A Study on The Implementing Biodegradable Polymers In Sustainable Packaging

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Abstract

Stable life offered by the synthetic plastic and their nonrenewable source results in waste disposal and environmental pollution. Bio degradable plastics can be obtained from various combinations of agricultural biology and micro biology. Starch, cellulose based bio degradable waste plastics would exchange with the nonrenewable plastics with lots of comparable packaging properties. Packaging industries have large applications and need in this field. Shelf life improving characters is needed by food packaging industries while high mechanical properties is needed in industrial packaging in order to resist mechanical damaging. In this paper we have discussed about the suitability factors and emerging techniques that are involved in improving packaging properties of bio plastics.
Keyword : Biodegradability, Bioplastic, Packaging, Starch, Sustainability

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1.Introduction

Packaging is one of the processes where the container or wrappers for the product are been designed and produced. It is one of the active tools for promoting and attracting the consumers to buy the products. The product should be very protective, handling and storage of the product should be easy, security and usability should be safe for handling etc. Packaging is done to in order to protect the products from impairment, impurities, drip, stealing things, vaporization, and contamination. Contents in the products can also be protected by packaging. Wood, paper, metals, glass, metals, plastics and composites are normally used as packaging materials. Plastics are most commonly used packaging applications like tubes, sprays, medical bottle, jars etc. Its pros are: flexibility, weight, price, and indestructible, non-permeability, inert to environment, durability, lightness, stability and availability while disadvantages are: resistance to chemicals, gas and vapour. Due to these properties plastics exist in the environment forever and are accumulate as solid waste, if they are not recycled properly. [1,2] Disposal of plastics in the environment will cause serious issues due to the presence of additives, plasticizers and colorants.[1,3] Bioplastics are maximum derived from renewable sources, such as vegetable fats and oils, corn starch, or microbiota.[4] Bioplastic is obtained from agricultural by-products, used plastic bottles. Bioplastics are derived from sugar derivatives, like starch, cellulose, lactic acid. As of 2014, 0.2% of the global polymer markets (300 million tons) are bioplastics approximately.[5] Bioplastics derived from renewable resources (which are biodegradable and less pollutant) are thought to be a replacement for synthetic polymers. [6] Biopolymers due to the action of micro-organisms, heat and moisture undergo bio-degradation. For biodegradation to take place there is no specific standard. Biopolymers are mainly processed from starch, proteins, cellulose, DNA, RNA and peptides. Sugar, nucleotides and amino acids are the monomer molecules of bio plastics. Bio based packaging materials require multistage processes required in designing and manufacturing of bio based packaging materials.[7] Permeability (gas and vapour), sealing and resistance to chemicals, UV and light, transparency, mechanical properties, machinability are some of good packaging material properties. Cost and availability are the key factors in any designing process of bio plastic. Finally, shelf life and disposal method of the bioplastic should also be taken into account. [7-11] Packaging levels are of three types

- Primary
- Secondary
- Tertiary

Primary packaging is the material that first envelops the product and holds it which is directly handled by the consumer. This is the package which will be in direct contact with the contents and this is the smallest unit.

Secondary packaging next to the primary packaging and which can be used to prevent stealing things. This can be used to group primary packages together which can be used for transportation. During storage or delivery they provide easy handling. Tertiary packaging is used for bulk handling, warehouse storage and shipping, pallets, trays, cartons. To protect the product from the mechanical damage and weather conditions tertiary packing is essential. [9, 10]

2. MATERIALS AND METHODS

Biopolymers are polymers which are obtained from renewable natural sources; they are normally biodegradable and mostly non-toxic. They are produced by biological systems like micro-organisms, plants and animals, or synthesized chemically from biological starting materials like corn, sugars, starch and natural fats. [12–20]

Bioplastics are a form of biodegradable plastics which are obtained from various renewable biomass sources, such as vegetable fats and oils, corn starch, or microbiota. Agricultural by-products and also from used plastic bottles and other containers using microorganisms bioplastic are prepared. From petroleum or natural gas, common plastics such as fossil-fuel plastics (also called petro based polymers), are derived. More amounts of fossil fuels are required for production of such plastics. Bioplastics are usually derived from sugar derivatives, including starch, cellulose, and lactic acid.

Table 1 Origin and examples of bioplastics.[13,20]

Category	Origin of extraction of polymer	Examples
1	Polymers extracted directly/removed from biomass	Polysaccharides starch, glycogen, cellulose, chitin, potato, maize, wheat, rice Proteins: Animal: Casein, whey, collagen Plant: Zein, soya, gluten
2	Polymers produced by classical chemical synthesis using renewable bio based monomers	Polylactic acid, polyacrylate, Polyesters and Poly(ester-urethane)s
3	Polymers produced by microorganisms or genetically modified bacteria	Polyhydroxyalkanoates, PHA, polyesters, and polyamides

3. TYPES OF BIOPLASTICS SUITABLE FOR PACKAGING

- ***Polysaccharides***

Polysaccharides are a class of polymeric carbohydrate molecules which can be polymerised into different forms having long chains of monosaccharide units bound together by glycosidic linkages, and monosaccharides or oligosaccharides are formed on constituent hydrolysis. The structure of polysaccharide consists of linear to highly branch. Storage polysaccharides such as starch and glycogen which acts as short term energy supply stores for plants and animals, and structural polysaccharides such as cellulose and chitin are some of the examples.

Polysaccharides are heterogeneous, with slight modifications in their repeating unit. Depending on the structure, these macromolecules will have distinct properties like they are amorphous or even insoluble in water from their monosaccharide building blocks. [21] Polysaccharides are a class of carbohydrate on polymerisation can be formed into various forms with varying carbon atoms. Polysaccharides may also contain atoms of hydrogen, oxygen, small quantities of alkali, alkaline earth and heavy metals apart from carbon. [8]

- ***Starch***

Starch is a hydrocolloid biodegradable polymer, which is considered to be a class of carbohydrate as it contains carbon, hydrogen and oxygen of ratio 6:10:5.[8] Starch has amylose in linear form and amylopectin in branched form, the end properties of starch would get affected when there is change in concentration of these compounds. Elongation strength of starch would increase when amylose content increases. Starch is hardly usable in its native state due to its fragility and low mechanical property which leads to poor film forming capacity. These defects are overpowering by plasticization and blending with other polymers.

[12] Water is considered as a primary plasticizer, it changes the structure of molecular bond of starch when heated with water. Water content affects the oxygen permeability of starch bio plastic film. At low humidity conditions, films are excellent barriers against oxygen transmission (Figure 1). [11] Pure starch has a capacity to absorb humidity, and is a proper material for the production of drug capsules. Flexibiliser and plasticiser such as sorbitol and glycerine could be added to make the starch process thermo-plastically.

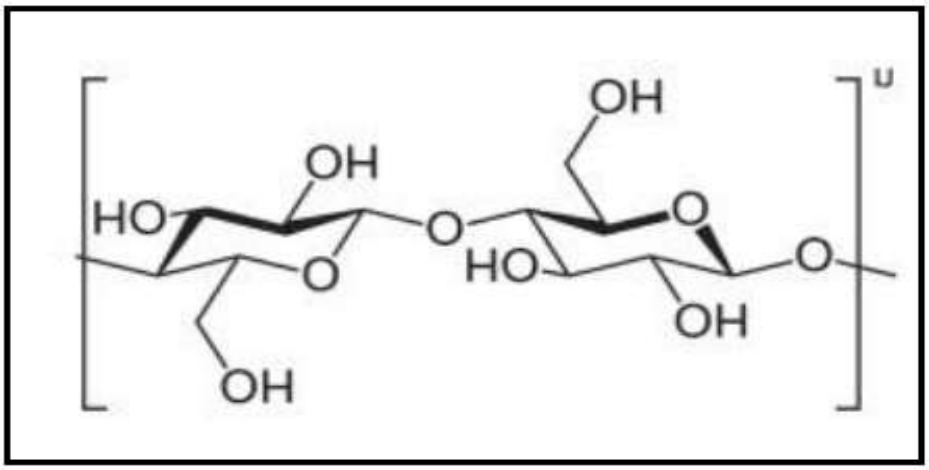

Figure1: Structure of Amylopectin

Cellulose is very stable chemically and insoluble component which serves as the structural component in plant cell walls and it is the most abundant organic molecule on earth. Cellulose is most abundant in wood, paper, and cotton. β glycosidic bonds are used in glucose to link cellulose, unlike the α glycosidic bonds found in glycogen and starch. β glycosidic linkages allow the glucose chains to assume an extended ribbon conformation. Cellulose is made tougher fibre than glycogen or starch due to the presence of hydrogen bonds between contiguous glucose units which leads to the formation of flat sheets that would be in staggered fashions and would be at the top, both within a chain and between adjacent chains.

Linear homopolymer glucose is cellulose which abundantly occurs in plants and it acts as a reinforcement material in bacteria and plants. [12, 13] Structure and array of hydroxyl group present in cellulose tends to form strong hydrogen bonded crystal structure. The repeat units of glucose are linked with β configuration by contrast with the α configuration in starch. Due to this the chains are crystallized in linear conformation with highly crystallinity , high aspect ratio and sub-micron diameter micro-fibrils that are aligned along the cellulose fibre that are aligned with high aspect ratio and sub-micron diameter micro-fibrils are known as single fibre (Figure 2).

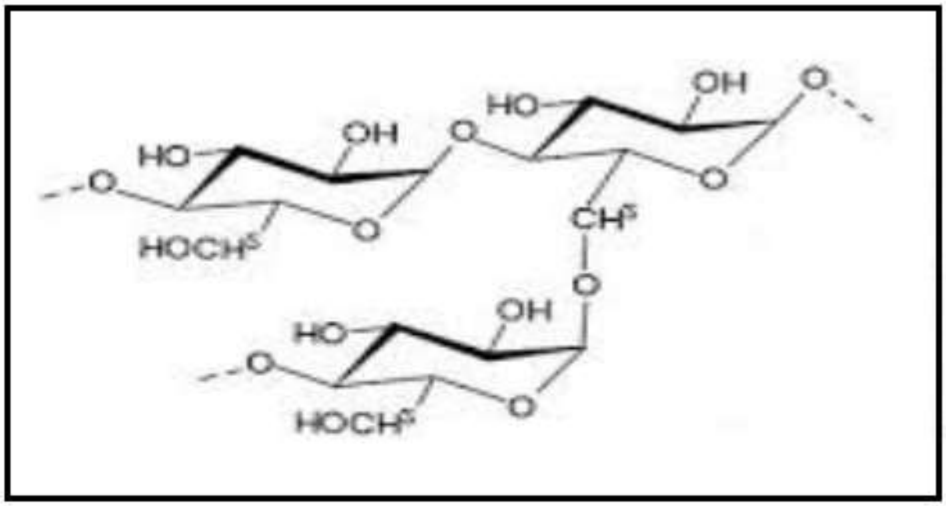

Figure 2 Structure of cellulose molecules.

Cellulose derivatives can be generated by dissolving of non-soluble cellulose, the replacement of hydroxyl group with radicals and reclamation from solution to produce films packaging. Common cellulose derivatives are carboxy methyl cellulose (CMC), methyl cellulose, ethyl cellulose, hydroxyl ethyl/propyl cellulose and cellulose acetate.[8]

- **Polylactic Acid**

On separating 100% fermented renewable compostable plant starch we can obtain biopoly ester called PLA.[8] PLA is considered to be hydrophobic due to the presence of methyl group. PLA is obtained from the natural acid called lactic acid, and it is mainly produced by fermentation of sugar or starch which is done by the help of micro-organisms. PLA that is obtained from lactic acid is thermoplastic, biodegradable aliphatic polyester which has enough capability for packaging applications. PLA is prepared from lactic acid monomers either by direct polycondensation or by ring opening polymerization (Figure 3).

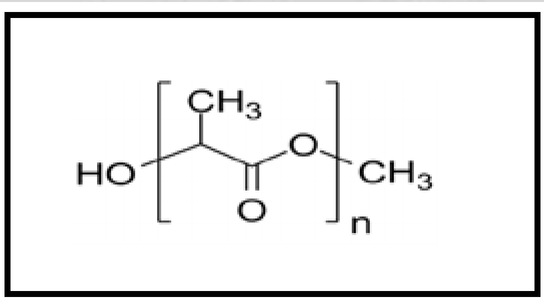

Figure 3 Structure of polylactic acid (PLA) molecules

- ***Polyhydroxyalkanoates***

Polyhydroxyalkanoates are one of the linear polyesters which are produced from sugar or lipids by bacterial fermentation method. PHA (Figure 4) is biodegradable and it is more ductile and less elastic than other plastics. They are much widely used in the medical industry. The repeating units of PHA may vary based on the bacteria and the feed that has been chosen. Most common repeating unit in PHA is (CH2) n-CH3. PHA is linear, semi-crystalline biopolymer. In addition to this PHB (Polyhydroxybutyrate) is also one of the biodegradable polymer.

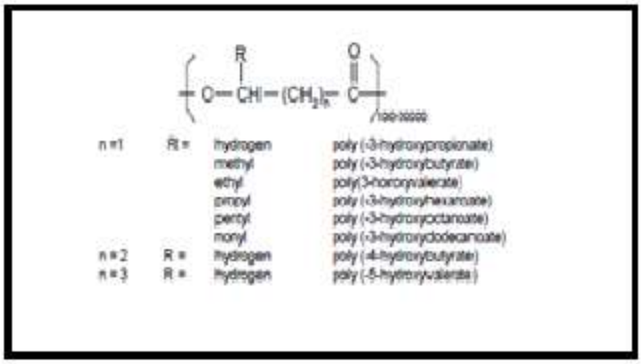

Figure 4 Structure of Polyhydroxyalkanoates(PHA)

Bacterial fermentation of sugar or lipids produces linear biopolymers. PHA may be either thermoplastic or elastomeric materials whose melting point ranges from 40–180°C.[17]

4. PREFERABLEPROPERTIESOFBIOPLASTICSFORPACKAGING APPLICATION

- ***Gas Barrier Properties***

Certain conditions like gas pressure are required to retain the quality and shelf life of food during the storage process in food packaging industry. Mixture of gases like oxygen, nitrogen, carbon di oxide or combination of these gases are found during packaging applications.[19] Materials are in need of gas barrier properties which are closely related to permeation capacity to withstand certain gas compositions inside the package. Gas barrier properties of bio plastics are closely related to their permeation capacity.[8] Water sustainability and oxygen permeability are the major requirements during shelf life of food material which is thermally processed in food packaging industry.[20,21] PLA and PLA based materials gas barrier properties depend closely with humidity.[19] As the crystallinity of film increases barrier properties also increase. [10] Plasticization effect increased the percentage of solubility in water and properties like elastic modulus and glass transition temperature where reduced. [45]

- ***Moisture Barrier Property***

Bio or bio-based materials have reduced moisture barrier property as they are basically hydrophobic.[8,19]Undesired effects of water absorbance of packaging materials results moisture regain of dry food or surface drying of frozen food, these can be avoid with films which have good moisture barrier capacity. Moisture resistant films can be developed by external coating of hydrophobic/ water resistant material such as polyester, wax, fatty acids and crosslinking of material with inorganic fillers, blending of material with moisture resistant material or reinforcement with natural fibres such as jute, coir, sisal.[25–27] Barrier properties of material increases as the crystallinity of material increases where the barrier property depends on the morphological properties of the material like crystallinity and chain conformation.[23] Shelf life of food in food packaging industry can be increased by increasing moisture barrier property. The effective blending of small quantity of bio based material increase the moisture sensitivity of protein films. [45, 49]

- ***Biodegradability***

Biodegradable plastics are very much used in packaging industry nowadays as they are ecologically friendly. During biodegradation of a polymer, the polymeric material gets broken down into smaller compounds by the action of naturally occurring microorganisms like bacteria, fungi or algae in the environment so that biodegradation starts occurring.[14,20,28] The process of biodegradation is favoured by the environmental conditions (e.g. temperature, moisture, available nutrients and pH) that the material and microbes are exposed.[8] Bio degradation as process can be explained in two steps. In the first step degradation or de fragmentation of the polymer takes place, which is initiated by heat, moisture, and microbial enzymes. And in the second step bio degradation takes place, where the longer molecular substances are transformed into smaller compounds, which is initiated by enzymes, and acids that occur naturally.

The substance would get absorbed in the organism's cell walls as the molecules are reduced in size and they would get metabolized for energy, during this biodegradation process carbon dioxide and methane gets liberated.[23,24] Due to photo degradation, microbial action or by chemical action polymer degradation may occur. Oxidation and additive technology is used to accelerate bio degradability of a polymer in Oxo-degradation method of a polymer. Degradation process is controlled by additives in a predictable manner, and initiation of bio degradation is mainly done either by light, heat or microorganisms. [29]

5. FILM AND COATING TECHNIQUES

- ***Atomic Layer Deposition***

Precise control of film thickness is assured by of the film even at relatively low temperatures. For the production of inorganic barrier coatings (Al_2O_3, SiO_2, ZnO) layer by layer self- limiting gas solid reaction deposition technique namely Atomic Layer Deposition is used. It can be used even at low deposition temperature and could develop thin film in a controlled manner. Atomic layer deposition technique can be used in porous materials to improve the gas barrier property. Advanced version of chemical vapour deposition (CVD) is Atomic layer deposition, and it also resolves the shortcomings of CVD such as high operating temperature requirements which exceed the melting point of the polymer. Slow batch processes can be applied generally to produce ALD coatings.

- ***Edible Film Coatings***

Edible coatings are considered as green and novel food packaging application, which can formed directly in the food surface by immersion of the food product in the coating solution. The coating will become a part of the food product and then directly consumed or removed before consumption. [30, 31] The coatings are characterized as nontoxic, non-allergic, and exhibits good structural stability during transportation and handling. It provides smooth surface and good adhesion on food surface and also exhibits adequate moisture and gas barrier properties.

For the production of edible film techniques like compression moulding, extrusion process and novel electro spinning process are used. [30–33] Edible films coating functionalities can be improved by natural extracts, nano composites, and modified polymers. For example, edible film coating of rice starch based film with coconut oil and tea leaf extracts improve surface integrity and stability.[34] Tomatoes when coated with rice starch based film reduces weight loss and extend storage film.[31,35]

- ***Products Made of Bioplastics***

Bioplastics products are preferred the most due to their biodegradability and so they are been used to make the disposable products in packaging sector like, fruit or vegetable containers/trays, egg cartons, bottling for soft drinks and dairy products. Medical implants that are made using polylactic acid (PLA), will get dissolved in the human body which saves time and money and offers a sustainable solution. In pharmaceutical industry pure starch is used in the production of drug capsules because it absorbs humidity. Starch polymers which are compostable are very much used in agricultural purposes as those films need not been collected back from farm land as they get degraded. The mechanical, chemical and physical properties of bio plastics can be improved by polymer-polymer blending process. The bio plastic units are similar to the fundamental molecular arrangement of synthetic plastic molecules. Packaging materials made from bioplastics with barrier properties, impenetrable to odours and with good performance on the machines are attainable and will promote consistent development in this arena.

- ***Blown Films (Barrier Films)***

Bio plastics can be blown as film or multilayer film, or extruded as flat film. They can be thermoformed they can be printed, glued and converted into packaging materials in various ways. Bio plastics can be used in making shopping bags, which can also be used as secondary bag to collect compostable kitchen and garden waste.

Oil derived polymer exhibits high mechanical and barrier properties as well as transparency. According to the applications blown films can be made as monolayer, laminated layer and multilayer. Food packaging and industrial application require optical transparency for the identification easiness. Renewable blowing films developed based on PLA based films shows good transparency and cellophane like mechanical properties. [19]

Gas barrier property is considered to be important in food packaging material as the gas pressure inside the package is very much dependent on shelf life of the food products. Thermoplastic film could act as a blown film by co-extrusion process with PLA or PHB/V act as coating materials. This can replace costly polyamides with low cost starch based bio materials. [34] Reinforcement of nano materials increases water as well as gas barrier properties.

- ***Foamed Products***

In packaging industry foamed products are very much used as they are stable, light weight, ecological good material. Starch based bio plastics which have insulating properties and densities are used to make foam, they are water sensitive and brittle so numbers of procedures are required to make them suitable material for cold or hot liquid environment. [36–38]

- ***Thermoformed Containers***

Thermofoaming process is used to prepare thermofoamed containers. It can be manufactured by thorough heating of plastic sheet to a pliable forming temperature in a mould, trimming process creates specific shape product.

Thermoformed inserts are used for manufacturing chocolate boxes, fruit and vegetable trays, meat and eggs (also foamed), dairy products tubs, bottles, nets or pouches for fruit and vegetables. Blister packs, where the film is closely formed to follow the profile of the packaged product, can also be produced. In muffins, cookies, ready to eat food packaging, chickens, cheese, etc. thermofoamed products are used for packaging

Most of the polymers are used in multilayers as a single polymer fail to give good barrier properties. Multilayer materials are generally developed by thermoforming where thermoplastic sheet is formed by heating it above its softening temperature. [39, 40]

- ***Coated Paper***

Bio plastic used in coating of paper and cardboard laminates are well used in packaging as they have good resistance towards moisture and fat or oil. Thin synthetic plastic coating is used to improve water and gas barrier properties.[41,42] Bio based material coating acts as an excellent anti gas and water permeable layer and also provides unique character like degradability.[43,28]

6. CONCLUSION

As we are aware that non-renewable resources are getting depleted it has become compulsory to find an alternative material which is derived from renewable and that would meet the properties of conventional plastics. Due to the microbial actions of microorganisms or by chemical synthetic methods on feedstock, bio plastics can be derived. Depending on mechanical and thermal properties of bio plastic the suitability of packaging materials would be. Plasticization effect of bioplastics would modify the mechanical and barrier and properties of polymers and reinforcement of nano-material would make suitable packaging materials for industrial use.

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