plastic. As a distribution partner of FKuR, they also offer broad range of Biobased and/ or biodegradable resin grades like Terralene, Fibrolon & Biograde [27-44]. Address; SKYi FKuR Biopolymers Pvt Ltd Office: PAP-S-60, 63, 64, Chakan Industrial Area Phase 2, Sawardari, Chakan, Pune - 410501 [27-44].
- **EcoBharat** based in Telangana, India is a leading manufacturer of organic bags based in India [32]. The specialize in creating high-quality, eco-friendly bags that are made from biodegradable and compostable materials [32]. EcoBharat bags are designed to meet the needs of a wide range of industries, including agriculture, food processing, and packaging. K-Innovative Hub Pvt. Ltd.'s EcoBharat is a sustainable, CSR program with the goal of fostering environmental transformation and instilling a sustainable lifestyle in people [32].
- J&K Agro Industries Ltd has started its joint venture with Earthsoul India to launch the country's first integrated biopolymer facility that manufactures 100% bio-degradable and compostable products. The facility manufactures flower pots and trays for floriculture, carry bags for shopping, packaging material for foodstuff and meats, bin liners for hotels, etc. **Ravi Industries** in Maharashtra, Harita NTI Ltd and Biotec Bags in Tamilnadu are also the pioneers in Bio-plastics in India [27-44].
- The Indian market has the presence of a large number of players. 1. Envigreen 2. Ecolastic 3. Plastobags 4. Earthsoul India 5. Truegreen 6. Environmental XPRT 7. Corbion India PL 8. Envigreen Biotech India Private Ltd, 9. TORAY INDUSTRIES, INC. Biogreen, India's pioneering biotechnology company for biodegradable products, stands at the forefront of this movement [27-44]. Other companies such as Truegreen, Plastobags, Ecolife, and Envigreen are already contributing to bioplastics production in India [27-44].
- Symphony Polymers Ltd. has established itself as a market-leading organization by manufacturing and supplying a wide range of plastic bags [27-44]. They are introducing Oxo Biodegradable Garbage Bags, Oxo Biodegradable Plastic Bags, and Oxo Biodegradable Garment Bags as part of the quality-assured product collection [27-44].
- Deluxe Scientific Surgico Pvt Ltd, often known as DESCO INDIA, has been making Medical Scientific & Hospital Furniture under the DESCO BRAND since 2005, and they are India's quickest-growing manufacturing firm [27-44].
- Paper Trading Private Limited is a renowned manufacturer of Millboard sheets, Baseboards, Duplex boards, and various other products [27-44].
- Packman Packaging is one of India's top manufacturers of corrugated boxes, rolls, bubble rolls, bubble pouches, courier bags, POD jackets, duct tapes, e-commerce shipping bags, and other goods [27-44].
- Vmosa Extrutech, established in 2017, is a prominent manufacturer of 100% Compostable Monolayer Blown and ABA Blown Film Plants. Good quality Monolayer Blown Film Plants, ABA Blown Film Plants, and Multilayer Blown Film Plants are available [27-44].
- Balson Industries was founded in 1995 as a sole concern, and manufacturing began in 1996. Balson Industries was founded to produce BioOXO – Biodegradable Plastic Bags, Sheets, and Covers. They also make anti-static bags. They successfully produced BioOXO – Biodegradable Plastic in response to the need for environmentally friendly polythene goods [27-44].
- Biogreen Biotech [28] is a pioneer in developing sustainable and creative biodegradable solutions [27-44]. The company boasts a solid record of producing viable biodegradable plastic solutions with over 15 years of expertise [27-44].
- **Ecolastic Products Pvt. Ltd**., [31] headquartered in Hyderabad, India, is a bio-plastics manufacturing & research company established to innovate, design, develop & manufacture differentiated bio-plastic, biodegradable & compostable products [31]. India's premier research organisation DRDO (Defence Research and Development Organisation), Ministry of Defense, Govt. of India, has collaborated with Ecolastic to replace single-use plastic products with compostable and biodegradable products [31]. The product range includes Bags of all types (Garbage Bags, Carry Bags, Plant Bags, Bio-Hazard Bags, Garment Bags, Courier Bags and more) in various color options and sizes. Pouches, Wraps, Agri-mulch Films, Stretch Films, Cutlery, Cups, Glasses, Ear-bud & Candy sticks, Granules and compounds for manufacturing [31]. Ecolastic is the only company in India to be recommended by **NITI Aayog** and the only compostable manufacturing company to be designated as the Official Sustainability Partner of the G20 Summit. Address; 8th & 9th floor, Vamsiram Jyothi Valencia , Road No.2 , Banjara hills, Hyderabad - 500034 [31].

- **Adsum Eco Solution** Pvt. Ltd. is an Innovative and Dynamic organization. They strive to provide the best solution to plastic waste problem to make clean India [27-44]. Adsum Eco Solution Pvt. Ltd are supplier and marketer of world renowned biodegradable additives and compounds for all application of plastic industries [27-44]. They are also marketer and supplier of biodegradable finish product e.g, all type of carry bags and disposable plastic product. The solution to this problem is – **BIODEGRADABILITY** and product **Addiflex® [**27-44].
- Green Tech Bio Products is proud to the the first and the one and only manufacturer of hot-water soluble biodegradable pellets in India [27-44]. **This uniquely formulated proprietary formula – GreenPlast™ pellets are one of a kind**. With PVOH and industrial starch as base with additives such as vegetable oil derivatives and other natural , harmless non-plastic materials, they formulated raw material results in high-quality, water-resistant films and bags [27-44]. All bags and films can be dissolved with cold/hot water, 70°C or above, stirring until fully dissolved, which is usually less than 5 minutes [27-44]. If not dissolved, the bags and films can be composted to degrade 90% within 180 days in compostable conditions. Address: Green Tech Bio Products No 3, Sri Ram Colony, Nanjundapuram Road, Ramanathapuram, Coimbatore - 641045.Tamilnadu, India [27-44].

10. Indian Bioplastic Market Size

Indian Bio Plastics Market size was valued at USD 447.25 Mn in 2023 and the India Bio Plastics Market revenue is expected to reach USD 1809.51 Mn by 2030, at a CAGR of 22.1 % over the forecast period [38, 39]. The Indian biodegradable plastic market generated a revenue of USD 124.0 million in 2023 and is expected to reach USD 516.7 million by 2030 [38, 39]. The Indian market is expected to grow at a CAGR of 22.6% from 2024 to 2030 [38, 39]. In terms of segment, starch based was the largest revenue generating product in 2023 [38, 39]. In terms of revenue, the biodegradable plastics market in India is likely to grow at a significant CAGR of 12.5% over the forecast period [38, 39]. The growing population, increasing consumption of apparel, and increasing foreign investments are some of the major socio-economic factors that are likely to support [38, 39]. Moreover, the rising demand for biodegradable plastics for medical and personal care packaging applications is anticipated to fuel the market in the country [38, 39]. In June 2023, Niine Sanitary Napkins launched PLA-based biodegradable sanitary pads [38, 39]. With more than 90% of the pad decomposing property within 175 days [38, 39]. The entire package, including the outer cover and disposable bags, is biodegradable [38, 39]. The product offers great absorption, comfort, and leakage protection as compared to normal sanitary pads [38, 39].

Based on Product, the market is segmented into biodegradable bioplastics and non-biodegradable bio-plastics [38, 39]. The biodegradable bioplastics segment dominated the market in 2023 and is expected to hold the largest India Bio Plastics Market share over the forecast period [38, 39]. The biodegradable bioplastics segment in the Indian bio plastics market is a specific category within the broader bioplastics industry [38, 39]. Bioplastics, in general, are derived from renewable resources, such as plants, and are considered more environmentally friendly than traditional petroleum-based plastics [38, 39]. The focus on biodegradability in bioplastics adds layer of eco-friendliness, as these materials can break down naturally into harmless substances over time [38, 39]. Increasing awareness of environmental issues and the need for sustainable practices has led to a growing demand for biodegradable alternatives to conventional plastics, which significantly boosted the Biodegradable bioplastics segment growth in Indian Bio Plastics Market [38, 39]. Jammu & Kashmir is the first state in India to have built a dedicated bio-plastic product manufacturing facility with an installed capacity of about 960 metric tons per annum [38, 39].

India has shown increasing interest in bio-plastics due to growing environmental concerns and a focus on sustainability [38, 39]. The Indian government has been taking steps to promote sustainable practices, and initiatives supporting bio-based products, including bio-plastics, have gained attention [38, 39]. Incentives, subsidies, and regulations promoting environmentally friendly alternatives that influence the India Bio Plastics market. India has a significant agricultural sector, providing a potential source for bio-based feedstocks used in the production of bioplastics [38, 39]. Growing environmental concerns and increased awareness of the impact of traditional plastics on ecosystems have driven interest in bio-plastics as more sustainable alternatives [38, 39]. Consumers and businesses are seeking eco-friendly solutions, contributing to the demand for bio-degradable and bio-based materials [38, 39].The Indian government has been implementing policies and initiatives to promote sustainable practices and reduce environmental pollution [38, 39]. Incentives, subsidies, and regulations supporting the use of bio-based and biodegradable materials have encouraged businesses to adopt bio-plastics, which significantly boost the India Bio Plastics Market growth. India's significant agricultural sector provides a rich source of bio-based feed stocks for the production of bioplastics. Crops such as sugarcane, corn, and other biomass materials are utilized in Bio Plastics manufacture, contributing to the growth of the industry [38, 39].

Based on Application, the market is segmented into Packaging, Textile, Agriculture & Horticulture, Consumer Goods, Automotive, Electronic, Building & Construction, and Others [38, 39]. The packaging segment dominated the market in 2023 and is expected to hold the largest India Bio Plastics Market share over the forecast period [38, 39]. The packaging segment in the Indian bio plastics market uses bio-based and biodegradable materials in the production of various types of packaging solutions [38, 39]. This sector is gaining attraction as a response to environmental concerns associated with traditional packaging materials, such as petroleum-based plastics [38, 39]. The use of bio-plastics in packaging aims to provide more sustainable and eco-friendly alternatives [38, 39]. These are derived from renewable resources, such as corn, sucoulde, or other plant-based materials. Bio-based plastics are used in various types of packaging, including bags, films, and containers [38, 39].

11. Conclusion

Bioplastics, in general, are derived from renewable resources, such as plants, and are considered more environmentally friendly than traditional petroleum-based plastics. Traditionally, plastics are made from petroleum-based compounds, which release toxic gases into the atmosphere. Petroleum-based plastics and its by-product have a devastating effect on the land, water, and wildlife. However, plastic waste contributes to a pressing environmental problem is as yet unsolved. The production of synthetic plastics, particularly non-degradable ones, is an environmental burden. This is because 'non-degradable' plastics take decades or centuries to break down. Biodegradable plastics decompose in environments such as soil or water, or in compost. In other words, creating an environment conducive to microbial activity is crucial for plastics to decompose effectively. Biodegradable plastic bags are made from all-natural plant-based raw materials that enable the natural decomposition process which is achieved when the bacteria and fungi present in the surrounding environment naturally metabolizes the plastics and helps to further breakdown the structure of a biodegradable plastic. The end result of which is less harmful to the environment as compared to regular plastic bags. India has shown increasing interest in bio-plastics due to growing environmental concerns and a focus on sustainability. As the consequential environmental impact of traditional plastics becomes increasingly apparent, the introduction of bioplastics has ignited a beacon of change. Consumers and businesses are seeking eco-friendly solutions, contributing to the demand for bio-degradable and bio-based materials. The Indian bio plastics market is still in its early stages, with only a handful of companies (EcoBharat, Adsum Eco Solution Pvt. Ltd, J&K Agro Industries Ltd, Envigreen, Ecolastic, Plastobags, Earthsoul India Truegreen, Environmental XPRT, Corbion India PL, Envigreen Biotech India Private Ltd, TORAY INDUSTRIES, INC. Biogreen, **Green Tech Bio Products**) currently operating in this segment. The Indian government has been implementing policies and initiatives to promote sustainable practices and reduce environmental pollution. Moreover, the rising demand for biodegradable plastics for medical and personal care packaging applications is anticipated to fuel the market in the country. Crops such as sugarcane, corn, and other biomass materials are utilized in Bio Plastics manufacture, contributing to the growth of the industry. In terms of segment, starch based was the largest revenue generating product in 2023. In terms of revenue, the biodegradable plastics market in India is likely to grow at a significant CAGR of 12.5% over the forecast period.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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