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Explorative research on bio-based plastics and its role in closing the loop of Circular Economy

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ABSTRACT

Excessive use of conventional plastics with increased environmental pollution and exploitation of fossil fuels has led scientists to come up with various alternatives such as bio-based plastics. Bio-based plastics can be defined as the plastic derived from organic material such as corn, starch, potatoes or from materials extracted from microbes. These can be biodegradable or non-degradable depending on what they are comprised of. Bio-based plastics are considered to be beneficial but it is very important to study the negative impacts of these plastics on the environment. The present review highlights the points regarding the types, applications of biobased plastics, bioplastic production in India, different environmental conditions required for the biodegradation of bio-based plastics and their acceptability as a step towards sustainable development.

Key words: *Bio-based plastics, Bio-degradable plastics, Organic waste, Polylactic acid, Waste management*

Introduction

Plastic undoubtedly plays a very important role in our everyday life. Its composition gives it the quality of non-biodegradability and durability resulting in the addition of serious environmental and health problems in the surroundings (Kibria, 2017). In 2018, approximately 359 million metric tons of plastic were produced globally each year with 62 million metric tons produced in Europe alone. Out of this, as much as 35% goes missing in the ecosystem (*Plastic Waste Worldwide - Statistics & Facts | Statista*, n.d.). It either ends up in landfills or in the oceans posing hazardous threats to landscapes and marine life. Very less amount of plastic, as little as 2% is recycled and bought back in the same or similar quality to complete the loop of circular economy (Break free from Plastic, 2018). Non- renewable resources are used as an input for the production of plastics and more than 3 percent of these resources is used to provide energy in the manufacturing processes. Plastic recycling helps in conserving the natural resources but it demands big infrastructure facilities and models (Hopewell *et al*., 2009).

Oil and gas prices in the world are predicted to increase in the next century and the sector greatly influences decisions made for other important sectors of the economy (*Oil & Gas Industry in India*, n.d.). Oil and gas play an important role in the production of conventional plastics, thereby scientists have come up with new bio-based plastic which is a large family of materials derived from renewable sources and is compostable (Pathak *et al.,* 2014; Saharan and Sharma, 2015).

Various types of bioplastics along with various methods of production and its role in sustainable future have been researched so far but the end life cycle of bioplastics has not been into picture anywhere (Selvamurugan Muthusamy and Pramasivam, 2019; Kumar and Thakur, 2017). The

main objective of this study is to find out where the biobased products end up and what are the various steps taken to dispose of them completely unlike conventional plastics.

Bio-based plastics' characteristics of biodegradability and production from a wide range of organic waste might help to move the linear economy scale to the circular economy loop (Garrison *et al.,* 2016) but, little research has been done if the bioplastics are really sustainable.

Literature review

Awareness regarding health-issues and strict ban of single-use plastic by governments has led scientists to pay attention to green alternatives and technology innovations to lower the carbon dioxide emissions and stop the growth of landfills, ocean waste and to create a circular economy (Proshad *et al*., 2017; Manusri, 2019). Indian plastic industry faces major challenges due to lack in technology and environmental myths (FICCI, 2014), (Garrison *et al.,* 2016). Availability of low-cost petrochemical-derived plastics kept bioplastics away from light for a long time (Saharan and Sharma, 2015). Biobased products have started attracting attention due to serious environmental concerns due to the accumulation of plastics and over-exploitation of non-renewable resources (Saraswat *et al.,* 2014). These plastics have potential to close the loop if produced commercially in larger volumes, but with the current volume of bioplastics produced, the economic feasibility for recycling bioplastics is a far thought process (Spierling *et al.,* 2018).

Bioplastics are derived from sources such as starch, cellulose, natural sugars, vegetable fats and oils which are renewable. They can be categorised into biodegradable and non-biodegradable with biodegradables such as polylactic acid, blends of starch, polybutyrate adipate terephthalate (PBAT), and polybutylene succinate (PBS). Non-biodegradable bioplastics can be further categorized into polyethylene, polyethylene terephthalate, polyamide and polytrimethylene terephthalate (Kalia *et al.,* 2000). Non-biodegradable bioplastics led the market with a share of 54.96% in 2019 and are expected to generate the highest revenues in the coming years.

Bioplastic is used for rigid and flexible packaging, coating & adhesives, in textiles, agriculture and consumer goods (Kumar and Thakur, 2017). Amongst these, it is also used in manufacturing automotive parts as the components made from bioplastics are lightweight, durable, rustproof and has a high strength to weight ratio which helps in reducing vehicle weight. Rigid packaging will flourish in the coming years and companies will opt for sustainable and durable packaging to bear heavy loads (Singh *et al.,* n.d.).

This market is also finding its way in the food industry and pharmaceuticals for flexible packaging due to its inertness towards the packaged product (*Bioplastics Market Size, Growth, Share | Global Report 2026*, n.d.). Currently, the main share of application is about 70% comprising of flexible and rigid packaging. While the other 30% market share is in long term applications such as building and construction (Spierling *et al.,* 2018).

In developing countries, 70% of municipal solid waste produced consists of organic matter which has a high moisture content (Bhat *et al.,* 2018). Organic municipal solid waste and agriculture sectors in India produce about 40-60% of the total solid waste streams and the figures are definitely set to increase by 2030 with an increase in demand and growth of population (Joshi and Ahmed, 2016). Several studies suggest that reutilizing the solid waste produced in viable management of organic waste is essential with the increasing demand of energy in the country and chaos created by improper disposal of the waste leading to unhygienic conditions in surroundings.

Bioplastics market value will increase from USD 6.04 Billion in 2018 to USD 19.93 Billion by 2026. The rising demand for bioplastics from the packaging industry will drive the growth of the bioplastics market (*Demand for Bioplastics Goes Up in India – Bioplastics News*, n.d.). According to N. Rajendran, Vice-Chancellor, Alagappa University, the demand for bioplastics in India has increased due to several cities banning single-use and other plastic items.

Methodology

The study uses an explorative research method by gathering information and reviewing the biobased plastic and its end life cycle. The research involves the material collection and an inductive research logic required for explorative research. An approach has been followed including reviewing 40 research papers available online on the study of sustainable bioplastics and conventional plastics.

Analysis of secondary sources available has been done in consultation with various published jour-

nals, pertinent books and case studies. For a systematic review, a technique called PRISMA technique has been followed. First, the types of biobased plastics were identified and studied through various papers available on Research Gate Search, Mdpi and online-journals.org. Applications of biobased plastics and the market share of in India and abroad were studied with electronic databases such as Science Direct and Elsevier journals.

Bioplastics production in India and small start-ups working in this field were identified through news and bioplastics news by the European Union. The overlapping news websites and journals were discarded by doing constant screening to match the objective of the study and to remove duplicates. Different environmental conditions required for the

S.No.	References	Major findings/inferences
1.	Kumar and Thakur, 2017	The production costs and sometimes the underperformed properties of bioplastics make them almost non-existent compared to conventional plastics. The small amounts of bioplastics contaminate the conventional plastic loads in recycling units.
2.	Ciriminna and Pagliaro, 2020	India and China with 37% of the world's population may expect a much larger bioplastic market than already forecasted 2.62 million tonnes by 2023. It means companies need to have efficient production techniques. Biodegradable plastics comprise very little market percentage share in India and Complete life cycle assessment of bioplastics is important from the raw material acquisition to the ultimate disposal or recycling phase.
3.	Zhao, 2019 and Emadian *et al*., 2017	The intrinsic properties and other factors such as water content, temperature and pH of the biodegradable components make it difficult to degrade them fully in MSW.If the Bioplastics end up in landfills, which is very common, they generate methane, contributing to greenhouse gas emissions which has a global warming potential of around 30 CO_2e along with other gases.
4.	Garrison *et al.,* 2016	Biodegradability degree varies if the biodegradable material is co-polymerized or cross-linked with non-degradable co-monomers.
5.	Rusu and Rusu, 2016	Scientists are blending polymers to get desired properties such as durability for better functioning of bioplastic. Polymers of low quality and less price are incorporated into good quality polymers to reduce the overall cost of the such as product. This leads to change in the composition of the plastic and hence it becomes difficult to degrade such plastics naturally.
6.	Soroudi and Jakubowicz, 2013	Methods for disposing of biobased plastics needs improvement as if we consider recycling bioplastics, it requires different infrastructure than the conventional plastic recycling units to avoid contamination.
7.	ten Brink *et al*., 2016	There are various methods of separating PLA from the plastic PET bottles in recycling but the methods are quite expensive due to less amount of PLA which makes it difficult in segregation.
8.	Tokiwa *et al*., 2009	The formation of miscible blends with non-biodegradable blends leads to slowing down of the degradation of components which are otherwise biodegradable or it may lead to complete inhibition of the degradation of the product.
9.	Ezgi Bezirhan Arikan and Havva Duygu Ozsoy, 2015	All bio-based plastics types are not compostable at home just like any other kitchen organic waste but requirean industrial composting treatment. For industrial treatment, infrastructure is required.
10.	Kalia *et al.,* 2000	Acceptance of biobased plastics mainly depends on customer response to costs, the achievement of complete biodegradability and availability of infrastructure to collect and process biodegradable polymers

biodegradation of bio-based plastics and their acceptability as a step towards sustainable development was studied through other journals available. The full-text articles were excluded which did not involve the end life cycle of biobased plastics.

Results

The review covers the basic bioplastics type, its degradability and misconceptions related to the term. It is important to have an appropriate sight and suitable techniques for the biodegradation of bioplastics. There is an abundant amount of materials available for the production of bioplastics but various factors and requirements affect the degradability of the plastics.

For the sustainability of bioplastics and its role in the circular economy in India, various parameters need to be thought upon for the disposal phase else the bioplastics will end up in landfills along with the conventional plastic or incinerated which adds to more greenhouse gas emissions.

India is well suited for large scale manufacturing of compostable bioplastics and biodegradables from biological resources just like its energy generation through solar and wind power. Better infrastructure is a requirement for the proper disposal of the bioplastics.

The study will be significant from the managerial point of view for letting the managers decide if they should consider bioplastic products or packaging for their organization's products keeping in mind the bio-based plastic's end life cycle. It will be of help for big companies to do their bit for the environment.

Discussion

Different innovations are worked over by various start-ups to find alternatives for sustainable living in India. Scientists from IIT Guwahati, India have developed biodegradable plastic in hope to replace the existent plastic which is contributing to drastic pollution on the planet earth. The centre has been successful in developing cutlery, decorative items and household furniture using bio-based plastic in Centre of Excellence-Sustainable Polymers (CoE-SusPOI). They have been able to do this at low costs in comparison to the US centres with the help of homegrown technology. The centre is able to produce 7-8 Kgs of biobased plastic at one go and is working for bringing it on a larger scale for commercial production. The bio-degradable plastic produced has passed the hot-beverage test, has no hazardous chemicals in its composition and will degrade automatically in soil (*IIT-Guwahati - Times of India*, n.d.).

With the development of polyhydroxy alkanoates (PHAs), Polylactic acid (PLA) and thermoplastic starches (TPS) it seems like bio-based plastics have emerged and is used everywhere but the reality is that bio-based polymers will account to only 2.5% of the overall plastic consumption in the world in 2020 (Babu *et al.,* 2013). Although biobased products can have many benefits, it is not fully accepted by both the consumers and manufacturers. However, it becomes very important from the managerial point of view to study the acceptance of bio-based plastics which is not yet been fully utilized by the companies (Confente *et al.,* 2020).

Investigation of the real end life of various types of biobased plastics is necessary to know if it really can be a solution in closing the loop for circular economy and to avoid any potential environmental consequences which are already prevailing due to conventional plastic present in society (Spierling *et al*., 2018). The biodegradability of biobased plastics is highly affected by their chemical composition and physical structure. It also depends on the environmental conditions in which biobased plastics are placed.

Bioplastics derived from different micro-organisms will have a different degree of biodegradation and the degrading micro-organisms differ too (Emadian *et al.,* 2017). PLA can compost like any other organic material in proper conditions with oxygen, heat and moisture (Sudhanshu Joshi and Ujjawal Sharm, 2016). Many pieces of researches have been conducted to study the biodegradability of bioplastics in soil, compost and aquatic environments (Emadian *et al*., 2017). Soil and compost have been found as more appropriate for the degradation of these plastics due to the wide availability of micro-organisms in these two mediums (Uttiya Dey, 2012; Sangale, 2012). This depicts that the bioplastics need certain conditions for degradability and it is prominent to know about the microorganisms which degrade polymers in various ecosystems (Tokiwa *et al.,* 2009).

Bioplastics contribute to very less percentage in market share as compared to the conventional plastics (*European-Bioplastics.Org*, n.d.), hence proper

disposal methods need to be considered so that the biobased plastics do not end up in landfills with conventional plastics or are incinerated to get rid of (*Green Matter: New Study Clears the Air for Bioplastics in Landfills*, n.d.) Separation at the source of disposal, collection and sorting of bio-based plastics is a big challenge before we really call the bioplastics as a step towards sustainability (*Bioplastics News*, n.d.).

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