

BIOPLASTICS: SCOPE & EXTENT OF USE IN FOOD INDUSTRY—A REVIEW

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Abstract

It would not be incorrect to call today's era as "Plastic Age", as disposables and other plastic utility items have become a very important and inseparable part of human life. Though plastics pose several health related negative effects, that can be carcinogenic, owing to the toxins present in them. Excessive use of chemicals of varied types, blazing of PVC plastic, making use of bio-chemicals, have all in turn contributed to the ecological imbalance. Proper and correct plastic waste management not solely reduces quantum and volume of waste generated, however conjointly changes the standard of waste. The problems associated with plastic wastes have compelled researchers to come up with the idea of "*Bioplastics*". Such plastics are able to degrade themselves into carbon dioxide, methane or water, by the action of either enzymatic action or specific environmental conditions. Some biodegradable plastic materials incipient are Poly hydroxy alkanoates (PHAs), Polylactic acid (PLA), poly-3-hydroxybutyrate(PHB), and co-polymers and blends of above. This review article was intended to study the scope and extent of usage of bioplastics in food industry, and in our lives.

IndexTerms: Bioplastics, biodegradable polymers, sustainability, petrochemical, food packaging

1. Introduction

Plastics are basically made up of long polymer chains and have made their way in almost all forms of industries, owing to their cost-effectiveness and variation in mechanical applications. They are basically petroleum products and are barely recyclable [1]. Misuse of any technology will results in curse. Plastic was thought to be a boon however it ended up to be a curse. Plastic is terribly harmful because it produces harmful gases once it is burnt. It is harmful to the soil, non bio degradable or takes many years to degrade[2] [3]. The Central Pollution Control Board (CPCB) in 2015 assessed that normal plastic waste . production in the nation is around 6.92 percent of the total municipal solid waste. [3]. Plastic waste generation data gathered from 60 major cities showed that around 25,940 tonnes of plastic waste per day (TPD) is generated in India However, the extended high development paces of GDP and proceeding with quick urbanization propose that India's direction of plastic utilization and plastic waste is probably going to have a huge increment.[4,5]

The plastic handling industry in 2018 assessed that polymer utilization from 2017 to 2022 is probably going to develop at 10.4 percent, almost 50% of which is single-utilize plastic.

The CPCB's Annual Report (2018) revealed that information on the status of execution of Plastic Waste Management Rules, 2016, were put together by just 13 State Pollution Control Boards. The report derived that complete plastic waste produced was 660,787.85 tons per annum. [6]. Research penetration into the specialized difficulties of bioplastics creation has uncovered their bewilderedness in their specialty markets and battles to enter the core market. There is an expanding issue of garbage removal and significant expense of unadulterated substrates in polyhydroxyalkanoates (PHA) manufacturing. This has prompted the future need of updating the waste streams from various ventures into the part of feedstocks for creation of PHA .[6]

Bioplastics are fundamentally plastic materials which are derived from renewable biomass sources, namely vegetable fats and oils, corn starch, straw, woodchips, sawdust, recycled food waste, etc. Another promising source for bioplastics, which has been recently researched and encouraged is from agricultural by-products and also from used plastics using microorganisms. Plastics have not always been produced from fossil materials, rather the very first plastics were actually biobased, i.e celluloid is regarded as the world's first "plastic", discovered in 1855 by the Englishman Alexander Parkes named Parkesine. [7] Major issue which needs to be looked into is that using only biodegradable plastics is not a permanent solution to the problem of litter and the plastic landfilling. On the other hand, biodegradability can be a useful characteristic for specific marine and soil related issues. [8][45].

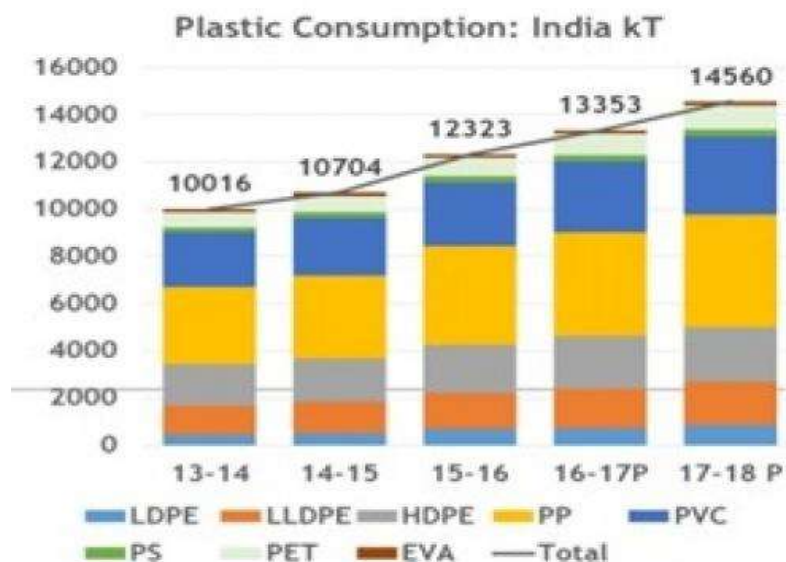


Figure 1: Plastic Consumption: India kT

Source: <https://www.downtoearth.org.in/blog/waste/india-s-plastic-waste-situation-wasn-t-created-today>

2. Classification of Bioplastics

There are various classification system for bioplastics that have been proposed, main reason being, that these bioplastics and biopolymers can be successfully derived from numerous renewable sources, so it is difficult to put them in a single class. Majorly, these biopolymers can be further classified into two main categories i.e. agropolymers (category 1) and biodegradable polyesters (categories 2-4) or biopolyesters. [9]

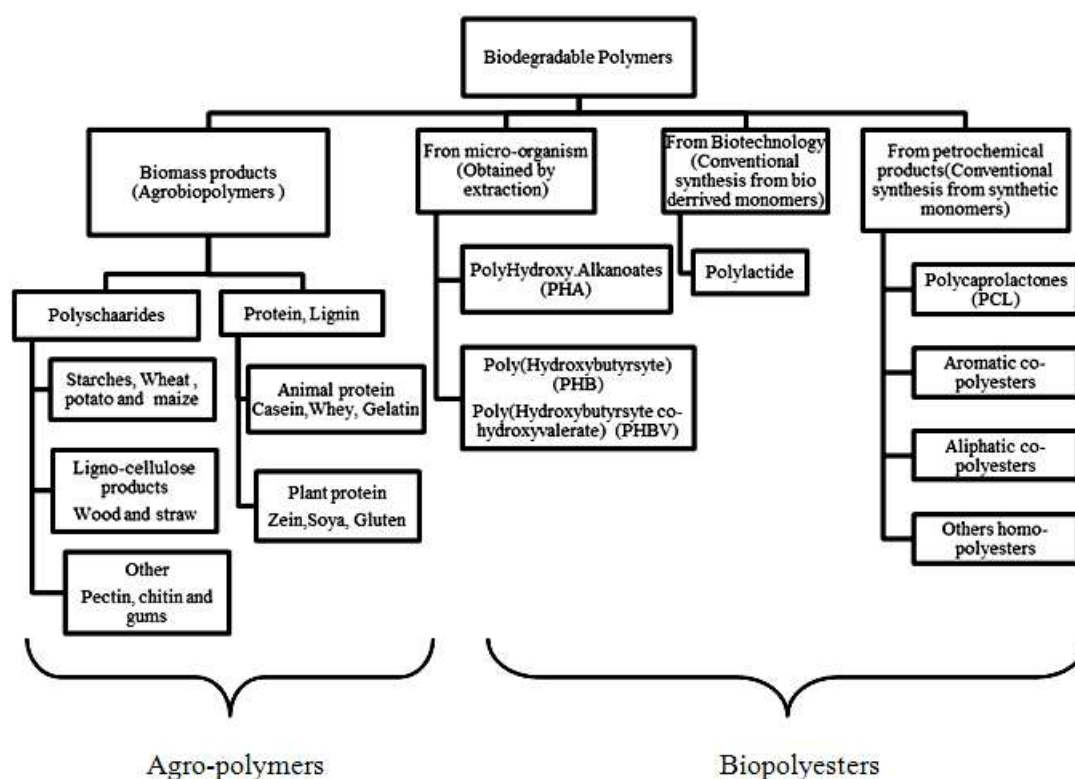


Figure 2: Classification of Bioplastics

Source: https://www.researchgate.net/figure/Classification-of-the-biodegradable-polymers_fig1_318017387

2.1. Bioplastics Based on Polysaccharides

2.1.1 Starch Based Bioplastics

Starch is a bountiful and naturally available material made out of two types of glucose polymers, amylose and amylopectin. The separate proportion of amylose and amylopectin, altogether influences the physicochemical properties of starch which, thusly, impacts its usefulness and possible applications. [10]. Higher amylose content adds to film strength be that as it may, stretched design of amylopectin by and large

prompts film with low mechanical properties which can be improved by utilizing plasticizers, for example, sorbitol and glycerol. Biopolymers created from starch have numerous points of interest like higher biodegradability, inexhaustibility and great oxygen obstruction properties which makes them the most reasonable option for some business applications with the above favourable circumstances as the essential prerequisites of a bundle. Local starch happen as a heteropolymer in nature and is utilized in various structures for mixing with customary polymers for the creation of biopolymers. Some major bioplastics obtained from polysaccharides are discussed below. [11]

2.1.2 Thermoplastic starch (TPS)

Thermoplastic starch is obtained by the spontaneous de-structurization of the starch granule within the presence of plasticizers. Extrusion processing employing, low moisture content, high temperature and pressure, melts the starch granules which acts as one continuous phase component which later are often mixed with other ingredients to make the film. [11,12].

2.1.3 Cellulose-Lignin Bioplastics

The lignin is a potential component for bio-compatibilizer. The addition of lignin could improve the compatibility between cellulose and matrix.[13]. Cellulose and lignin play different parts in cellulose–lignin bioplastics in general, cellulose reinforces mechanical strength of the composites, while lignin reduces water uptake, improves thermal stability of the polymer matrix and assures the good dispersion of cellulose in biopolymers and can generate mutual effects on the bioplastics.[14]. A number of bio-based composites based on starch, lignin and cellulose have been fabricated and has been found that the mechanical strength of the bio-composites was evidently depending on the contents of lignin, starch and cellulose, resulting from the mutual supplement among different components. High gas barrier ability and great thermal stability were clearly observed in the bio-composites. Conversely, high ductility and improved elongation at break were provided by the acid insoluble lignin in the PLA bioplastics.[14][15].

2.1.4 Polylactic acid (PLA)

Among the wide selection of biodegradable polymers, PLA an aliphatic polyester commonly made of hydroxyl acids, that has polyglycolic acid (PGA) which might easily be modified by polymerization is that the most promising biopolymer having highest market share. [16] Polylactic acid (PLA) behaves quite similarly to poly-olefines and may be converted into plastic by standard processing methods like injection moulding and extrusion.

Currently main obstacle in commercial production of PLA based bioplastic is high price of the staple and therefore the lack of a composting infrastructure within the markets which is a vital prerequisite for commercial use of PLA. [16,17]. PLA based packaging potentially have highest utilization within the food packaging. this global marketplace for carboxylic acid is 100,000 tonnes/annum, of which quite 75 which there's employed in the food industry.

In addition, cellulose-lignin nanocrystals can function as outstanding fillers for PLA to develop the bioplastics. To improve the thermo-mechanical and rheological properties of PLA bio-composites, cellulose nanocrystals coated with spray-dried lignin were combined. The results found that the lignin-coated cellulose nanocrystals enhanced their interfacial interaction with the PLA bio-composites. [18]

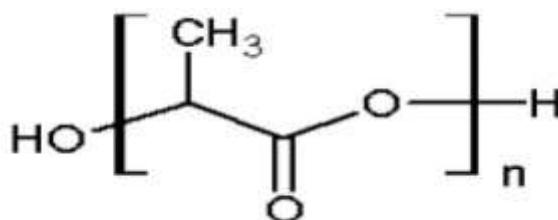


Figure 3: Chemical structure of PLA

Source: https://www.researchgate.net/figure/Chemical-structure-of-poly-lactic-acid-PLA_fig4_51832364

2.2 Bioplastics Derived from Proteins

For many years, various raw materials have been used for production of renewable and biodegradable packaging and one such material proteins have a vast and empirical potential. The functional properties of these materials are highly dependent on structural heterogeneity, thermal sensitivity, and hydrophilic behaviour of protein molecules. A large number of proteins from vegetable and animal sources can be used as the raw material for developing bioplastics materials. [16][18]

Wheat gluten a by-product from the bio-ethanol industry is relatively inexpensive, abundantly available and most widely used as animal feed however, their potential application as packaging in baking industry has shown growing interest as they have interesting film formation, gas barrier, mechanical and biodegradation properties. The wheat gluten have two type of proteins depending on their solubility in aqueous ethanol solution and their molecular weight gliadins and glutenins which are responsible for ultimate properties of the polymer developed from them, with the former acting in intra-molecular and later in inter-molecular disulphide linkages. [16][17][18].

Casein is the protein component in the milk of higher mammals that is not found in whey. From the end of the 19th century until the 1930s casein was one of the raw materials for the plastic called galalith, which was used among other things for making buttons, personal decorative items, and also as an insulation material in electrical installations.[18]

2.3 Bioplastics from Microbial Sources

Microbes have been a wellspring of examination for bioplastics and biopolymers (polysaccharides) using the rural waste as the development medium. The cycle of the creation of bioplastics from microorganisms have been advanced with a scope of finished results having broadened up properties.[19][20]. Countless biopolymers created have acquired adequacy in food and other modern applications and one such microbiologically-integrated plastic is, polyhydroxyalkanoate regularly known as (PHA) which is orchestrated from various gatherings of bacterial from modest inexhaustible assets and is debased vigorously to CO₂ and H₂O, totally by microorganisms under animated control climate. For utilising the total advantages and the business creation of these biopolymers it is imperative to choose a bacterial strain having most elevated creation of PHA which simultaneously can develop on cheap carbon sources with effective aging with straightforward recuperation measure.[21,22] As of now, 250 diverse PHA-makers have been recognized and only a couple have made it for the business biosynthesis including *Alcaligenes latus*, *B. megaterium*, *C. necator* and *P. oleovorans*, as they can use the effectively accessible and monetary crude materials as the carbon sources. *C. necator* has been the most broadly read and ordinarily bacterium for PHA creation.[23][24]

Polyhydroxybutyrate (PHB) is a biodegradable microbial polymer which is accumulated in bacteria as intracellular storage granules in the presence of excess carbon sources and limited nitrogen source. The polymer is known to occur as intracellular granules in several genera of microorganisms. The granules are synthesized by prokaryotes using fatty acids, sugars and other carbon sources. PHB is insoluble in water, resistant to ultraviolet radiation and is impermeable to oxygen, and is very much suitable for use as food packaging material. This polymer is readily degraded in the soil and sewage, and can be processed using the extrusion technology that is currently used in making polyethylene or polypropylene films.[24].

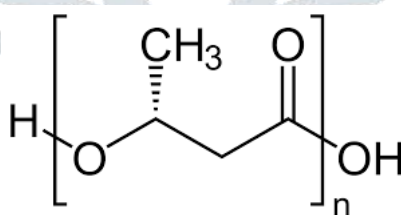


Figure 4: Chemical structure of Polyhydroxyalkanoates(PHA)

Source: <https://en.wikipedia.org/wiki/Polyhydroxyalkanoates>

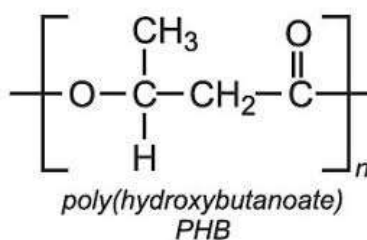


Figure 5: Chemical structure of Polyhydroxybutanoate

Source: <https://www.dreamstime.com/polyhydroxybutyrate-phb-biodegradable-plastic-chemical-structure>

2.4 Petrochemical Based Bio-plastics

Polycaprolactone (PCL) is one of the earliest, commercially available, synthetic polymers characterized by a large set of biodegradation and mechanical properties that can be finely controlled by regulating the local environmental driving forces like, microorganisms, enzymes, hydrolysis.[25]. Owing to their faster resorbability and long-term degradation in the presence of water (up to 3 to 4 years), PCL has been widely investigated as a bioinspired material able to target selective cell response via controlled intracellular resorption pathways. In comparison with other aliphatic polyesters, the superior rheological and viscoelastic properties render PCL easy to manufacture and manipulate into a wide range of three-dimensional platforms.[26].

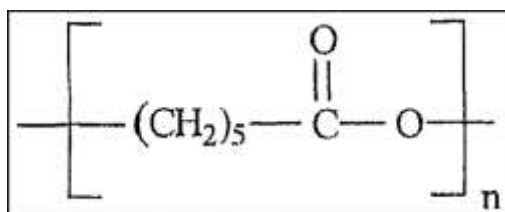


Figure 4: Chemical Structure of PCL

Source: https://www.researchgate.net/figure/General-Structure-of-PCL_fig3_296674465

Aliphatic polyesters have been used mainly because of their biodegradability. The feature of biodegradability has effectively been used in outdoor applications where the aliphatic polyesters are used and disposed.[26][27]

Remarkably, the homo-polyester poly(4HB) has material features completely different from those observed for other scl-PHA, such as PHB or poly(3HB-co-3HV); it has an outstanding elongation at break of up to 1000 %, which makes it highly stretchable and flexible.[27]

3. Degradation of Bioplastics in the Environment

As mentioned in Endres “degradability is a functional property or a disposal option at the end of the material’s life cycle”. Bioplastics have a fixed life cycle, owing to the huge variety of bioplastics, the life cycle of every material differs.[28]. The degradability of bio-polymers is plagued by the chemical and organic structure of the materials and not by the origin of their resources or their production process. [29]. The degradation process depends on a mixture of abiotic (UV, temperature, moisture, pH) and biotic processes and parameters (microbial activity) . The residues from the bioplastics’ biodegradation don't seem to be generally toxic and may be consumed by other living organisms . However, some issues are mentioned in recent literature linked to the presence of fossil resins within the bioplastic items composition. a very important factor affecting the speed of biodegradation is that the thickness of the biodegradable material: The thicker the merchandise, the longer its biodegradability. [30] . Biodegradable plastics is subject to different biodegradation pathways; a number of them (e.g., PHAs) is directly biodegraded by microorganisms while the biodegradation of others is assisted and augmented by natural factors (e.g., UV, oxygen, heat).[29][31] Oxidative-degradable polymers accelerate their decomposition under the effect of oxidation through heat and/or UV light . UV radiation can disrupt polymer chains, since the radiation is absorbed by oxygen-containing components to initiate a primary degradation; these polymers are referred to as photodegradable polymers.[31][32]. In other words, sunlight combined with oxygen can result in photo-oxidative degradation, whereas sunlight combined with heat causes oxidative-degradation. During photodegradation, both molar mass and crystal structure are affected. The plastics characterized as hydro-biodegradable are the ones who have the capacity to biodegrade by hydrolytic mechanisms like biopolymers product of cellulose, starch, and polyesters like PHA. [33].

The process of biodegradation of the bioplastics is divided in three stages.

1. Firstly, the stage of bio-deterioration, within which the polymers undergo chemical, mechanical, and natural process, as a results of the microorganisms’ biological activity on the surface of the fabric, the porosity highly influences this step.
2. The second stage is that of bio-fragmentation , where the microbial activity causes the breaking down of polymers into oligomers and monomers .
3. The third stage describes the assimilation of bioplastics, during which the bio-fragmented compounds are employed by the microorganisms and are converted to biodegradation end products, like CO₂, H₂O and bio-mass . [34].

4. Advantages and Disadvantages of Bioplastics

4.1 Advantages

- Lower energy costs in manufacturing.
- Plastics are made up of ~4% of the oil that the globe uses per annum. With oil scarcity the manufacture of plastics becomes increasingly exposed to fluctuating prices.
- Potentially a far lower carbon footprint
- Reduction in litter production and ameliorated compostability.
- The power to print a highly legible text or image on the plastic is highly improved. [35]
- A less oily feel:- Bioplastics are engineered, to supply a far more acceptable surface feel than conventional plastics.
- Less likelihood of imparting a distinct taste to the contents, in an exceedingly plastic container. Milk, for example, will acquire a replacement taste in a very styrene cup but the bioplastic alternative has no such effect.
- A bioplastic can feel softer and more palpable. For applications like cosmetics packaging, this will be a serious perceived consumer benefit.
- Bioplastics may be made clearer and more transparent, than their petroplastics counterparts.[36][37].

4.2 Disadvantages of Bioplastics

- Biodegradable plastics require favourable climatic conditions in easing their degradation process.
- Biodegradable plastics require horticultural grounds to supply things.
- Biodegradable plastics may release methane in landfills. [38][41]
- Risk of Contamination:- Biodegradable plastics shouldn't be blended in with non-biodegradable plastics
- When tossed in trash bins. When these two styles of plastics are combined, these bioplastics become sullied and can't be utilized any longer. Therefore, these polluted bioplastics will end in landfills and enlarge the amount of refuse. [39][40].

5. Summary and Conclusion

At the point when one glances at the current market for biodegradable food bundling materials it is as yet non-existent, contrasted with regular plastics utilized in bundling and food packaging. In the cutting edge society, plastic are the fundamental apparatuses for the headway of the country yet they likewise cause some ecological perils because of absence of appropriate use. Yet there is a load of chances for the enterprises to grow new items with explicit properties and more examination is needed to put these bioplastics in direct applications for various items.

The biodegradable properties of some bioplastics have been distinguished as a promising answer to redirect food and food bundling waste from landfills, while dodging plastic spilling into the climate. The main question that comprises is, production, handling and showcasing structures up and down the worth added chain with the end goal that an equilibrium is guaranteed among financial matters and security of supply. Of specific significance here is the utilization, that is, everything being equal, so as to decrease the necessary land region for the creation of bioplastics through expanded asset and material effectiveness.

In a short term, bioplastics would set up specialty jobs in high worth premium and 'natural' ranges, along with an unmistakable utility and evident post-use courses. Regardless of whether they become standard options in contrast to most of other plastic items in the long run remains to be seen. No doubt, bioplastics will be utilized as corresponding items to the more common and flexible materials accessible.

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