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REVIEW ARTICLE

Bio-Plastics: A Perfect Tool for Eco-Friendly Food Packaging: A Review

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Abstract

Revolutionary changes are always associated with food packaging. For last few years, this field is completely dominated by mineral oil derived polymers such as polyethylene (PE) and polystyrene (PS). These materials have brought so much convenience and attraction to food industry that nobody was bothered about the diminishing availability of these materials as they are coming from non-renewable sources and their safe disposal. But, due to the growing concern over environmental problems associated with these materials, renewed interest in packaging research are underway to develop and promote the use of "bio-plastic." Bio-plastic is a term used for packaging materials derived from renewable resources i.e. produced from agricultural sources, biological raw materials such as starch and bio-derived monomers and which are considered safe to be used in food applications. In general, compared to conventional plastics derived from petroleum, bio-plastics have more diverse stereochemistry and architecture of side chains which enable research scientists a greater number of opportunities to customize the properties of the final packaging material. This review evaluates the suitability of bio-plastics for food packaging. Additionally, it identifies the challenges involved while using bio-plastics for different food products.

Keywords: Bio-plastic, Food preservation, Food quality, Food packaging.

1. Introduction

Food packaging, an important discipline in the area of food technology, concerns preservation and protection of all types of foods and their raw materials from oxidative and microbial spoilage (Tharanathan, 2005; Dash *et al.*, 2013). Stability of a packaged commodity greatly depends on the characteristics of the packaging material and proper conditions of harvesting, storage and distribution (Said *et al.*, 2013). During the last decade, food industries have changed the whole scenario of food packaging by using petroleum derived plastics. However, conventional plastics remain persistent in the environment and improperly disposed plastic materials are a significant source of environmental pollution, potentially harming life (Nir *et al*., 1993). Plastic has both environmental and health hazards. It can also affect the health of workers who are related with cleaning or maintaining the processing equipments (Jayasekar *et al*., 2005). At present, the consumer demand has also shifted to eco-friendly biodegradable materials that come from agro-food industry wastes and renewable low cost natural resources. So there is a need of technical guidelines for protecting human health and the environment from the improper management and disposal of plastic wastes (Sturges, 2000) and to develop a material that can, not only perform all the actions as plastics but also able to solve all the environmental related concerns associated with them as well. Natural polymers can be an alternative source for packaging development due to their palatability and biodegradability (Siracusa *et al.*, 2008). Hence, the most important reason of this article is to address the packaging industry and related personals about the growing problem of waste management. Additionally, it identifies the future prospect of bio-plastics in packaging industry and the challenges associated with them.

2. Plastic

Plastics are manmade long chain Polymeric molecules (Scott, 1999). Plastics exhibit many desirable features like transparency, softness, heat seal ability and good strength to weight ratio (Bohlmann, 2006). The most widely used plastics used in packaging are Polyethylene (LDPE MDPE. HDPE and LLDPE), Polypropylene (PP), Polystyrene (PS) Polyvinyl chloride (PVC), Polyurethene (PUR), Poly ethyl terepthalate (PET), Polybutylene terephthalate (PBT), and Nylons (Said *et al.*, 2013).

The widespread application of plastics are not only due to their favourable mechanical and thermal properties but also mainly due to the stability and durability (Rivard *et al*., 1995). Originally, plastics were mimicking and replacing natural products (lacquer, shellac, amber, horns tusks, tortoise shell), and the early synthetic materials were chemical modifications of naturally occurring cellulosic polymers. But as time progresses, the challenges surrounding plastics waste treatment are further being compounded. In the United States, synthetic polymers are estimated to be approximately 20% of total volume of municipal solid waste, dumped as landfill. They are estimated to account for 8% of the total weight (Glover, 1993; Alexander, 1994). Polymer biodegradability depends on molecular weight crystallinity and physical forms (Gu *et al.*, 1998). Generally an increase in molecular weight results in a decline of polymer degradability.

Table 1: Timeline for synthetic polymer development

Year	Plastic Type
1869	Cellulose Nitrate
1889	Rayon
1931	Poly vinyl chloride
1933	Polyethylene
1937	Polystyrene
1938	Poly tetra fluoro ethyle (Teflon)
1939	Polyamide (Nylon)
1943	Silicon
1956	Acetal
1957	Polypropylene
1958	Polycarbonate

(Source: Dyllingowski and Hamel, 2004).

3. Bio-plastic

According to IUPAC, bio-based polymer or bio-plastics derived from the biomass or issued from monomers derived from the biomass. A number of bio derived materials and their innovative applications in food-related packaging have gained much attention over the past several years. These new materials mostly include starch, cellulose. Bio-plastic development efforts have focused predominantly upon starch, which is a renewable and widely available raw material. Starch is economically competitive with petroleum and has been used in several methods for preparing compostable plastics (Chandra and Rustgi, 1997). Corn is the most common source of starch for bio-plastics, although more recent global research is evaluating the potential use in bio-plastics for starches from other sources like potato, wheat, rice, barley, oat and soy (James *et al.*, 2005). Some acceptable bio-plastics are listed below (Park *et al.*, 2001; Plastics Task Force, 2008)

3.1 Cellulose

Cellulose is the most abundantly occurring natural polymer on earth. It is comprised of glucose monomer units that are joined together via β-1, 4 glycosidic linkages, which enable cellulose chains to pack tightly together and form strong inter-chain hydrogen bonds. Cellulose is isolated from its crystalline state in micro fibrils by chemical extraction (Griffin, 1978). It is fusible and soluble in hydrogen bond-breaking solvents such as N-methylmorpholine-N-oxide. Cellulose is a very inexpensive natural resource. It is, however, difficult to use in packaging because of its hydrophilic nature, poor solubility characteristics, and highly crystalline structure. The alternating hydroxyl side chains along the cellulose backbone are responsible for the poor moisture-barrier properties of cellulose-based packaging materials. They also contribute to the highly crystalline structure of cellulose which, in turn, results in a packaging material that is brittle and demonstrates poor flexibility and tensile strength (Jamshiddi *et al.*, 1988). As a result, academic and industrial research has been focused in recent years on the development of cellulose derivatives for use in packaging applications.

3.2 Cellulose Derivatives

Cellulose derivatives are polysaccharides composed of linear chains of β (1–4) glucosidic units with methyl, hydroxypropyl or carboxyl substituents. Only four cellulose derivative forms are used for edible coatings or films: Hydroxypropyl cellulose (E463; HPC), hydroxypropyl methylcellulose (E464; HPMC), Carboxymethylcellulose (E466; CMC) or Methyl cellulose (E461; MC). Cellulose derivatives exhibit thermo-gelation. Therefore when suspensions are heated they form a gel whereas they return to their original consistency when cooled (Murray, 2000). However, cellulose derivative films are poor water vapour barriers because of the inherent hydrophilic nature of polysaccharides and they possess poor mechanical properties (Gennadios *et al.*, 1997). One method in enhancing the moisture barrier would be by incorporation of hydrophobic compounds, such as fatty acids into the cellulose ether matrix to develop a composite film (Morillon *et al.*, 2002).

3.3 Starch

Starch, composed of amylose (20-30%) and amylopectin (70-80%), is primarily derived from cereal grains like corn (maize), with the largest source of starch. Other commonly used sources are wheat, potato, tapioca and rice. Starch is the major carbohydrate reserve in plant tubers and seed endosperm where it is found as granules, each typically containing several million amylopectin molecules accompanied by a much larger number of smaller amylose molecules (Walstra, 2003). Regarding to its application in biodegradable plastics it is either physically mixed with its native granules or melted and blended on a molecular level with the appropriate polymer. Amylose is responsible for the film forming capacity of starch (Romero-Bastida, 2005). High amylose starch films have been made that are flexible, oxygen impermeable, oil resistant, heat-sealable and water soluble. Films of high-amylose corn starch or potato starch was more stable during aging (Krogars *et al*., 2003). Starch-based films exhibit physical characteristics similar to plastic films in that they are odourless, tasteless, colourless, non-toxic, biologically absorbable, semi-permeable to carbon dioxide and resistant to passage of oxygen. Since the water activity is critical for microbial, chemical and enzymatic activities, while edible starch based films can retard microbial growth by lowering the water activity within the package (Wong *et al*., 1994). Biodegradation of starch-based polymers is due to enzymatic attack at the glycosidic linkages between the sugar groups, leading to a reduction in chain length and splitting out of lower molecular weight sugar units. When a plasticizer, such as water, is added starches exhibit thermoplastic behaviour (Krochta and De, 1997).

3.4 Poly-Beta-Hydroxyalkanoates (PHB)

PHB, a member of poly hydroxyl alkanoates, degrades under the presence of various microorganisms which upon contact with the polymer secrete enzymes that break the polymer into smaller parts. The three most unique properties of PHB are (i) 100% resistance to water, (ii) 100% biodegradability, (iii) thermoplastic process ability. They are biodegradable on soil contact, water resistant, and are readily processed in standard industrial plastic plants (Biopol-Natures Plastic).

3.5 Polylactide Acid (PLA) Plastics

PLA is emerging as one of the most attractive packing material because of its excellent biodegradability, process ability, and biocompatibility. PLA, a thermoplastic, is processed by injection molding, blow molding, thermoforming, and extrusion. Its degradation is dependent on time, temperature, low molecular weight impurities, and catalyst concentration. PLA films have better ultraviolet light barrier properties than low density polyethylene (LDPE). It has lower melting and glass transition temperatures. PLA is mainly composed of lactic acid (2-hydroxy propionic acid) and contains pendent methyl group on the alpha carbon atom which gives rise to a specific structures. This in turn increases the molecular weight and when sufficiently high it becomes insoluble in water. Polylactates also perform well compared with standard thermoplastics, and the production of flexible, water-resistant film has been demonstrated (Hakola, 1997). So it can be assumed that, in the family of biodegradable synthetic polymers, poly-lactic acid (PLA) appears one of the most attractive for applications in agriculture and as packaging material due to its biodegradability and the bio-renewable profile (Fortunati *et al*., 2012).

3.6 Chitin/Chitosan

Chitosan is obtained from chitin, which is an important waste of the fishery industry, by deacetylation in the presence of alkali (Sánchez *et al*., 2010). This is the second most abundant natural and non-toxic polymer in nature after cellulose (Shahidi, 1999). Some desirable properties of chitosan are that it forms films without the addition of additives, exhibits good oxygen and carbon dioxide permeability, as well as excellent mechanical properties and antimicrobial activity against bacteria, yeasts, and molds. However, a major drawback of chitosan is its poor solubility in neutral solutions. The required degree of deacetylation to obtain a soluble product must be 80–85% or higher (Park *et al*., 2001). Chitosan products are highly viscous, resembling natural gums (Peniston and Johnson, 1980). Chitosan can form transparent films to enhance the quality and extend the storage life of food products (Ribeiro *et al*., 2007). Pure chitosan films are generally cohesive, compact and the film surface has a smooth contour without pores or cracks (Hood and Zottola, 1995). The functionality of chitosan films can be improved by inclusion of inert materials or reactive compounds in the polymer matrix (Rhim *et al*., 2009).

3.7 Application of Biopolymers for Food Packaging

For many years, cellulose in the form of paper and cardboard enjoys wide usage as an exterior packaging layer (Petersen *et al*., 1999). However, paper is fibrous and opaque with poor barrier and moisture resistance properties. Hence, its role will remain limited to exterior packaging of foods except in very specific cases (e.g. dry products). Coated cellophane and cellulose acetate have been utilized for food packaging. Coated cellophane is used for e.g. baked goods, fresh produce, processed meat, cheese, and candy. Cellulose acetate is used mainly for baked goods and fresh produce (Krochta and Mulder, 1997). The moisture and gas barrier properties of cellulose acetate are not optimal for food packaging. However, the film is excellent for high-moisture products as it allows respiration and reduces fogging (Hanlon, 1992). Films based on biodegradable materials can be produced by different techniques such as casting, extrusion, thermo-molding, and injection, sheeting and blowing (Averous *et al*., 2001; Gennadios *et al*., 1993). Films made from proteins and carbohydrates are excellent barriers to oxygen, because of their tightly packed, ordered hydrogen-bonded network structure (Yang and Paulson, 2000). Holton *et al*. (1994) evaluated the suitability of an ordinary polyethylene (PE) film and a PE film containing 6% corn starch when used for packaging of broccoli, bread, and ground beef stored under normal time and temperature conditions. The type of packaging film seemingly did not affect the evaluated quality parameters, i.e. bread staling, broccoli colour and lipid oxidation of ground beef. Hood and Zottola (1995) and Kim and Pometto (1994) found that Starch addition (0±28%) in polyethylene films did not impair heat-sealing, nor did it accelerate microbial growth in ground beef. Fresh mushrooms when packaged in a glass jar covered with gluten film and stored at 10ºC for 5-6 days, a modified atmosphere containing 2-3% CO_2

Table 2: Comparison between some common plastics and bioplastics

Polymer	Moisture permeability	Oxygen permeability	Mechanical properties
Cellulose	High- Medium	High	Good
Cellulose acetate	Moderate	High	Moderate
Starch	High	Low	Good
Polylactate	Moderate	High	Good
Low density polyethyle	Low	High	Moderate
Polystyrene	High	High	Poor- Moderate

(Source: Petersen et al., 1999).

and 2-3% O_2 developed during the storage period (Barron *et al.*, 2002). Makino and Hirata (1997) also found Laminate of chitosan (14.5% by weight) cellulose (48.3%) and polycaprolactone [glycerol (36.2%) and protein (1.0%)] suitable as a packaging material for the storage of fresh vegetables upto 4-6 days at 10-25ºC. Suman *et al*. (2010) showed that coating ground beef patties with chitosan reduced TBARS values and improved the surface red colour of patties as compared to non-coated samples.

4. Limitations

One of the challenges facing the food packaging industry in its efforts to produce bio-based primary packaging is to match the durability of the packaging with product shelf-life. The biologically based packaging material must remain stable without changes of mechanical and/or barrier properties and must function properly during storage until disposal. Subsequently, the material should biodegrade efficiently. It appears that the barrier properties of bio-packaging materials, in particular the moisture barrier properties, are inferior to existing packaging materials. The most important parameters for controlling stability of the biologically based packaging material are appropriate water activity, pH, nutrients, oxygen, storage time, and temperature. The main disadvantage of biodegradable starch based films is their hydrophilic character, which leads to low stability when these materials are submitted to different environmental conditions. Thus, moist foods would have limited storage periods (Krochta and Mulder, 1997). The immediate solution is to package foods that are compatible with the materials and their properties. Therefore, Holton *et al*. (1994) recommended that corn starch based PE film be used only for packaging of wet and dry low-lipid foods. With respect to polyalkanoate, suggested use within the food sector includes beverage bottles, coated paperboard milk cartons, cups, fast food packaging, and films (Hocking and Marchessault, 1994). In some classes of bio-plastics certain limitations associated with their production, and cost effectiveness also arises, such as poly-beta-hydroxyalkanoates and polylactates generally perform very well and are easily processed into films using standard plastics techniques, but tend to be expensive compared with their synthetic analogues. According to Kester and Fennema (1986) hydrophilic films and coatings (polysaccharide or protein-based) generally provide a good barrier to oxygen transference. But this property is in turn greatly affected by the water availability and temperature.

5. Future Scope

The environmental impact caused by the excessive quantity of non-degradable waste materials is promoting research and efforts to develop new biodegradable packing materials that can be manufactured with the utilization of environmental friendly raw materials (Averous *et al*., 2001). However, citing above limitations it is necessary to modify the bio-based materials to improve their properties with respect to food packaging like; many bio-based food packaging materials are biodegradable hence, the microbial stability of the material during storage until disposal must be tested before using the material as a primary packaging material for foods. There is now much research effort being expended world-wide, both fundamental and applied. The global market for biodegradable polymers exceeds 114 million pounds and is expected to rise at an average annual growth rate of 12.6% to 206 million pounds in 2010 (Aruas *et al*., 2003). Therefore, it may be assumed that most of the present problems will be solved within a reasonable time. However, there seems to be a gap between research and its implementation in the industry (Arora and Kempkes, 2008) to make a case for continued collaboration between academic and industry in order to bridge the yawning gap between research in the field of food processing technologies and its implementation in the industry. Moreover, there is need of further research efforts towards the study of interaction between bio-plastics and the food material packed within because of only few number of publications in this area indicates that this area remain unexplored till date.

6. Conclusion

Each year more than 140 million tonnes of plastics are produced worldwide. In many countries, plastics are disposed off through open, uncontrolled burning and land filling. Open burning releases pollutants into the air that could cause various health problems. These pollutants circulate globally and have been associated with a number of adverse effects in living beings, including immune and enzyme disorder and they are classified as possible carcinogens. The present review is pointing towards the growing problems associated with the use of plastics and the possibilities for bio-plastics in this area as because in today's world of global markets, due to stiff competition and growing customer curiosity, it becomes necessary for companies to explore ways to improve their productivity by adopting novel technology and proven management principles. Emerging field of bio-plastics development produces the necessary resources to address the growing environmental concern. Important reason for this attention is the marketing of environment friendly bio-plastics packaging materials, as use of biodegradable packaging materials has the greatest potential in areas where landfill is the main waste management tool. Although research efforts to date primarily have focused on the laboratory production of the bio-based polymers there is need for a more practical system analysis of the entire operation and to investigate why the practical implementations of these advancements seem to lag behind research in the field. So that it will help bio-plastics to fully demonstrate their socioeconomic benefits and replacement of traditional petroleum-based plastics in future.

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