Indian Journal of
Advances in Chemical Science

Review Article

Sustainable Food Packaging: A Review of Polylactic Acid as Biodegradable Material

Reham M. Faheem*, Venessa Robert Osta

Department of Chemistry, Isabella Thoburn College, Lucknow, Uttar Pradesh, India

ABSTRACT

Plastic is an integral part of our life and with the spread of COVID-19, it has become all the more important as packaging materials for maintaining hygiene. Due to bioaccumulation and the detrimental effects of plastics, there is an urgent need for alternatives. To restore our environment, this alternative has to be as comfortable as plastic material. As a result, in the recent past, the concept of biodegradable plastics has gained much attention among researchers. The studies have reported polylactic acid as an alternate material for plastics. The use of this polymer as an alternative is restricted due to its high cost and characteristics such as thermal degradability and an inadequate barrier to oxygen and water. The present review gives a comparative evaluation of biopolymers and their advantages and disadvantages as packaging material. The insight of this analysis will be suggestive of designing sustainable food packaging biopolymers, which will further help in reducing its detrimental effect on the environment.

Key words: Sustainable packing, Plastic waste, Biopolymers, Polylactic acid.

1. INTRODUCTION

In the past few decades, the use of plastics has increased tremendously and has shown its detrimental effect on both humans and the environment [1]. Around 70 million tons of the produced plastic are reported to have been a break down into microplastics, thus contaminating the aquatic, terrestrial, and aerial life [2]. Twelve million tons of plastic are poured into the ocean every year; 100,000 marine mammals and turtles and 1 million sea birds are killed by marine plastic pollution annually; 90% of plastic is produced from feedstock obtained from fossil oil and gas and producing 1 ton of plastic generates up to 2.5 tons of carbon dioxide. Among the plastic pollution composition, packaging contributes the major percentage [3]. The outbreak of COVID-19 has given much importance to health and hygiene. Food packaging is an important unit of operation in food production processes [4,5]. Due to the packaging involved in both online and offline ventures, the use of plastics has increased extensively. In the year 2005, the United States Environmental Protection Agency has given a model for the Sustainable Packaging Coalition and proposed the standards for the materials which include their shelf life and also address their harmful effect [6-9]. To address this issue of plastic pollution, the effective step is to use a sustainable material for packaging. Therefore, biodegradable plastic-like polylactic acid (PLA) which has good process ability and mechanical properties have become quite popular. Biodegradable polymers are those which decompose into natural elements by the action of microorganisms within a short time period [10].

2. BIO-POLYMER PLA

PLA is biodegradable thermoplastic polyester produced by condensation polymerization of lactic acid (LA) which is derived by fermentation of sugar from carbohydrates sources such as corn, sugar cane, or tapioca [11]. The time taken by PLA for degradation is 1–2 years while petroleum-based plastics take more than 500–1000 years for their breakdown [12]. The food contained in PLA packing can be sent directly for composting without cleaning as PLA has the advantage of being compostable together with organic waste [13]. The end life of PLA is composting, which is beneficial from an environmental point of view [14]. Composting is the controlled aerobic or organic degradation of natural substances to generate carbon and nutrient-rich compost that acts as a natural fertilizer that may be used to grow vegetation and accordingly lowering the call for chemical fertilizers [15]. Figure 1 represents the lifecycle of PLA bioplastic. Its degradation takes place through the scission of the backbone ester bonds and in humans and animals, PLA undergoes hydrolysis to form soluble oligomers that may be metabolized through cells [16]. The use of PLA results in an intrinsic zero material carbon footprint value [17]. The significant use of these substances for packaging can result in decreased plastic pollution and landfills.

3. ADVANTAGES OF PLA

PLA possesses a wide range of properties. These are:

- Good biocompatibility
- Favorable mechanical properties help in its molding into various shapes.
- Excellent transparency
- Absorbance to carbon dioxide compared to that of oxygen (perm selectivity) is higher than most conventional fossil fuel-based plastics
- Good chemical resistance toward fats and oils
- Better thermal process ability due to its relatively high glass transition temperature and low melting temperature

***Corresponding author:**
E-mail: rehamfaheem18@gmail.com

ISSN NO: 2320-0898 (p); 2320-0928 (e)
DOI: 10.22607/IJACS.2021.904027

Received: 08th October 2021;
Revised: 21st October 2021;
Accepted: 22nd October 2021

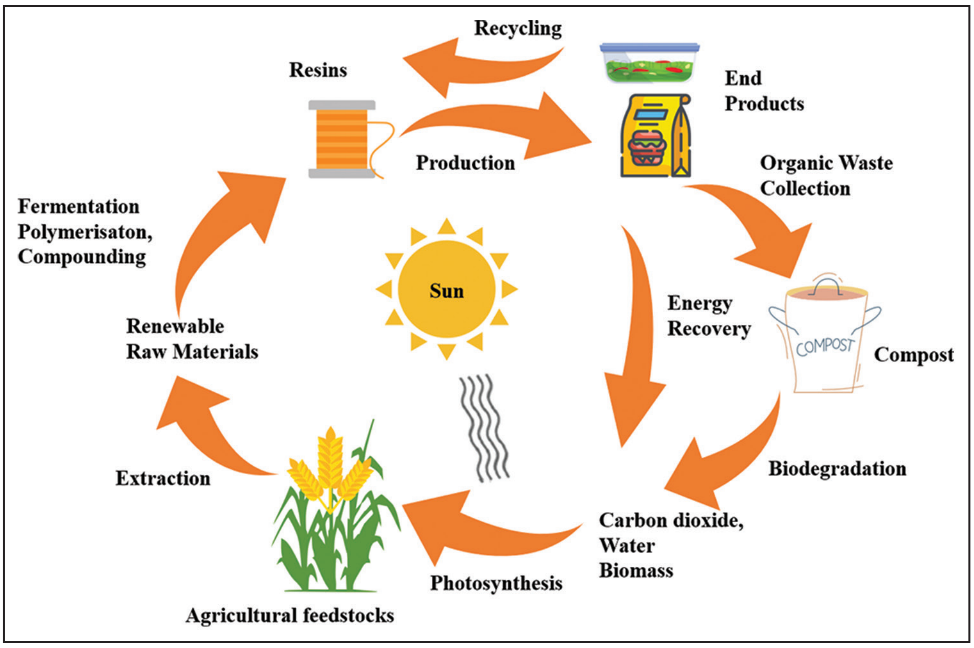


Figure 1: Lifecycle of polylactic acid bioplastic.

- Excellent ultraviolet barrier properties t
- Chemically suitable as A can be hydrolyzed to LA, leading to molecular recycling.

It also shows properties comparable to that of petroleum-based plastics [18]. For example, the polyethene terephthalate (PET) and PLA bottle have comparable tensile strength and elastic modulus, but the manufacturing of a PLA bottle consumes 36% less energy [19] and emits 44% less carbon dioxide when compared to regular PET bottles. Thus, the use of PLA gives similar benefits with less environmental pollution [16]. Table 1 shows some properties of PLA compared to that of PET. The Food and Drug Administration approved the LA monomer as a safe food ingredient, and this made PLA a green polymer that possessed low toxicity [20]. PLA is a safe material for food packaging applications as the migration of LA from PLA packaging containers to food is insignificant [21].

Table 1: Comparison of PLA properties to PET.

Property	PET	PLA
Permeability to CO_2	Poor	Excellent
Chemical resistance	Good	Poor
Transparency (Clarity)	Excellent	Excellent
Water absorbance	Low	High
Oxygen barrier	Poor	Good
Glass transition temperature	High	Low

PET: Polyethene terephthalate, PLA: Polylactic acid.

4. DISADVANTAGES OF PLA

Due to the high cost of the polymer, low availability, and limited molecular mass, the main application of PLA has been mostly limited to medical applications [22]. Furthermore, the mechanical and barrier properties are not at par with fossil-based polymers. It can have excessive brittleness and an unsatisfactory barrier to oxygen and to water compared to benchmark polymer PET [23]. PLA presents challenges in rigid thermoform packaging as a result of its low deformation at the break, high modulus, and hydrophilic properties.

5. MODIFICATION OF PLA AND ITS EFFECT ON PHYSICAL PROPERTIES OF PLA

To overcome the present problems with PLA, different substances and additives fillers have been integrated into PLA structure, to produce PLA composite films [24]. Various substances such as plasticizers different polymers nanoclays, carbon nanotubes, and starch [25] had been combined with PLA matrix to enhance its properties. Modified PLA with 2-methacryloyloxyethyl isocyanate (MOI) showed improved mechanical and thermal properties. The MOIPLA composite showed 20 times better elongation than the neat PLA. PLA mixed with different bioplastics along with thermoplastic starch, polyhydroxyalkanoates, poly ε-caprolactone, polybutylene succinate, and polybutylene adipate-co-terephthalate, exhibited advanced ductility and toughness [26].

6. STANDARD TESTING METHODS AND LABELS FOR BIODEGRADABLE POLYMERS

Standard organizations, the American Society for Testing and Materials as well as the International Organization for Standardization, have published a series of standards for biodegradability and composability. These requirements describe definitions, testing guidelines, time frames, procedures, conditions, limits, and consequences interpretation [27,28]. Table 2 summarizes some of the important parameters of the standards (2014) to be followed class [29]

7. CONCLUSION

Although biopolymers are environmental-friendly and most attractive packaging materials, their industrial applications are limited because of some factors such as their oxygen/water vapor barriers, thermal resistance, and other mechanical properties related to costs [30]. Compared to most other bio-degradable and bio-based plastics, PLA has emerged as a safe and promising polymer for primary food packaging applications [31]. The challenges it faces can be addressed by mixing various renewable biomass products as additives. Various natural fillers such as hemp fibers, waste from wine production, and cocoa bean shells and fibers have been mixed in past with PLA to

Table 2: List of currently active American Society for Testing and Materials standards sorted by category.

Category	Standard
Aerobic atmosphere	D6400e12 "Standard specification for labeling of plastics designed to be aerobically composted in municipal or industrial facilities."
	D5338e11 "Standard test method for determining aerobic biodegradation of plastic materials under controlled composting conditions, incorporating thermophilic temperatures."
	D5988e12 "Standard test method for determining aerobic biodegradation of plastic materials in the soil."
	D6340e98 (2007) "Standard test methods for determining aerobic biodegradation of radiolabeled plastic materials in an aqueous or compost environment."
	D6691e09 "Standard test method for determining aerobic biodegradation of plastic materials in the marine environment by a defined microbial consortium or natural sea water inoculum."
Anaerobic atmosphere	D5210e92 (2007) "Standard test method for determining the anaerobic biodegradation of plastic materials in the presence of municipal sewage sludge."
	D5511e12 "Standard test method for determining anaerobic biodegradation of plastic materials under high-solids anaerobic-digestion conditions."
	D5526e12 "Standard test method for determining anaerobic biodegradation of plastic materials under accelerated landfill conditions."
Another auxiliary standards	D5929e96 (2009) "Standard test method for determining biodegradability of materials exposed to municipal solid waste composting conditions by compost respirometry."
	D6691e09 "Standard test method for determining the stability of compost by measuring oxygen consumption."
	D6954e04 (2013) "Standard guide for exposing and testing plastics that degrade in the environment by a combination of oxidation and biodegradation."

improve its quality [32]. This gives an idea to explore and develop more novel additive which has to be cost-effective, biodegradable, and better in terms of durability.

8. ACKNOWLEDGMENT

I would like to express my special thanks to President, Dr E.S. Charles and Principal, Dr V. Prakash for giving motivation. A sincere thanks to Dr S. Joshi, Head of the Department of chemistry, Isabella Thoburn College for guiding us in writing this review article. Thanks to Dr A. Lawrence, Professor, Isabella Thoburn College, Lucknow for giving us the opportunity to present our thoughts through this review article.

9. CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

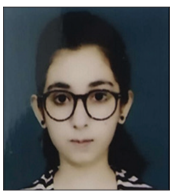
REFERENCES

1. H. A. Khalil, Y. Davoudpour, C. K. Saurabh, M. S. Hossain, A. Adnan, R. Dungani, M. Paridah, M. Z. I. Sarker, M. N. Fazita, M. A. Syakir, (2016) review on nano cellulosic fibres as new material for sustainable packaging: Process and applications, ***Renewable Sustainable Energy Reviews***, **64:** 823-836.
2. P. Cazón, G. Velazquez. J. A. Ramírez, M. Vázquez, (2017) Polysaccharide-based films and coatings for food packaging: A review, ***Food Hydrocoll***, **68:** 136-148.
3. Z. Ma, N. Zhao, C. Xiong, (2012) Degradation and miscibility of poly(DL-lactic acid)/poly(glycolic acid) composite films: Effect of poly(DL-lactic-co-glycolic acid), ***Bulletin Materials Science***, **35(4)**: 575e-578.
4. T. Takayama, Y. Daigaku, H. Ito, H. Takamori, (2014) Mechanical properties of bioabsorbable PLAPGA fibre-reinforced composites, ***Journal Mechanical Science Technology***, **28(10)**: 4151e-4154.
5. K. Marsh, B. Bugusu, (2007) Food packaging-roles, materials, and environmental issues. ***Journal of Food Sciences***, **72**: R39-R55.
6. Sustainable Packaging Corporation, (2013) Available form: http://www.sustainablepackaging.org. [Last accessed on 2013 Mar 14].
7. J. Jacob, U. Lawal, S. Thomas, R. B. Valapa, (2020) Chapter 4-biobased polymer composite from poly (lactic acid): Processing, fabrication, and characterization for food packaging. In: Y. Zhang, (Ed.), ***Processing and Development of Polysaccharide-Based Biopolymers for Packaging Applications***. Amsterdam, Netherlands: Elsevier, p97-115.
8. J. Song, M. Kay, R. Coles Bioplastics, (2011) ***In Food and Beverage Packaging Technology.*** 2nd ed. Hoboken, NJ, USA: Wiley-Blackwell. p295-319.
9. R. Grujic, D. Vujadinovic, D. Savanovic, (2017) Biopolymers as food packaging materials. In: ***Advances in Applications of Industrial Biomaterials***. Cham, Switzerland: Springer, p139-160.
10. B. Hu, (2014) Biopolymer-based lightweight materials for packaging applications. In: ***Light Weight Materials from Biopolymers and Biofibers***. Washington, DC, USA: ACS Publications, p239-255.
11. N. Kumar, P. Kaur, (2017) Bhatia advances in bio-nano composite materials for food packaging: A review, ***Nutrition Food Science***, **47:** 591-606.
12. T. F. D. Silva, F. Menezes, L. S. Montagna, A. P. Lemes,

F. R. Passador, (2019) Effect of lignin as an accelerator of the biodegradation process of poly (lactic acid)/lignin composites, ***Material Sciences and Engineering B***, **251:** 114441.
13. E. Castro-Aguirre, R. Auras, S. Selke, M. Rubino, (2018) Marsh enhancing the biodegradation rate of poly (lactic acid) films and PLA bio-nano composites in simulated composting through bioaugmentation, ***Polymer Degradation Stability***, **154:** 46-54.
14. M. Hiebel, D. Maga, S. Kabasci, A. Lieske, K. Jesse, C. Westphalen, J. Bauer, L. Kroll, R. Ringberg, (2017) ***Hartmann PLA in the Waste Stream***. Bonn, Germany: Federal Ministry of Food and Agriculture Germany.
15. J. Song, M. Kay, R. Coles, (2011) Bioplastics. In: ***Food and Beverage Packaging Technology.*** 2nd ed. Hoboken, NJ, USA: Wiley-Blackwell, p295-319.
16. Y. Byun, Y. T. Kim, (2014) Bioplastics for food packaging: Chemistry and physics. In: J. H. Han, (Ed.), Innovations in Food Packaging. 2nd ed., Ch. 142. San Diego, CA, USA: Academic Press. p353-368.
17. E. Castro-Aguirre, F. Iñiguez-Franco, H. Samsudin, X. Fang, (2016) Auras poly (lactic acid)-mass production, processing, industrial applications, and end of life, ***Advanced Drug Delivery Reviews***, **107:** 333-366.
18. N. Peelman, P. Ragaert, B. De Meulenaer, D. Adons, R. Peeters, L. Cardon, F. Van Impe, F. Devlieghere, (2013) Application of bioplastics for food packaging, ***Trends Food Sciences Technology***, **32:** 128-141.
19. Y. Dahman, (2014) Poly (lactic acid): Green and sustainable plastics, ***Fermentation Technology***, **2**: e121.
20. P. Scarfato, L. Di Maio, L. Incarnato, (2015) Recent advances and migration issues in biodegradable polymers from renewable sources for food packaging, ***Journal of Applied Polymer Science***, **132:** 13.
21. S. Imam, G. Glenn, E. Chiellini, (2012) Utilization of biobased polymers in food packaging: Assessment of materials, production and commercialization. In: ***Emerging Food Packaging Technologies***. Amsterdam, Netherlands: Elsevier, p435-468.
22. R. Porta, M. Sabbah, P. Di Pierro, (2020) Biopolymers as food packaging materials, ***International Journal of Molecular Sciences***, **21:** 4942.
23. M. R. Havstad, (2020) Biodegradable plastics. In: T. M. Letcher, (Ed.), ***Plastic Waste and Recycling***. Ch. 5. Cambridge, MA, USA: Academic Press, p97-129.
24. I. Pillin, N. Montrelay, Y. Grohens, (2006) Thermo-mechanical characterization of plasticized PLA: Is the miscibility the only significant factor? ***Polymer***, **47:** 4676-4682.
25. L. Yu, K. Dean, L. Li, (2006) Polymer blends and composites from renewable resources, ***Progress in Polymer Sciences,*** **31:** 576-602.
26. S. Aslan, L. Calandrelli, P. Laurienzo, M. Malinconico, C. Migliaresi, (2000) Poly(D, Llactic acid)/poly(ε-caprolactone) blend membranes: preparation and morphological characterization, ***Journal of Matererial Sciences***, **35:** 1615-1622.
27. R. Jayasekara, I. Harding, I. Bowater, G. Lonergan, (2005) Biodegradability of a selected range of polymers and polymer blends and standard methods for assessment of biodegradation, ***Journal Polymer Environment***, 13: 231e-251.
28. U. Pagga, (1997) Testing biodegradability with standardized methods, ***Chemosphere***, **35:** 2953e-2972.
29. ASTM, D6400-12, (2012) ***Standard Specification for Labeling of Plastics Designed to Be Aerobically Composted in Municipal or Industrial Facilities***. West Conshohocken, PA: ASTM International.
30. ASTM, D5338-11, (2011) ***Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials under Controlled Composting Conditions, Incorporating Thermophilic Temperatures***. West Conshohocken, PA: ASTM International.
31. ASTM, D5988-12, (2012) ***Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in Soil***. West Conshohocken, PA: ASTM International.
32. M. J. Fabra, A. L. Rubio, J. M. Lagaron, (2014) 15-biopolymers for food packaging applications. In: M. R. Aguilar, J. San Román, (Eds.), ***Smart Polymers and their Applications***. Cambridge, UK: Woodhead Publishing, p476-509.

*Bibliographical Sketch

Miss Venessa Robert Osta is a post graduate student in the Department of Chemistry, Isabella Thoburn College Lucknow. She also holds B.ed degree and is currently doing her internship work under the supervision of Dr. Ratnashekhar CH(Department of Phytochemistry), CIMAP Lucknow. She has attended many online skill development and training programmes notably from CSIR-IITR, Lucknow,CSIR-CERI Karaikudi and CSIR-IMMT Bhubaneswar- Odisha, India. Her areas of interest include chemistry, phytochemistry and medicinal chemistry.



Miss Reham Mohammad Faheem has done her B.Sc from Isabella Thoburn College and is currently perusing M.Sc. from the Department of Chemistry, Isabella Thoburn College, Lucknow. She has done internship in the field of testing and processing of plastics from Central Institute Of Petrochemicals Engineering and Technology, Lucknow. She has attended many online skill development and training programmes notably from CSIR-IITR Lucknow, CIPET Lucknow.