Jabeen et al., *Cogent Food & Agriculture* (2015), 1: 1117749
http://dx.doi.org/10.1080/23311932.2015.1117749

cogent food & agriculture

Received: 17 October 2015
Accepted: 21 October 2015
Published: 14 December 2015

*Corresponding author: Gulzar Ahmad Nayik, Department of Food Engineering & Technology, SLIET, Longowal 148106, Punjab, India
E-mail: gulzarnaik@gmail.com

Reviewing editor:
Fatih Yildiz, Middle East Technical University, Turkey

Additional information is available at the end of the article

FOOD SCIENCE & TECHNOLOGY | REVIEW ARTICLE

Bioplastics and food packaging: A review

Nafisa Jabeen[1], Ishrat Majid[2] and Gulzar Ahmad Nayik[2]*

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 O_2, 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 CO_2, CH_4, 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

Keywords: bioplastic; petrochemical; polymerase; packaging; biodegradable

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

ABOUT THE AUTHORS

Nafisa Jabeen completed her Masters degree in Food Technology from IUST Awantipora, India. Currently she is a doctoral research fellow at Division of Post Harvest Technology, SKUAST-Kashmir, India. She has one publication to her credit.

Ishrat Majid completed her Masters degree in Food Technology from Jamia Hamdard New Delhi. Currently she is a doctoral research fellow at Department of Food Engineering & Technology, SLIET, Longowal, Punjab, India having 4 International publications to her credit.

Gulzar Ahmad Nayik received his Masters degree in Food Technology from IUST Awantipora, India. Currently he is a doctoral research fellow at Department of Food Engineering & Technology, SLIET, Punjab, India. He has more than 21 International research papers to his credit and is serving as editorial board member and reviewer of more than 30 reputed international journals.

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.

cogent oa

© 2015 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

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, Narayan, & 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, Kopitzky, & Michels, 2010). The bioplastic aim is to emulate the life cycle of biomass, which includes conservation of fossil resources, CO_2 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 *Tg* 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	Britle
		Good film forming property	

cogent • food & agriculture

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, Commisso, 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		
Coffee and tea	Cardboard cups coated with PLA	KLM
Beverages	PLA Cups	Mosburger (Japan)
Fresh salads	PLA Bowls	McDonald's
Fresh cut fruits and vegetables	Rigid PLA trays and packs	Asda (retailer)
Potato chips	PLA Bags	PepsiCo's Frito-lay
Yoghurt	PLA Jars	Stonyfield (Danone)
Bread	Paper bags with PLA window	Delhaize (retailer)
Starch based		
Milk chocolates	Cornstarch trays	Cadbury Schwepps
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, Thomton
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.

Funding
The authors received no direct funding for this research.

Competing interests
The authors declare no competing interest.

Author details
Nafisa Jabeen[1]
E-mail: nafisabhat@gmail.com
Ishrat Majid[2]
E-mail: ishratmajid89@gmail.com
Gulzar Ahmad Nayik[2]
E-mail: gulzarnaik@gmail.com
ORCID ID: http://orcid.org/0000-0001-8372-5936
[1] Division of Post Harvest Technology, SKUAST-Kashmir, Srinagar 190025, India.
[2] Department of Food Engineering & Technology, SLIET, Longowal 148106, Punjab, India.

Citation information
Cite this article as: Bioplastics and food packaging: A review, Nafisa Jabeen, Ishrat Majid & Gulzar Ahmad Nayik, *Cogent Food & Agriculture* (2015), 1: 1117749.

References

Averous, L., Fringant, C., & Moro, L. (2001). Plasticized starch cellulose interactions in polysaccharide composites. *Polymer, 42*, 6566–6572.

Cyras, V. P., Commisso, M. S., Mauri, A. N., & Vázquez, A. (2007). Biodegradable double-layer films based on biological resources: Polyhydroxybutyrate and cellulose. *Journal of Applied Polymer Science, 106*, 749–756. http://dx.doi.org/10.1002/(ISSN)1097-4628

Demirgöz, D., Elvira, C., Mano, J. F., Cunha, A. M., Piskin, E., & Reis, R. L. (2000). Chemical modification of starch based biodegradable polymeric blends: Effects on water uptake, degradation behaviour and mechanical properties. *Polymer Degradation and Stability, 70*, 161–170. http://dx.doi.org/10.1016/S0141-3910(00)00102-6

Guilbert, S., Cuq, B., & Gontard, N. (1997). Recent innovations in edible and/or biodegradable packaging materials. *Food Additives and Contaminants, 14*, 741–751. http://dx.doi.org/10.1080/02652039709374585

Haugaard, V. K., Danielsen, B., & Bertelsen, G. (2003). Impact of polylactate and poly(hydroxybutyrate) on food quality. *European Food Research & Technology, 216*, 233–240.

Jamshidian, M., Tehrany, E. A., Imran, M., Jacquot, M., & Desobry, S. (2010). Poly-lactic acid: Production, applications, nanocomposites, and release studies. *Comprehensive Reviews in Food Science and Food Safety, 9*, 552–571. http://dx.doi.org/10.1111/crfs.2010.9.issue-5

Koller, I., & Owen, A. J. (1996). Starch-filled PHB and PHB/HV copolymer. *Polymer International, 39*, 175–181. http://dx.doi.org/10.1002/(ISSN)1097-0126

Mensitieri, G., Di Maio, E., Buonocore, G. G., Nedi, I., Oliviero, M., Sansone, L., & Iannace, S. (2011). Processing and shelf life issues of selected food packaging materials and structures from renewable resources. *Trends in Food Science & Technology, 22*, 72–80.

Modi, S. J. (2010). *Assessing the feasibility of poly-(3-,hydroxybutyrate-co-3-valerate) (PHBV) and poly-(lactic acid) for potential food packaging applications* (Thesis). Ohio State University.

Müller, C. M. O., Laurindo, J. B., & Yamashita, F. (2009). Effect of cellulose fibers addition on the mechanical properties and water vapor barrier of starch-based films. *Food Hydrocolloids, 23*, 1328–1333. http://dx.doi.org/10.1016/j.foodhyd.2008.09.002

Park, H., Li, X., Jin, C., Park, C.-Y., & Cho, W.-J. (2002). Preparation and properties of biodegradable thermoplastic starch/clay hybrids. *Macromolecular Materials and Engineering, 287*, 553–558. http://dx.doi.org/10.1002/1439-2054(20020801)287:8<553::AID-MAME553>3.0.CO;2-3

Petersen, K., Nielsen, P. V., Bertelsen, G., Lawther, M., Olsen, M. B., Nilsson, N. H., & Mortensen, G. (1999). Potential of biobased materials for food packaging. *Trends in Food Science & Technology, 10*, 52–68.

Rasal, R. M., Janorkar, A. V., & Hirt, D. E. (2010). Poly(lactic acid) modifications. *Progress in Polymer Science, 35*, 338–356. http://dx.doi.org/10.1016/j.progpolymsci.2009.12.003

Rhim, J. W., Hong, S. I., & Ha, C. S. (2009). Tensile, water vapour barrier and antimicrobial properties of PLA/nanoclay composite films. *Food Science and Technology, 42*, 612–617.

Sanchez-Garcia, M. D., Lagaron, J. M., & Hoa, S. V. (2010). Effect of addition of carbon nanofibers and carbon nanotubes on properties of thermoplastic biopolymers. *Composites Science and Technology, 70*, 1095–1105. http://dx.doi.org/10.1016/j.compscitech.2010.02.015

Scott, G., & Wiles, D. M. (2001). Programmed-life plastics from polyolefins: A new look at sustainability. *Biomacromolecules, 2*, 615–622. http://dx.doi.org/10.1021/bm010099h

Singh, R. (2011). Facts, growth, and opportunities in industrial biotechnology. *Organic Process Research & Development, 15*, 175–179.

Siracusa, V., Rocculi, P., Romani, S., & Dalla Rosa, M. (2008). Biodegradable polymers for food packaging. *Trends in*

Food Science & Technology, 19, 634–643.

Song, J. H., Murphy, R. J., Narayan, R., & Davies, G. B. H. (2009). Biodegradable and compostable alternatives to conventional plastics. *Philosophical transactions of the royal society B: Biological sciences, 364*, 2127–2139. http://dx.doi.org/10.1098/rstb.2008.0289

Sorrentino, A., Gorrasi, G., & Vittoria, V. (2007). Potential perspectives of bio-nanocomposites for food packaging applications. *Trends in Food Science and Technology, 18*, 84–95. http://dx.doi.org/10.1016/j.tifs.2006.09.004

Sudesh, K., & Iwata, T. (2008). Sustainability of biobased and biodegradable plastics. *CLEAN - Soil, Air, Water, 36*, 433–442. http://dx.doi.org/10.1002/clen.v36:5/6

Tharanathan, R. N. (2003). Review e biodegradable films and composite coatings: Past, present and future. *Trends in Food Science & Technology, 14*, 71–78.

Yoon, J. S., Lee, W. S., Jin, H. J., Chin, I. J., Kim, M. N., & Go, J. H. (1999). Toughening of poly(3-hydroxybutyrate) with poly(cis-1,4-isoprene). *European Polymer Journal, 35*, 781–788. http://dx.doi.org/10.1016/S0014-3057(98)00068-8

Zepnik, S., Kesselring, A., Kopitzky, R., & Michels, C. (2010). Basics of cellulosics. *Bioplastics Magazine, 1*, 44–47.

© 2015 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

You are free to:
Share — copy and redistribute the material in any medium or format
Adapt — remix, transform, and build upon the material for any purpose, even commercially.
The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:
Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made.
You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
No additional restrictions
You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

Cogent Food & Agriculture **(ISSN: 2331-1932) is published by Cogent OA, part of Taylor & Francis Group.**

Publishing with Cogent OA ensures:

- Immediate, universal access to your article on publication
- High visibility and discoverability via the Cogent OA website as well as Taylor & Francis Online
- Download and citation statistics for your article
- Rapid online publication
- Input from, and dialog with, expert editors and editorial boards
- Retention of full copyright of your article
- Guaranteed legacy preservation of your article
- Discounts and waivers for authors in developing regions

Submit your manuscript to a Cogent OA journal at www.CogentOA.com