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Biodegradable Packaging: An Alternative to Non-Biodegradable Plastics

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Abstract- **Plastic packaging, used extensively nowadays, poses huge threats to environment. Plastics, especially non-biodegradable polymers accumulate in the environment and adversely affect wildlife, wildlife habitat, or humans. To overcome this problem we can replace traditional non-environment friendly plastics with biopolymers, in particular polysaccharides or macromolecules having film-forming properties. These biodegradable materials, which find applications mostly in food packaging, can largely contribute to the reduction of environmental pollution. This review summarizes some of the widely used biodegradable packaging materials.**

Index terms**: Biopolymers; non-biodegradable polymers; packaging; polysaccharides**

I. INTRODUCTION

Food packaging is essential for products containment, protection, preservation, convenience, to provide information about the product, brand communication, among others. Plastic packaging represents almost 40% of the European plastics market and is essential for processing, storing, transporting, protecting and preserving food. In fact, over 50% of all European goods are packaged in plastics, and this commercial success is due to a combination of properties such as flexibility, strength, lightness, stability, impermeability and ease of sterilization. However, the crucial problem of using plastics for packaging is the post-consumer waste, once packaging is by far the largest contributor (63%) of plastic waste. In addition, some materials are difficult to reuse and it is estimated that less than 14% of plastic packaging materials are recyclable [1]. So, to avoid all these problems biodegradable plastics with functionalities comparable to traditional petrochemical-based plastics have been developed for packaging applications. *Biodegradable polymers (BDPs) or biodegradable plastics* refer to polymeric materials that are 'capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of microorganisms, that can be measured by standardized tests, in a specified period of time, reflecting available disposal condition'. Typically, these are made from renewable raw materials such as starch or cellulose. Interest in biodegradable plastic packaging arises primarily from their use of renewable raw materials (crops instead of crude oil) and end-of-life waste management by composting or anaerobic digestion to reduce landfilling [2].

The development of biodegradable packaging alternatives has been the subject of much research and development in recent times, particularly with regard to renewable alternatives to traditional oil-derived plastics. There are two major groups of biodegradable plastics currently entering the marketplace or positioned to enter it in the near future: polylactic acid (PLA) and starch based polymers. These new polymers are truly degradable but full degradability will occur only when products made from these polymers are disposed of properly in a composting site.

Different polysaccharides used for manufacture of biodegradable packaging

Lactic acid

The efforts of biotechnology and agricultural industries to replace conventional plastics with plant derived alternatives have seen recently the following three approaches: converting plant sugars into plastic, producing plastic inside microorganisms and growing plastic in corn and other crops. Cargill-Dow[3] (2000) has scaled-up the process of turning sugar into lactic acid and subsequently polymerises it into the polymer polylactic acid, NatureWorks™ PLA. Lactic acid can be produced synthetically from hydrogen cyanide and acetaldehyde or naturally from fermentation of sugars, by *Lactobacillus.* Fermentation offers the best route to the optically pure isomers desired for polymerisation. Condensation polymerisation of lactic acid itself generally results in low molecular weight polymers. Higher molecular weights are obtained by condensation polymerisation of lactide, the intermediate monomer. When racemic lactides are used, the result is an amorphous polymer, with a glass transition temperature of about 60ºC, which is not suitable for packaging.

Polylactic acid

Polylactic acid (PLA) is a polymer of lactic acid. It behaves quite similarly to polyolefins. PLA, a fermentation product of low cost polysaccharides, is a product which is produced from a combination of biotechnology and chemical technology, and can be converted into plastic products by standard processing methods such as injection moulding and extrusion. It has potential for use in the packaging industry as well as hygiene applications. The current global market for lactic acid demand is 100,000 tons per annum, of which more than 75% is used in the food industry. Perhaps the biggest opportunities for PLA lie in fibres and films. An important market niche for PLA can be found in the agricultural industry such as crop covers and compostable bags. Biodegradations of PLA have been a subject of interest and so far proteinase K (EC 3.4.21.64) is the only reported enzyme that will degrade PLA amorphous regions of low MW [4]. Microbial degradation studies of PLA have been inclusive [5]. Although most microorganisms studied can utilise lactic acid and its dimer, microbial degradation of oligomers and polymers of PLA have not yet been observed at appreciable rates. A microbial degradation study on PLA/CL only showed the degradation of the PCL segments [6]. Compost, field and environmental degradations of PLA are primarily due to hydrolysis [7].

Native starch

Starch is nature's primary means of storing energy and is found in granule form in seeds, roots and tubers as well as in stems, leaves and fruits of plants. Starch is totally biodegradable in a wide variety of environments and allows the development of totally degradable products for specific market needs. The two main components of starch are polymers of glucose: amylose (MW 10^5-10^6), an essentially linear molecule and amylopectin (MW 10^7-10^9), a highly branched molecule. Amylopectin is the major component of starch and may be considered as one of the largest naturally occurring macromolecules. Starch granules are semi-crystalline, with crystallinity varying from 15 to 45% depending on the source. The term 'native starch' is mostly used for industrially extracted starch. It is an inexpensive (< 0.5 Euro/kg) and abundant product, available from potato, maize, wheat and tapioca.

Thermoplastic starch

Thermoplastic starch (TPS) or destructurised starch (DS) is a homogeneous thermoplastic substance made from native starch by swelling in a solvent (plasticiser) and a consecutive 'extrusion' treatment consisting of a combined kneading and heating process. Due to the destructurisation treatment, the starch undergoes a thermo-mechanical transformation from the semi-crystalline starch granules into a homogeneous amorphous polymeric material. Water and glycerol are mainly used as plasticisers, with glycerol having a less plasticising effect in TPS compared to water, which plays a dominant role with respect to the properties of thermoplastic starch.

Chitin and chitosan

Chitin is the second most abundant naturally occurring biopolymer (after cellulose) and is found in the exoskeleton of crustaceans, in fungal cell walls and other biological materials [8]. It is mainly poly (ß-(1-4)-2-acetamide-D-glucose), which is structurally identical to cellulose. Chitosan is derived from chitin by deacetylation in the presence of alkali. Chitosan can form semi-permeable coatings, which can modify the internal atmosphere, thereby delaying ripening and decreasing transpiration rates in fruits and vegetables. Films from aqueous chitosan are clear, tough, flexible and good oxygen barriers [9,10]. Carbon dioxide permeability could be improved by methylation of polymers. Films from chitosan are rather stable and their mechanical and barrier properties change only slightly during storage [11]. Chitosan coatings are usually used on fruit and vegetable products such as strawberries, cucumbers, bell peppers as antimicrobial coating [12,13], and on apples, pears, peaches and plums as gas barrier [14,15].

Cellulose

Cellulose is the most abundant occurring natural polymer on earth, being the predominant constituent in cell walls of all plants. Cellulose is composed of a unique monomer: glucose under its β-d-glucopyranose form [16]. Due to its regular structure and array of hydroxyl groups, it tends to form strong hydrogen bonded crystalline microfibrils and fibers and is most familiar in the form of paper, paperboard and corrugated paperboard in the packaging context [17,18].

Shellac resins

Shellac is a resin secreted by the female lac bug (*Laccifer lacca*), on trees in the forests of India and Thailand. It is processed and sold as dry flakes and dissolved in ethanol to make liquid shellac, which is used as a brush-on colorant, food glaze and wood finish. Shellac functions as a tough natural primer, sanding sealant, tannin-blocker, odour-blocker, stain, and high-gloss varnish. Shellac is a natural bio-adhesive polymer and is chemically similar to synthetic polymers, and thus can be considered a natural form of plastic. It can be turned into a moulding compound when mixed with wood flour and moulded under heat and pressure methods, so it can also be classified as thermoplastic. This resin is soluble in alcohols and in alkaline solutions. Shellac is not a GRAS substance; it is only permitted as an indirect food additive in food coatings and adhesives. It is mostly used in coatings for the pharmaceutical industry [19]. Shellac is also used as a coating on citrus fruits as it has good gas barrier properties.

Shellac- and wood resin-based coatings also tend to increase prevalence of post-harvest pitting [20,21].

Polyhydroxyalkanoates or (PHA's)

These are linear polyesters produced in nature by bacterial fermentation of sugar or lipids. They are produced by the bacteria and store carbon and energy. PHAs are produced from a wide variety of substrates such as renewable sources (sucrose, starch, cellulose, triacylglycerols), fossil resources (methane,mineral oil, lignite, hard coal), byproducts (molasses, whey, glycerol), chemicals (propionic acid, 4-hydroxybutyric acid) and carbon dioxide. More than 150 different monomers can be combined within this family to give materials with extremely different properties. They can be either thermoplastic or elastomeric materials, with melting points ranging from 40 to 180 °C.

Polycaprolactone (PCL)

PCL a biodegradable polyester with a low melting point of around 60 °C and a glass transition temperature of about −60 °C. The most common use of polycaprolactone is in the manufacture of speciality polyurethanes. Polycaprolactone (PCL), a bioresorbable and biocompatible polymer, has been widely used in long-term implants and controlled drug release applications [22]. Polycaprolactones impart good water, oil, solvent and chlorine resistance to the polyurethane produced. This polymer is often used as an additive for resins to improve their processing characteristics and their end use properties (e.g., impact resistance). Being compatible with a range of other materials, PCL is usually mixed with starch to lower its cost and increase biodegradability. PCL is added as a polymeric plasticizer to polyvinyl chloride (PVC).

II. CONCLUSION

Biodegradable polymers will play a greater role in the packaging sector in the future. Post-use biodegradable plastics and other biowastes like paper, food and garden waste are generally unsuitable for landfill due to their potential to release methane under anaerobic conditions and their disposal by this method is inconsistent with policies like the EU Landfill Directive. Biodegradable bioplastics are most suitable for biological waste treatment through industrial and/or domestic composting and, subject to further demonstration, potentially in anaerobic digestion systems. Intensive academic and industry research is being carried out to find new and improved polymers, production methods, sources and properties, to obtain biopolymers (in particular, polysaccharides) that may replace the conventional synthetic and non-biodegradable ones as packaging materials.

REFERENCES

[1] K. S. Tumwesigye, J. C. Oliveira, and M. J. Sousa-Gallagher, "New sustainable approach to reduce cassava borne environmental waste and develop biodegradable materials for food packaging applications". *Food Packag. Shelf Life*. 2016;7:8–19.

[2] R. Murphy, and I. Bartle, "Summary report, biodegradable polymers and sustainability: insight from life cycle assessment". National Non Food Crops Centre, UK., 2004

[3] L. L. C. Cargill-Dow, "Product information", published June, 2000.

[4] M. S. Reeve, S. P. McCarthy, M. J. Downey, and R. A. Gross, "In *Macromolecules*", 1994, **27**, 3, 825, 1994.

[5] A. Torres, S.M. Li, S. Roussos, and M. Vert, "In *Journal of Environmental Polymer Degradation*", 1996, **4**, 4, 213.

[6] M. R. Lostocco, , C. A. Murphy, J. A. Cameron, and S. J. Huang, "In *Polymer Degradation and Stability*", **59**, 1-3, 303, 1998.

[7] K. L. G. Ho, A. L. Pometto, A. Gadea-Rivas, J. A. Briceno, and A. Rojas, "In *Journal of Environmental Polymer Degradation*", 1999, **7**, 4, 173.

[8] A. L. Andrady, and P. Xu, "Elastic behavior of chitosan films". *Journal of Polymer Science* 5: 307-521, 1997.

[9] P. A. Sandford, "Chitosan: commercial uses and potential application. In Skjak-Braek, G., Anthosen,. T. and Sandford, P. (Eds.)". "Chitin and Chitosan: Source, Chemistry, Biochemistry, Physical Properties, and Application", p. 51-69. New York: *Elsevier Applied Science*, 1989.

[10] D. L. Kaplan, J. M. Mayer, D. Ball, J. McCassie, A. L. Allen, and P. Stenhouse, "Fundamental of biodegradable polymer. In Ching, C., Kaplan D., and Thomas E. (eds."). *Biodegradable Polymers and Packaging*, p. 1-42, 1993.

[11] B. L. Butler, P. J. Vergaro, R. F. Testin, J. M. Bunn, and J. L. Wiles, "Mechanical and barrier properties of edible chitosan films as affected by composition and storage". *Journal of Food Science* 61: 953-961, 1996.

[12] A. El Ghaouth, J. Arul, R. Ponnampalam, and M. Boulet, "Chitosan coating effect on stability of fresh strawberries". *Journal of Food Science* 57: 1618-1620, 1991[a].

[13] A. El Ghaouth, J. Arul, R. Ponnampalam, and M. Boulet, "Use of chitosan coating to reduce water loss and maintain quality of cucumber and bell pepper fruits". *Journal of Food Processing and Preservation* 15: 359-368, 1991[b].

[14] C. M. Elson, and E. R. Hayes, "Development of the differentially permeable fruit coating Nutri- Save® for the modified atmosphere storage of fruit". Proceedings of the 4th National Controlled Atmosphere Research Conference: *Controlled Atmosphere for Storage and Transport of Perishable Agricultural Commodities*, p. 248-262,1985.

[15] D. H. Davies, C. M. Elson, and E. R. Hayes, "N, O-carboxymethyl chitosan, a new water soluble chitin derivative". In Skjak-Braek, G., Anthosen, T. and Sandford, P. (Eds.). "Chitin and Chitosan: Source, Chemistry, Biochemistry, Physical Properties, and Application", p. 467-472. New York: *Elsevier Applied Science*, 1989.

[16] J. Credou, T. Berthelot, " Cellulose: From biocompatible to bioactive material". *J. Mater. Chem. B.* 2:4767–4788, 2014.

[17] M, Cruz-Romero, J. P. Kerry, "Crop-based biodegradable packaging and its environmental implications". CAB *Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour.* 3:1–25, 2008.

[18] R. Babu, K. O'Connor, R. Seeram, "Current progress on bio-based polymers and their future trends". *Prog. Biomater*., 2:1–16, 2013.

[19] E. Hernandez, "Edible coating from lipids and resins". In: *Krochta, J. M., Balwin, E. A. and Niperos-Carriedo, M. O. (Eds.). Edible Coatings and Films to Improve Food Quality*, p. 279-303, 1994.

[20] P. D. Petracek, H. Dou, and I. Malik, "A postharvest pitting of Temple oranges stimulated by high temperature storage and wax application". *Florida State Horticultural Society* 110: 211–214, 1997.

[21] P. D. Petracek, H. Dou, and S. Pao, "Influence of applied waxes on postharvest physiological behavior and pitting of white grapefruit". *Post-harvest Biology and Technology* 14: 99–106, 1998.

[22] F. Hajiali, S. Tajbakhsh, and A. Shojae, "Fabrication and Properties of Polycaprolactone Composites Containing Calcium Phosphate-Based Ceramics and Bioactive Glasses in Bone Tissue Engineering: A Review". *Polymer Reviews*, page 1-44, 2017.

[23] I. Coelhoso, F. Freitas, V. Alves, M. M. Reis "Biodegradable organic matter". In: Drioli E., Giorno L., editors. *Encyclopedia of Membranes*. Springer Berlin Heidelberg; Heidelberg, Germany: pp. 1–2, 2015.

[24] R. Coles, D. McDowell, and M. J. Kirwan, "Food Packaging Technology". *Taylor & Francis*; Oxford, United Kingdom, 2003.

[25] A. Gennadios, T. H. McHugh, C. L. Weller, and J. M. Krochta, "Edible coating and films based on protein". In Krochta, J. M., Balwin, E. A. and Niperos-Carriedo, M. O. (Eds.). Edible Coatings and Films to Improve Food Quality, p. 201-277, 1994.

[26] Green Facts Report highlights- "Trends of plastic waste in the EU".

[27] S. Guilbert, "Technology and application of edible protective films". In: *Mathlouthi, M. (Ed.), Food packaging and preservation*, p. 371–394. London, UK: Elsevier Applied Science, 1986.

[28] Plastics Europe, "Plastic Packaging: Born to Protect". Plastics Europe- Association of plastics manufacturers; Brussels, Belgium: 2012.

[29] Plastics Europe, "Plastics- The facts 2014/2015". Plastics Europe- Association of plastics manufacturers; Brussels, Belgium: 2015.

[30] J. J. Kester, and O. R. Fennema, "Edible films and coatings: A review". *Food Technology* 40(12): 47-59, 1986.

[31] M. Rinaudo, "Chitin and chitosan: Properties and applications". *Prog. Polym. Sci.*, 31:603–632, 2006.

[32] M. S. Roby, "In *Proceedings of Biopolymers – Advances in Medical and Material Science Applications*", Cambridge, MA, USA, 2001.

[33] D. Twede, "Logistical/distribution packaging". In: Brody A and Marsh K, *The Wiley Encyclopedia of Packaging Technology*, second edition, John Wiley & Sons, Inc ISBN 0-471-06397-5 pp. 572–9, 1997.