Biodegradable Smart Biopolymers for Food Packaging: Sustainable Approach Toward Green Environment

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Abstract The advantage of biodegradable plastics over conventional synthetic plastics in respect to complete and safe disposal makes a way for its use in broad range of usage including agriculture, biomedical, and food packaging. In present scenario, biodegradable materials used for wrapping food products are mostly synthesized renewable raw materials like polylactide, starch-/cellulose-based polymers, polybutylene succinate, and polybutylene succinate-co-adipate. Spoiling of food by microbial contamination along with lipid and protein oxidation is a major concern in terms of food safety and quality, and it may occur in packaged foods even after using traditional food preservation techniques such as freezing, drying, heating, salting, and fermentation. All these problems can be overcome by using bio-based active and smart packaging that provides great opportunities for enhancing quality, tenderness, and freshness along with antimicrobial assets. Recently, antioxidant packaging is developed with bioactive molecules in encapsulated form that also improves aroma characteristics. This chapter gives an overview of different types of biodegradable polymers that are applied for covering of foodstuff and what consequences it confers on environment after biodegradation and composting.

Keywords Biodegradable polymers · Food packaging · Smart packaging · Biodegradation · Environmental impact

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1 Introduction

The basic application of packaging on food products is meant for safeguard from external environment and destruction and also to provide information to consumers regarding ingredient and nutrition (Coles et al. 2003). A few secondary purposes are also important such as flexibility, accessibility, and interference. Other advantages of packaging are that they delay the corrosion of the product, maintain the valuable impact of development, improve existence, and enhance the excellence of food. Food packaging also helps in transportation across long distances securely and can be stored for long periods of time. Airtight packaging must increase the food quality; it is essential for food to maintain its marketable properties. Ideally the material is recyclable and can be used again and again. Due to tampering of food and pharma products, special packaging is used to provide extra protection so that packages cannot be tampered with in stores. Tamper-evident features, which are usually comprised of additional packing materials, may involve special bottle liners or closures. A heat seal that changes color upon opening is an example of an additional packaging feature. It is important for manufacturer to maintain balance between safety issues and other factors such as cost and eco-friendly perspective. Many consumers are paying closer attention to environmental issues that are involved with packaging technology.

2 Types of Material Used for Packaging

As per the literature reports, 35% of the packaging materials used were paper and board (cartons) worldwide, while 30% accounts for plastics including polyethylene terephthalate (PET), polyvinyl chloride (PVC), and polystyrene (PS) (Tonjes and Greene 2012). Plastics have swiftly added share 10% more in the market in the early 1960s. The rest of the packaging material includes metals like aluminum, steel, and glass. Increased consumption in European countries results in increased amount of packaging used, which is much harmful to the environment. The area of landfills is increasing and waste filling them is not spontaneously disintegrated (Kale et al. 2006). Food packaging refuse accounts for major portion of municipal waste. Thus, for proper choice, it is necessary to remain updated with different packaging materials actually used for food packaging. Food and beverage packaging with regard to raw substance required in the production can be classified as follows: metal, glass, plastic, paper, and cardboard in addition to packaging from assorted material. All mentioned materials have their own advantages and disadvantages.

2.1 Glass

Glass can take different shapes and undergo recycling without changing its mechanical properties (but glass processing needs high temperature), has efficient barrier properties (lack of permeability of gasses and water vapor), but are disadvantageous in terms of ratio of mass to volume (glass packaging are heavy). Glass is also brittle, and is nondegradable (but it does not damage the environment); it is mainly used for manufacturing of bottles and jars.

2.2 Metals (Steel and Aluminum)

Metals possess very good barrier properties, are quite expensive, can be recycled, and are mainly used for canned food (food in cans are pasteurized) and in producing temperature-resistant metallic trays that are probably used for frozen and hot meals; thin aluminum foils are mostly used for wrapping of sweets, cheese, coffee, tea, etc.; bottle caps and jar lids are also metallic.

2.3 Paper and Cardboard

Paper and cardboard based packaging are usually cheap cellulose-based material (from wood); paper waste often involves recycling, incineration, and biodegradation while decaying in the environment. It is light; is easily printable; shows permeability for breezing, aqueous vapor, and oxygen; has reduced tearing resistance; is applied on different fields in the form of boxes and belongings; and is mainly employed for packing of dry stuffs like sugar, salt, and baked foods. Papers are also employed in labeling of packages made of different materials such as glass and plastics.

2.4 Synthetic Plastic

Synthetic polymers like PET, PS, and PVC are categorized by low production cost, good mechanical and barrier properties, and easy processability and modification for getting required properties; it is light, esthetic, unbreakable, elastic, transparent or colored, and nondegradable in nature and can be recycled.

2.5 Mixed Materials (Laminates)

Packaging composed from few thin layers, e.g., metallic, plastic, and paper films, has very good barrier properties; laminate packaging are sealed owing welding possibility; it is difficult for utilization because of problems with layer separation. Layering packaging are active and intelligent packaging, which contains substances extending shelf-life, that do not interact with food article; these substances are mainly oxygen and ethylene absorbers, compounds emitting or binding oxygen dioxide, are water regulators, and also have antioxidants and antibacterial substances.

2.6 Nanocomposites

New-generation packaging with specific properties, containing small amount of mineral fillers (such as glass or carbon fibers, calcium carbonate, or silicates) with very small size particles, which improve mechanical and barrier properties; can be used for manufacturing of bottles or films with very low permeability of oxygen and water vapor; though it is expensive, it has the potential to be recycled.

2.7 Non-biodegradable Materials

Non-biodegradable packaging materials are inorganic and man-made packaging material that will not decompose or break down into simpler forms of matter. PP and PVC packaging material generally belong to non-biodegradable packaging materials.

We cannot use non-biodegradable packaging material much because it remains in the environment as pollutants. The commercial packaging materials do not degrade naturally to the monomers, and so the conserved energy could not be regenerated in the environment. Dependence on synthetic polymers for food packaging is an indefensible and non-ecological practice toward earth pollution. The energy stored in these persistent polluting substances could not be reclaimed due to the nondegradable behavior of synthesized polymer. Recycling is thus an alternative toward the reuse of such nondegradable materials in order to make desired products. This approach is very economical to save the natural resources with the reduction in the gathered persistent pollutants. A sustainable development for recycling and reuse of packaging materials like glass, metals, and pulp has been achieved although the reduction in availability of toxic pollutant as a waste in landfill is not so successful (Northwood and Okaley-Hill 1999). Synthetic packaging materials are copolymerizing with different chemical substances to enhance the mechanical properties. Most of the chemical substances include different additives like plasticizers and colorants. Thin layer coatings of food packaging films are an essential need to create a functional film, which act as a barrier toward the impermeability of oxygen, water, and moisture content of food. The process of recycling of plastic wastes involves several steps such as collection, identification, and transportation of plastic material from the dump site that frequently renders the recycling as non-economical, making incineration or landfill more convenient.

3 Biodegradable Materials

A distinction between biopolymer and biodegradable polymer is very important for its application in packaging industry. Biodegradable polymers are the materials that undergo degradation that result in inorganic substances with the generation of CO_2, CH_4, and H_2O in aerobic as well as anaerobic conditions by the enzymatic action of microorganisms, while biopolymer synthesis is based on renewable substrate. Based on the route of production, the degradable bio-derived polymers are characterized into the following groups (Valdés-García et al. 2014):

(i) *Polymers derived from organic waste*: substances from agricultural waste as polysaccharides (chitin, corn, galactomannan) and protein (zein, casein, gluten, whey)
(ii) *Polymers synthesized by microorganisms naturally*: such as polyhydroxybutyrate (PHB)
(iii) *Polymer produced by using agro-resource substances*: such as polylactic acid (PLA)
(iv) *Polymers where monomers are produced by conventional method* from fossil resources

Bioplastics synthesized naturally by utilizing the natural resources are the recent developments in new-generation packaging materials and very effective in reducing the greenhouse effect on the earth. The biodegradable plastic produced through the sustainable method follows the composting cycle of degradation by the action of microorganism. Biodegradable plastic is a choice of materials while recycling is neither convenient nor economical. Bioplastics are alternatives toward the reduction of hazardous effect on environment caused by conventional plastics comparatively. Biodegradable plastics are disposed of through composting along with food waste comprising 25–30% of total solid waste. Other methods of plastic disposal include sewage treatment plants (hydrolyzed biological plastics) or landfill (agricultural applications). A sustainable development toward the study on bioplastics is a subject of great interest the last 10 years. Biodegradable plastics produced from using natural resources accomplished the necessary needs in application sectors and is an innovative solution toward technical as well as environmental examination. The biodegradable plastics derived from renewable resources have a wide range of application in food packaging. One should always remember that bio-based and biodegradable are not equal terms. Biodegradability is the property that the bio-based material may possess, whereas bio-based is not essentially biologically derived.

The biodegradable polymer accounts a very low percentage of total material waste (e.g., 3% PLA). Since, conventional plastics are not meant to degrade during composting, to retard confusion, all plastic materials are barred out from composting of all polymer in sewage waste. Bioplastics required in food cuisine may assure flow of waste for composting, comprising only in small amount. Composting may come up with different problems. Standards are as follows in commercial composting condition at higher temperature: 58 °C is the standard degradation rate for biological degradation, while for domestic waste it is in the range of 20–30 °C, while in UK 20–25 °C is applied in custom mode of composting (Song et al. 2009). In spite of being degradable and eco-friendly, bioplastics such as PLA are still not contributing a major part in packaging industry. At present, the manufacturing of bioplastics at industrial scale is not so appropriate due to the insufficient facility of production. The polymer film demands some mechanical modifications required to be satisfied taken into account for packaging material. In comparison to the conventional packaging materials, the bioplastics should accomplish the required expectations to function as multilayer packaging film. The biodegradation does not account with the currently available packaging materials. The development of biodegradable packaging materials is an area of vigorous study (Robertson 2013).

4 Biodegradable vs. Non-biodegradable Biopolymers

1. The polymers that acquire decomposition by natural substitutes have been designated as biodegradable. Natural means naturally acquired microorganisms, water content, presence of oxygen and water vapors, etc., while non-biodegradable does not degrade or decompose under natural ecology.
2. Organic materials generated from food waste such as fruit and vegetable inedible skin, deceased animals and plants, etc. are included in the category of biodegradable substances while the polymers synthesized through chemical methods such as polystyrene, polyethylene metal substances, and aluminum products come in non-biodegradable category.
3. A simple decomposed organic substance is assimilated in the soil by natural agents and consequently processed under atmospheric carbon cycle, while non-biodegradable polymers that opposed the degradation by natural ecology and do not break into small constituent consequently cause accumulation of solid waste.
4. Biodegradation usually occurs within a few weeks or months, whereas non-biodegradable substances require thousands of years or even do not decompose and stay in its forms the way it is.

5 The Advantages of Bio-Based Bioplastics

In the process of assimilation of biodegradable products, complex compounds are broken down into monomers. The use of biodegradable plastics is very beneficial to human beings, and they are eco-friendly to the environment as some of them are recyclable while few are synthesized from organic raw materials which are degradable in a particular period of time without the generation of any toxic substances. Bio-based bioplastics synthesized by microbes by utilizing natural organic carbon sources are biodegradable and thus reduce depletion of the natural resources required for synthesis of conventional plastics. Conventional synthetic materials are nondegradable, while print and paper products are degraded through biological process. Products such as goods' packaging and disposable plasticware made up of plant- and/or corn-derived degradable polymers have several ecological advantages over nondegradable products. The development in the production of packaging bio-derived material from live feedstocks is receiving an increasing concern (Mostafa et al. 2015).

A lesser amount of energy is required in the production of biodegradable plastic as compared to the conventional petroleum-derived plastics. One report provided by FoodServiceWarehouse (US) informs that ~65% less energy is required in biodegradable plastic production as compared to the synthetic plastics. Singh et al. (2014) in his review has summarized that cyanobacteria can synthesize the PHB as an intracellular bioplastics in the presence of sunlight that reduces greenhouse gas emission with no generation of CO_2. PLA, bioplastics developed by renewable resources such as cornstarch, has been addressed as a successful replacement of conventional plastics for packaging, produced on low energy requirement basis (Guo and Crittenden 2011). Moreover, cost of bioplastics has significantly dropped in recent years as reported by Khalil et al. (2016), where PLA amounted to be 3 dollars/pound in 1990 and dropped to 90 cents/pound in 2010. This feature signifies that the use of bioplastics is now up to the reach of common man. The price of bio-based plastics is made comparable to the conventional one due to increased oil price. Comparably less amount of energy is required in production of bioplastics than synthetic polymer as 2.20-pound production of PLA requires 27.2 MJ/kg energy based on fossil fuel while PP and HDPE requires 85.9 and 73.7 MJ/kg, respectively. Cellulose nano-fibers have emerged as the most renewable resource material for food packaging applications (Azeredo et al. 2017). Cellulose-based food packaging films will result in the reduction of production cost due to its low-cost availability on a wide range. The decomposition of biodegradable packaging materials is concerned with the impact on environment. The landfill of biodegradable plastics including food packaging material and restaurant and kitchen waste is affected by the generation of greenhouse gas, i.e., methane, much higher to CO_2 under anaerobic digestion, which can be captured as an energy source (Song et al. 2009).

Eco-friendly packaging of food material is also known as green packaging as the materials have some unique properties such as they are biodegradable and can be recycled or reused. Some of these eco-friendly packaging can be reused in their native form while other can be decomposed in an eco-friendly environment. Studies based on environmental impact of cellulose-based packaging film have shown that a comparatively low toxicity as well as environmental risks is associated with it (Ni et al. 2012). Being originated from renewable feedstocks, the bio-based, bio-derived, or blended bioplastics have shown eco-friendly nature of degradation. Decomposition of biodegradable plastics in the soil improves the nutritional efficacy by releasing extracellular compounds and thus enhances the soil fertility. Mixing of biodegradable plastics along with the biodegradable products such as agricultural waste and paper products in composting generates humus material in the soil, which enhances the increase in crop-yield with low requirements of chemical fertilizers (Song et al. 2009). At present, bioplastics can only be decomposed in commercial composting site under the maintenance of high temperature, in contrast to the paper and textile products, which is composted in garden-bin. However, a rise in such composting facility has evolved.

6 Disadvantages of Non-biodegradable Polymers

Synthetic packaging material derived from inorganic resources is nondegradable as well as not decomposed into the smaller molecules or the simpler forms. Packaging materials made of polypropylene, polyethylene, and polyvinyl chloride are included into the non-biodegradable polymers' category, which on the other hand restricts their use as in packaging due to the long time accumulation in the environment. These gathered toxic non-biodegradable polymers are causing pollution to the environment as nature could not decompose it and no energy is thus generated. The production of non-biodegradable packaging materials traps lots of natural resources as well as energy, which cannot be reclaimed due to the long time persistence of these materials, leading to depletion in resources and gathering of polluting substances. The gathered plastic debris has several adverse effects. The accumulated nondegradable plastics enter into marine environment and affect adversely the marine organisms. The floating plastic debris on the seawater serves as mistaken food material and is ingested by seabird species. Moore (2008) has reported that plastic debris alone is affecting the marine organisms. Until now, 267 marine species have been affected by floating plastic debris due to the inevitable ingestion of non-biodegradable accumulates. Synthetic non-biodegradable food packaging materials accumulate in the ocean as well as in the land. In a report of Derraik (2002), 23,000 t of conventional packaging plastic polymers were dumped into the ocean every year. Accumulated food packaging materials made up of polystyrene and polyamides (nylons) have led to severe health hazards such as cancer, allergies, and system dysfunction. Li et al. (2016) has reported that 64.3% of macroplastic debris based on packaging materials was accumulated in marine environment and affected the franciscana dolphins (*Pontoporia blainvillei*).

In the manufacturing stage of conventional plastics, traces of chemical compounds are added in the form of plasticizer or softeners to enhance the softness. These chemical compounds such as bisphenol A (BPA), phthalates, and polybrominated di-phenyl ether (PBDE) remain intact or cause several inevitable effects on human beings and to the environment. In the previous studies, it is observed that BPA affects the animal reproductive system while the styrene monomer is found as the most emerging carcinogens. Sahu et al. (2016) has reported from a study based on exposure to BPA that an increased level of chemicals was observed in the urine, which leads to diabetes and heart diseases. The accumulated plastic wastes reach to ocean through many ways like in the form of leaches leaked from landfill sites of plastic debris. The persistent chemical present in the plastic debris releases toxic compound. In a report by Barnes et al. (2009), about 40–80% of mega plastic debris was from packaging material as most of them are single-use material and usually dumped into landfill sites. This accumulated debris will remain the same for long duration if no other solution is found as these are very durable due to non-biological degradation and will not fade away.

7 Biodegradable Polymers in Food Packaging Industry

The packaging material which remains in close contact with food material includes utensils, salad packs, wrappers, laminating films, dairy products, and meat items. These products thus come in contact with aqueous and nonaqueous condition of stored food at low to high temperature (Conn et al. 1995). Growing concern by the researchers in the last few years forces the industries for the production of recyclable and compostable biopolymers from renewable feedstocks. Modification in the properties (physical and mechanical) of biopolymer by planning and designing could in consequence produce biodegradable polymer as compared to other conventional packaging material like PS and PET.

8 Aliphatic: Aromatic Blending

Aliphatic polyesters comprise a higher fraction in biodegradable bioplastics as compared to the aromatic copolymers due to the favorable hydrolysis of di-carboxylic backbone present in polyesters. These food packaging materials are developed by the blending of conventional polymers with the biologically degradable polymer such as polyethylene terephthalate (PET) with other polyesters. In spite of its good mechanical property, PET has high melting point and is inactive over microbial attack which makes it unfavorable for polymer degradation. The blending of aliphatic polyesters results in the formation of weak points that helps in the hydrolysis. Although it is biologically degradable, produced by utilizing nonrenewable natural resources (oil and fossil fuels), its accumulation affects the total waste dumped worldwide. The degradation of PET thus depends on the way it is disposed off as it breaks down in about 8 weeks after disposal in a controlled way, while the degradation can account for 50 years of time period in an uncontrolled way of disposal. This polymer is generally used in kitchenware and plastic bottles but is very expensive (Siracusa et al. 2008).

9 Aliphatic Polyesters

Aliphatic polyesters have the analogous properties to the conventional polymer like polyethylene (PE) and polypropylene (PP). These biodegradable materials are synthesized by condensation reaction of high molecular weight monomers derived from natural resources. These odorless polymers are utilized in the packaging of beverages. The aliphatic polyesters are biodegradable and produces CO_2 and H_2O as end products. Nodax is the commercially available polymer developed by Procter & Gamble Company that is degradable in aerobic as well as in anaerobic environment.

10 Polycaprolactone (PCL)

Based on the category of biodegradable polymer, the PCL are polymerized from nonrenewable substances. PCL has thermo-softening property and shows resistance toward water and other chlorinated solvents with melting point of around 60 °C. Low-priced biodegradable plastic for food application (trash bags) could be achieved by mixing PCL with starch.

11 Polylactide Aliphatic Copolymer (CPLA)

This polymer is developed by blending D/L-lactide and aliphatic polyesters having hardness like polystyrene (PS) and is elastic like polypropylene (PP) depending upon the mixture ratio. The polymer is found to be stable at higher temperature range (200 °C). As compared to the synthetic polymer, low amount of carbon dioxide could be produced in combustion and no organic pollutants can be produced in burning. Biologically the degradation of CPLA occurs within 5–6 months of disposal, while with food waste the decomposition starts within 2 weeks of disposal.

12 Polylactic Acid (PLA)

PLA is the feasible biopolymer that can be synthesized from renewable feedstocks such as corn and sugarcane under fermentation (Sin 2012) conditions. PLA polymer is degradable, recyclable and translucent, has high average molecular weight, and is sensitive to water solubility. Polymerization of PLA is accomplished with the two existence forms of lactic acid (D/L). The characteristics of PLA depend and vary on the ratio of both the forms of lactide monomers. Various studies on the properties of PLA polymer have been carried out where D-lactide content was in varied concentrations (6–12%). Variation in properties was observed, i.e., from semicrystalline to amorphous state, respectively. However, the higher ratio (12%) of D-lactide is a favorable property for its application in food packaging (Saeidlou et al. 2012) (Table 1).

In a study of Kale et al. (2006), composting of biodegradable PLA materials (bottles, trays, and containers) was carried out under different atmospheric conditions. A different technique (gel permeation chromatography, thermal gravimetric analysis) was applied to study the breaking and visualization of these materials in composting conditions. In the composting, the soil was mixed with cow dung and wood flakes at higher temperature (60 °C). The composting was carried for different times (up to 4 weeks) at a relative humidity of 68%. The effect of temperature on

Table 1 Characteristics of amorphous PLA

Characteristics	Unit	PLA
Glass transition temperature (Tg)	(°C)	62.1 ± 0.7
Melting temperature (Tm)	(°C)	195–245
Enthalpy	($\Delta H^{c}{}_{m}$) (J g^{-1})	93–148
Percent crystallinity	%	
Density (ρ)	(g/cm^3)	1.36
Solubility	–	Dichloromethane, acetonitrile, chloroform
Degradation	–	Hydrolysis (random nonenzymatic, enzymatic by microbes)
Molecular weight (Mw)	(kDa)	66
Stereoisomer	–	L-lactic acid
O_2 permeability	cm^3 mil/m^2	550
CO_2 permeability	cm^3 mil/m^2	3000
Water vapor transmission	g·μm·kPa^{-1}·m^{-2}·d^{-}	161–237
Tensile modulus (E)	(GPa)	3500
Tensile strength (σ)	(MPa	48–53
Elongation at break	(%)	7
Percent of elongation	(%)	12
Transmission	(230–250 nm)	95%
Thermal conductivity	(190 °C	0.195

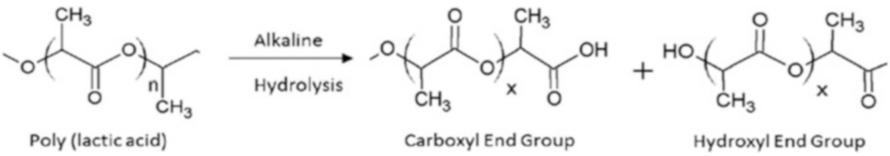

Fig. 1 PLA hydrolysis and molecular cleavage

PLA degradation was also studied as it was well known that PLA is susceptible to water hydrolysis and breaking of ester bonds. In a result, it was found that crystallinity affects the degradation of different PLA materials having different concentrations of D/L-lactide. Percentage of lactide monomers changes the rate of degradation as higher rate of degradation was observed with low content, making the polymer crystalline difficult to degrade. Hydrolysis was observed with decrease in thickness and thus resulting material becomes more fragile (Fig. 1). Measurement in the variation of material property and thickness was calculated. During the first 2 weeks of degradation, a small increase in molecular weight of PLA material was reported due to the cross-linking of subsequent monomer, produced under the effect of UV radiation. In view of the fact that hydrolysis is occurring arbitrarily, PLA chains with longer linear backbone are more susceptible than the shorter ones. The long tails of PLA is more acquire to cleave in comparison to short tails. Decomposition of PLA materials carried out in municipal as well as industrial amenities proceeds with the process of hydrolysis at higher temperature range. Further studies on decomposition techniques of food packaging materials under composting condition is required to be evaluated.

13 Polyhydroxyalkanoates (PHA)

Microorganisms synthesize PHA polymers naturally in rich availability of carbon sources. This class of biopolymer is biodegradable, biocompatible, and thermostable having melting temperature of about 180 °C. Similar to PLA, the crystallinity depends upon the type and number of monomer and hence indirectly affects the melting temperature. In the field of packaging, PHA has various ranges of food application. Amongst PHA, polyhydroxybutyrate (PHB) is the most studied and characterized polymer; polymers alone or in combination with the conventional polymers constitute an excellent source of food packaging films (Tharanathan 2003). PHB accumulates in the bacterial cell as a cell inclusion, which sometime may comprise about 80% of cell dry weight (Khosravi-Darani and Bucci 2015). PHB can be derived by polymerization of hydroxyl-butyrate monomer, showing the comparable properties of polypropylene but with more crystallinity. Besides being insoluble to water, PHB is optically active and has good barrier properties toward gas. Khosravi-Darani and Bucci (2015) has studied a comparison between PP and PHB as food packaging material. Author's reported that 50% lower deformation value of PHB was observed as compared to PP. PHB performs in better way as compared to PP at freezing and higher temperature. The other copolymer named polyhydroxybutyrate-valerate (PHBV) is used as packaging material due to its good mechanical properties (less brittle). In spite of the fact that the production and availability of PHBV polymer are cost-effective but is showing a good rate of degradation of about 1 month in an active microbial environment. Yu et al. (1998) reported the synthesis of different PHA polymers by utilizing different food wastes as carbon sources. Different polymers show diverse mechanical characteristics such as tensile strength, viscosity, etc. Thus, digesting food waste as carbon source can help in the reduction of production price.

14 Polybutylene Succinate (PBS)

The recent development in the techniques of food packaging made from PBS includes retention of food quality, aroma emitters, antimicrobial activity, and gas scavenger/emitters (CO_2/O_2). Consistent change in the flavor of packaged foodstuffs is an important emerging issue toward its acceptance by the customer and hence needs to be resolved. The undesirable change in flavor of foodstuff is generally achieved by the removal of active aroma compounds present in the food items. This technique of aroma scalping could essentially be overcome by the use of biodegradable packaging materials. Cihal et al. (2015) reported that the aroma scalping properties, i.e., sorption and permeation of PBS-based packaging film, were evaluated by using different sets of aroma compounds such as ethyl acetate, ethyl butyrate, and ethyl hexanoate. Litreature results confirmed that biopolymer PBS has comparable permeable properties that are even lower than the nondegradable film and is found to be a replacement for conventional food packaging material due to its production from renewable resources.

15 Polysaccharide-Based Biodegradable Polymer

15.1 Starch

Polysaccharide-based packaging materials are the most renowned form of food packaging as they are the richest macromolecules present in the environment. Among different polysaccharides (chitosan, chitin, galactomannan), starch is the most studied material in food packaging applications derived from plant. Fundamentally, starch is the cheapest renewable carbon source, is completely biodegradable, and can show thermoplastic properties. Commercially the starch is obtained from the corn and potato. The blending of starch with conventional polymers improves its flexibility towards the packaging material and makes it comparable to the oil-based polymer. Different percentages of starch (up to 90%) were added into the petrochemical-derived plastic which enhanced its susceptibility toward water (hot/cold). Decomposition of starch-based material accelerates with the action of microbial enzymes making the thermoplastic surface porous. The addition of starch into nondegradable material exceeds the disintegration up to 60%. Conversion of starch-based thermoplastic material into foam could also be achieved by using water steam in spite of PS as packaging substance. Deformation of thermoplastic into desirable packaging products such as tray and dishes is successful due to its consumption by microorganism within about 10 days of disposal.

16 Cellulose

The cellulose occurs in the earth as the most abundant form and is obtained by removing lignin from woody pulp. Cellophane film is produced by dissolving the degradable polysaccharides into sodium hydroxide solution with carbon disulfide in solvent casting process. Derivatization of cellulose is accomplished by removing hydroxyl groups in esterification. Now derivatization of cellulose is an issue of current study. Cellulose derivatives like cellulose (di-)acetate and cellulose (tri-) acetate involve some plasticizers to construct thermoplastics. Different derivatives have different solubilities toward water such as hydroxypropyl cellulose is water-soluble while ethyl-cellulose is not. Blending of plasticizer with ethyl-cellulose enhances its use in lamination and molding. Derivatization of cellulose increases its use as in food packaging; however, it is cost-effective (Cyras et al. 2007). Few other polysaccharide-based biodegradable polymer materials are listed in Table 2.

17 Bio-Based Packagings

Processing and designing of packaging materials are multifunctional treads which require watchfulness and a variety of considerable engineering processes to make it a proper material having the desired properties. Some characteristics to be taken into account for manufacturing of food packaging films that involves impermeable barrier towards gas and water vapor, waterproof ability, thermo-tolerance, UV light tolerance, transparency, printability, availability, antifogging capacity and costs. More than that, an important thing to think about is the course of degradation which is essential. Because of this, the disposal of used packaged should be taken into a careful consideration.

It is essential to understand that the possible market need and packaging could not be fulfilled by using a single bio-based material. Consequently, rising concerns are seen toward development of packaging material having multiple layers of bio-based polymer and conventional method to produce food packaging film having layers of polymer that act as a barrier and protects food. In conventional method, coating of food packaging materials is achieved with ethylene-vinyl alcohol or polyamides

Table 2 Properties and applications of polysaccharide-based biodegradable polymer

Raw materials	Origin	Solubility	Advantages	Disadvantages	References
Zein	Corn	Ethanol, acetone	Good film properties	Brittle	Ghanbarzadeh et al. (2006) and Sozer and Kokini (2009)
Soy protein isolate (SPI)	Soybean	Water, ethanol	Good gas barrier property, optically active	Water resistance	Zink et al. (2016)
Whey protein	Cheese	Water, ethanol	Mechanically good Low O_2 and CO_2 permeability	Moderate barrier to gas	Schmid et al. (2012)
Wheat (gluten derived films)	Starch	Water	Moderate barrier to oxygen	Moisture resistance, brittle	Zink et al. (2016)
Chitosan	Chitin	Polar solvents	Desired tensile strength and barrier to gas and water, antimicrobial property	Good water retention	Rhim et al. (2007)

blended with low-density polyethylene containing the barrier properties of polyamide as well as the water-resistant and mechanical properties of LDPE. Similar method can also be applied for the development of bio-based packaging material having necessary properties, and so bio-based coating could be developed by means of having gas barrier properties with chitosan, a protein or corn-derived material blended with PLA or PHA, which supports the mechanical strength (Weber et al. 2002).

18 Potential Food Packaging Applications

The packaging films comprise about 25% of usage among the 125 million tons of waste material generated per annum and is an apparent approach toward the possible market need for biologically derived packaging substances, which on the other hand could be enhanced by appropriate procedure at a comparable cost. Particularly the bioplastics will have to contend with conventional packaging materials, which are inexpensive, easy to produce, and have enhanced packaging properties such as lightweight, durable, disposable, and chemically inert to the food stuff. A rise in the production of bio-derived bioplastics would be achieved in the subsequent years. Food packaging comprises the highest growing sector among the plastic packaging field. In a report by Ferreira et al. (2016), plastic food packaging covers about 40% of the European conventional packaging required in the field of transportation, preservation, and storing of food items. In reality, about 50% of European food items are usually packed in the plastic material, and this is very economical due to the good mechanical properties like infirmity, plasticity, strength, etc. These properties make them an excellent source of packaging as well as are very economical for the food packaging industry.

19 Fruits and Vegetables

It is very important to protect fruits and vegetable after harvesting. The presence of ethyl acetate leads to its ripening and affects respiration by changing the concentration of water and gas content in packing material. Choosing a packing material is very tough as different foodstuffs have different rate of transpiration and respiration. Impermeability toward gas and water leads to damage of the fruits as well as vegetable due to fermentation process inside packaging.

Different biopolymers have distinctive gas barrier property. A comparatively low transmittance between carbon dioxide and oxygen rate is obtained in bio-based packaging film with 1:4 by conventional while 1:30 from bio-derived material transmitting carbon dioxide in comparison to oxygen is an appealing demand of packaging material for fruits and vegetables (Sandhya 2010). However, in some cases, transmittance is not required all the time.

20 Cheese

Cheese is protein rich, high water content product that respires continuously, producing carbon dioxide, that makes the use of bio-based packaging material very interesting. Permeability of packaging material for carbon dioxide is very essential requirements to protect the seal from inflation (Auras et al. 2006). Both the biodegradable polymers (PHA and PLA) can be applied for such type of packaging; however, blended materials could also develop.

21 Chilled or Frozen Products

The low gas barrier property of PHA and PLA materials made them extensively a choice of application in food industry. As suggested by Weber et al. (2002), dairy items have very feasible packaging application with PLA. Aliphatic polyesters have wide range of application in packaging of beverages (bottle and cups) as well as non-beverage items. In addition to packing with cardboard, these materials can be applied in the form of thin coating as compared to the conventional one. Haugaard et al. (2001) has found positive assumption in packing of dairy products.

Table 3 Miscellaneous applications of bio-based packaging films in food sector

Applications	Biopolymers	References
Beverages	PLA-coated cups	Jager (2010)
Curdled milk	PLA jars	
Baked items	PLA packs	
Chocolates	Cornstarch trays	Grumezescu (2017)
Organic crop	Cornstarch packs	
Potato chips	Cellulose sheet	
Organic pasta	Cellulose packs	
Sweets	Cellulose films	
Salads	PLA dishes and packs	Haugaard et al. (2003)
Fizzy items	PLA bottles	Sudesh and Iwata (2008)
Kiwi	Cellulose-based trays	Kumar and Thakur (2017)
Fruits and vegetables	PLA packs	Koide and Shi (2007)
Organic bread	PLA bags	Weston (2010)
Chilled fries	PLA sheet	Nieburg (2010)

22 Single-Use Tableware

Application of degradable tableware manufactured from bio-based material opens up an era of disposable material for restaurants. If all the fast-food packing materials and tableware are developed from biodegradable process, then it will lead to an enormous way of waste disposal under the process of composting (Muhammadi et al. 2015). Some more current applications of bioplastics have been listed in Table 3.

23 Main Limitations of Biodegradable Films

Employment of bio-derived plastics as food packages is restricted due to different limitations. Besides high production cost as compared to petrochemical-derived plastics, the use and availability of land are also major limiting factors for its production, which prohibited the functionality of its production at industrial level. Although the properties of bioplastics fascinates its use, several disadvantages such as fragility, thermal volatility, low Tm, complex heat stability, and high accessibility toward water and oxygen restrict them to be a good food packaging material (Peelman et al. 2013).

24 Conclusion

Development of biodegradable packaging materials is one of the recent and innovative processes in the area of food packaging. To enhance biodegradable polymers, it is necessary that our surroundings should have more concern regarding environmental health. Such packaging needs more and more study so that the property, storage period, dietary standards, and biosafety may be improved. Besides these properties, the barrier properties also required improvement. Starch- and cellulose-derived degradable bioplastics are mostly building its firm growth toward application in food packaging. Since starch is renewable, low-priced, and easily accessible biopolymer, blending with a few plasticizers additionally with water is required to make it accessible as a distortable thermoplastic called TPSs. Other nondegradable materials are also employed in packaging that exists as a waste in its original form for long duration and releases harmful effects to the environment. Landfilling and incineration are the methods usually applied to wipe out the packaging waste; however, it is not appropriate for plastics degradation.

Microbe-derived biopolymers found to be attarctive in several ways but they are not so economical. Presently biodegradable packages are in use for such foodstuffs that do not necessitate high impermeability for oxygen and water vapor and have short storage period such as fresh green groceries and fruits, or for long-storage products, like dumplings and fries, that do not require excessive oxygen- and/or water-impermeable properties. Yet, the armory of films depicts extensive diversity in properties that could design them to be used as packages meant for further food products with more strict conditions. Tests for preservation and other investigation on the industrialized packaging equipment should be done to confirm that these films could use commercially. Thus, it could be summarized that bio-derived materials have a wide variety of applications in the packaging industry. However, it is quite significant to understand that analysis and assessment of the operative assets of a bio-based polymer is very important prior to use as an alternative for conventional film materials.

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