FOOD SCIENCE & TECHNOLOGY | REVIEW ARTICLE

Bioplastics and food packaging: A review

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Abstract: Food packaging as a vital part of the subject of food technology is involved with protection and preservation of all types of foods. Due to economical abundance, petrochemical plastics have been largely used as packaging material due to their desirable properties of good barrier properties towards O₂, aroma compounds, tensile strength and tear strength. Meanwhile, they have many disadvantages like very low water vapour transmission rate and the major disadvantage is that they are non-biodegradable and result in environmental pollution. Keeping in view the non-renewable nature and waste disposal problem of petroleum, newer concept of use of bioplastics came into existence. Bioplastics of renewable origin are compostable or degradable by the enzymatic action of micro-organisms. Generally biodegradable polymers get hydrolysed into CO₂, CH₄, inorganic compounds or biomass. The use of bio-origin materials obtained through microbial fermentations, starch and cellulose has led to their tremendous innovative uses in food packaging in the last few years.

Subjects: Food Additives & Ingredients; Food Chemistry; Food Engineering; Food Laws & Regulations

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1. Introduction

There has been an increased interest in the last 10 years from the food packaging industry towards the development and application of bioplastics for food packaging. According to the European

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PUBLIC INTEREST STATEMENT

The petrochemical-based plastics are totally non-biodegradable and therefore lead to environmental pollution. Because of this growing problem of waste disposal and non-renewable source with diminishing quantities, renewed interest in packaging research is underway to develop and promote the use of bioplastics in food industry. Bioplastics have been increasingly used as packaging materials in the field of food packaging. The present review work collects informative knowledge that may be of interest to researchers, scientists and industrialists.
Bioplastics organization, bioplastics can be defined as plastics based on renewable resources (bio based) or as plastics which are biodegradable and/or compostable. Bioplastics have many different renewable sources such as vegetable oil, corn starch, potato starch, fibres obtained from pineapple, jute, hemp, henequen leaves and banana stems (Siracusa, Rocculi, Romani, & Dalla Rosa, 2008; Sudesh & Iwata, 2008). Major source of starch for bioplastics is corn although starches from potato, wheat, rice, barley, oat and soy sources are also used nowadays (Guilbert, Cuq, & Gontard, 1997; Scott & Wiles, 2001; Song, Murphy, Narayanan, & Davies, 2009). Bioplastics can also be made using bacterial micro-organisms and sometimes various nanometre-sized particles especially carbohydrate chains (polysaccharides) (Jamshidian, Tehrany, Imran, Jacquot, & Desobry, 2010; Petersen et al., 1999; Sorrentino, Gorrasi, & Vittoria, 2007; Zepnik, Kesselring, Kapitzky, & Michels, 2010). The bioplastic aim is to emulate the life cycle of biomass, which includes conservation of fossil resources, CO₂ production and water (www.european-bioplastic.org). Meanwhile there is huge demand to explore the other suitable plants available for this specific purpose.

2. Classification of bioplastics

2.1. Starch-based plastics

Major source of bioplastics is the storage polysaccharide of cereals, legumes and tubers i.e. starch which is a renewable and widely available raw material (Park, Li, Jin, Park, & Cho, 2002; Tharanathan, 2003). For processing of starch, flexibilizer and plasticizer such as sorbitol and glycerine are added. After addition of plasticizers and application of thermal and mechanical energy, these constitute thermoplastic starch (TPS) could be used as substitute for polystyrene (PS). Starch works as effective packaging material when it is modified to form films that provide adequate mechanical properties of high percentage elongation, tensile and flexural strength. Starch is modified by either plasticization, blending with other materials, genetic or chemical modification or combinations of different approaches (Demirgöz et al., 2000). These starch-based thermoplastic materials such as, polyethylene-vinyl alcohol or polyvinyl alcohol, polycaprolactone have found wider industrial applications ranging from extrusion applications, injection moulding, blow moulding, film blowing and foaming (Mensitieri et al., 2011; Müller, Laurindo, & Yamashita, 2009).

2.2. Chemically synthesized bioplastics

During the conventional chemical synthesis of polymers, there is also a huge potential of production of “bio-polyesters”. A large number of “bio-polyesters” are produced however, the polylactic acid (PLA) among them can be commercialized at a larger scale for the production of renewable packaging materials (Jamshidian et al., 2010). All the classical packaging materials derived from mineral oil in the present time can be obtained from renewable source-based monomers derived from fermentation. However, presently the process is found to be uneconomical due to costs incurred in production of monomers and thus a greater insight of knowledge through research is required in this context.

2.3. PLA plastics

PLA plastics are derived from the fermentation of agricultural byproducts such as starch-rich substances like maize, wheat or sugar and corn starch. The process involves conversion of corn, or other carbohydrate sources into dextrose followed by fermentation into lactic acid. PLA derived from lactic acid is thermoplastic, biodegradable aliphatic polyester having ample potential for packaging applications (Rhim, Hong, & Ha, 2009). The lactic acid monomers are either directly polycondensed or undergo ring-opening polymerization of lactide resulting in formation of PLA pellets (Modi, 2010; Rasal, Janorkar, & Hirt, 2010). The properties of PLA as packaging material depend on the ratio between the two optical isomers of the lactic acid monomer. When 100% L-PLA monomers are used it results in very high crystallinity and melting point, whereas 90/10% D/L copolymers result in polymerizable melt above its Tg and thus fulfils the requirements of bulk packaging by facilitating it’s processing. PLA is the first bio-based polymer commercialized on a large scale and can be shaped into injection moulded objects, films and coatings (Rasal et al., 2010). PLA has replaced high-density polyethylene, low-density polyethylene (LDPE), polyethylene terephthalate and PS as packaging material.
3. Genetically modified or naturally occurring organism-based bioplastics

Starch or glucose is processed by certain bacteria to produce commonly used polyesters such as Poly Hydroxy alkanoates (PHA’s) and Poly Hydroxy butyrate (PHB) which are extracted using solvents (chloroform, methylene chloride or propylene chloride) (Koller & Owen, 1996). PHA’s are usually low crystalline thermoplastic elastomers with lower melting point. PHA’s characteristics are dependent on the type of carbon source, micro-organism involved in fermentation and composition of the monomer unit (Modi, 2010). The most desirable property of PHA’s as renewable resource-based packaging material is its low water vapour permeability which is as good as that of LDPE and posses other characteristics similar to PS (Yoon et al., 1999). PHB is used in bulk shrink packaging and flexible intermediate bulk containers (Haugaard, Danielsen, & Bertelsen, 2003; Koller & Owen, 1996). PHB is similar to isotactic polypropylene (iPP) with respect to melting temperature (175–180°C) and mechanical properties (Haugaard et al., 2003; Koller & Owen, 1996). Its $T_g$ is around 9°C and the elongation to break of the ultimate makes it suitable for bulk packaging and the mechanical properties can be enhanced by the process of annealing that changes it’s lamellar morphology and at the same time prevent ageing considerably. Addition of 3HV or 4HB comonomers results in considerable changes in mechanical properties. The ratio of comonomer addition is directly proportional to toughness and inversely proportional to the stiffness and tensile strength. The PHAs can be used as alternatives for several traditional polymers, since they exhibit similar chemical and physical characteristics (Singh, 2011).

3.1. Polyamides 11

PA11 a biopolymer derived from natural oil known by the trade name Rilson B commercialized by Arkoma. It has ample applications where extensive mechanical strength is required such as automotive fuel lines, pneumatic airbrake tubing and flexible goods.

3.2. Polycaprolactones

Polycaprolactones are crude oil-based chemically synthesized biodegradable thermoplastic polymer. They possess good water, oil, solvent and chlorine resistance and are used in thermoplastic polyurethanes, resins for surface coatings adhesives and synthetic leather and fabrics.

| Table 1. Raw materials: Origin, advantages and their disadvantages |
|---------------------------------------------------------------|
| **Raw material** | **Origin** | **Advantages** | **Disadvantages** |
| Zein | Maize protein | Good film forming properties | More brittle which can be overcome by using plasticizers |
| | | Good tensile and moisture properties | |
| | | Antimicrobial and antifungal activity | |
| | | Good mechanical properties | |
| | | Low oxygen and CO$_2$ permeability | |
| Chitosan | Chitin derivate | Antimicrobial and antifungal activity | High water sensitivity |
| | | Good mechanical properties | |
| | | Low oxygen and CO$_2$ permeability | |
| Whey protein isolate | Cheese derivative | Good oxygen and aroma barrier | Moderate moisture barrier |
| Gluten | Wheat derivative | Low cost | High sensitivity to moisture |
| | | Good oxygen barrier | Brittle |
| | | Good film forming property | |
3.3. Cellulose

Cellulose is a biodegradable polysaccharide from which cellophane film can be made by dissolving it in a mixture of sodium hydroxide and carbon disulphide to obtain cellulose xanthate which is then dipped into an acid solution (sulphuric acid) to yield cellophane film (Averous, Fringant, & Moro, 2001; Sanchez-Garcia, Lagaron, & Hoa, 2010). Another way of obtaining cellulose derivatives is the derivatization of cellulose from the solvated state, through the process of esterification or etherification of hydroxyl groups (Cyras, Commiss, Mauri, & Vázquez, 2007). Further, additives are added to these cellulose esters viz. cellulose (di)acetate and cellulose (tri)acetate in order to convert them into thermoplastic material. These are processed by laminating, injection or extrusion moulding and exhibit good film forming properties (Zepnik et al., 2010). Other materials with their advantages and disadvantages are listed in Table 1.

4. Disadvantages of bioplastics

Besides the uneconomic feasibility of bioplastics in contrast to traditional packaging there are certain other disadvantages that limit their use in the present time. The use of land for the production of bioplastics is a major hurdle in the success of bioplastic functionality. Properties of certain bioplastics like thermal instability, difficult heat saleability, brittleness, low melt strength, high water vapour and oxygen permeability of PLA limit their use as films in food packaging applications (Rhim et al., 2009). Other starch- and cellulose-based packaging materials due to their hydrophilic nature possess low water vapour barrier, which is responsible for poor process ability, brittleness, vulnerability to degradation, limited long-term stability and poor mechanical properties (Cyras et al., 2007). In case of PHA/PHB stiffness, brittleness (due to high glass transition and melting temperatures), thermal instability and poor impact resistance also restrict their applications in food packaging (Modi, 2010). The above mentioned drawbacks have opened gate way of research for improving the functionality of bioplastics.

5. Methods to enhance bioplastic functions

Many different methods have been employed to enhance the properties of bioplastics especially improving gas and water barrier properties. Some of the strategies are coating, blending, addition of nanoparticles, addition of cellulose, chemical/physical modification, etc.

| Table 2. Current applications of bioplastics |
|---------------------------------------------|
| **Packaging application** | **Biopolymer** | **Company** |
| PLA | Cardboard cups coated with PLA | KLM |
| Coffee and tea | PLA Cups | Mosburger (Japan) |
| Beverages | PLA Bowls | McDonald’s |
| Fresh salads | Rigid PLA trays and packs | Asda (retailer) |
| Fresh cut fruits and vegetables | PLA Bags | PepsiCo’s Frito-lay |
| Potato chips | PLA Jars | Storyfield (Danone) |
| Bread | Paper bags with PLA window | Delhaize (retailer) |
| Starch based | | |
| Milk chocolates | Cornstarch trays | Cadbury Schweppes |
| Organic tomatoes | Corn-based packaging | Iper supermarkets (Italy) Coop Italia |
| Cellulose | | |
| Kiwi | Bio-based trays wrapped with cellulose film | Wal-Mart |
| Potato chips | Metalized cellulose film | Boulder Canyon |
| Sweets | Metalized cellulose film | Qualitystreet, Thornton |
| Organic pasta | Cellulose-based packaging | Birkel |
6. Present applications
Among the widely used bio-based plastics, PLA is widely used. Moreover, the bioplastics nowadays have found applications for both short-shelf life products like fresh fruits and vegetables and long-shelf life products, like potato chips and pasta (Table 2).

7. Conclusion
The current applicability of bioplastics for packaging of both short-shelf life as well as long-shelf life products which do not require that much excellent oxygen and/or water barrier properties necessitates the commercial exploitation of these bio-based packaging materials. However, several advancements in the bio-based packaging materials have resulted in their use for packaging of food products requiring MAP packaging. It is clear that bio-based packaging materials offer a versatile potential in case of packaging industry however, there is need of certain storage tests to be performed on packaging machinery in order to certify the use of these packaging films on a commercial scale. So a critical evaluation is required to access the functionality of bio-based packaging materials before they are launched into the market as sole substitutes for conventional packaging materials.
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