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Biodegradation of bioplastics in natural environments

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ABSTRACT

The extensive production of conventional plastics and their use in different commercial applications poses a significant threat to both the fossil fuels sources and the environment. Alternatives called bioplastics evolved during development of renewable resources. Utilizing renewable resources like agricultural wastes (instead of petroleum sources) and their biodegradability in different environments enabled these polymers to be more easily acceptable than the conventional plastics. The biodegradability of bioplastics is highly affected by their physical and chemical structure. On the other hand, the environment in which they are located, plays a crucial role in their biodegradation. This review highlights the recent findings attributed to the biodegradation of bioplastics in various environments, environmental conditions, degree of biodegradation, including the identified bioplastic-degrading microorganisms from different microbial communities.

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1. Introduction

Plastics are considered to be the most widely used polymers in our daily life especially in packaging applications. The annual production of petroleum based plastics exceeded 300 million tons in 2015 (Mekonnen et al., 2013). This excessive production of petroleum-based plastics demands sustainable alternatives from renewable resources. In addition, the adverse environmental impacts including carbon dioxide (CO₂) emissions and their long-period accumulation in the environment due to their non-biodegradability are the significant drawbacks of using the non-biodegradable plastics (Tokiwa et al., 2009; Pathak et al., 2014; Jain and Tiwari, 2015). In fact, 34 million tons of plastic wastes

are generated each year throughout the world and 93% of them are disposed of in landfills and oceans (Pathak et al., 2014). Although some members of the European Union (EU) have banned landfilling applications, approximately 50% of plastic wastes are still disposed of in landfills. Countries such as Germany, Netherlands, Sweden, Denmark and Austria were successful in achieving 80–100% in recovery of the plastic wastes, however, they were able to recycle only 28% on average (EU, 2013). Although, the EU attempts to encounter the disposal of plastic wastes and improve reusing and recycling applications, developing countries are still dependent on the conventional landfilling. The plastic consumption in developing countries has been reported to be more than that of the world average because of the higher rate of urbanization and economic development (Muenmee and Chiemchaisri, 2016). For instance, developing countries including China, Indonesia, Philippines, Sri Lanka and Vietnam were reported to generate more

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Table 1
Classification of the most produced bioplastics (European Bioplastic, 2015).

	Source	Name	Abbreviation
Bioplastics	Petroleum based	Polybutylene succinate	PBS
		Polycaprolactone	PCL
		Polyethylene succinate	PES
		Polybutyrate adipate terephthalate	PBAT
		Polyamide	PA
	Bio-based	Polyethylene	PE
		Poly(ethylene terephthalate)	PET
		Polypropylene	PP
		Poly(lactic acid)	PLA
		Polyhydroxyalkanoate	PHA
		Starch plastics	–
		Cellulose esters	–
		Bio-polyethylene	Bio-PE
		Bio-poly(ethylene terephthalate)	Bio-PET
		Bio-polyamide	Bio-PA

than 50% of global plastic pollution in marine environment (Li et al., 2016). Although the technologies for recovering the plastics wastes have been improved, an increase in the world population to about 9 billion in 2050 requires a higher demand for plastic production and eventually, an increase in the amount of plastic wastes (EU, 2013). Incineration of plastic wastes were also particularly applied in European countries such as Denmark which had the highest rate of incineration (76%). Despite constructing incineration plants according the standard criteria, some environmental drawbacks can be encountered during this process. Energy recovery from plastic wastes may enhance the net CO₂ emissions. Moreover, a huge amount of ash and slag containing hazardous and toxic compounds are required to be disposed of which can cause other serious environmental problems (European Commission, 2011). Thus, in order to create a sustainable environment and prevent the possible disposal of recalcitrant plastic wastes in the environment, production of bioplastics gained a lot of attention due to their biodegradability. Actually, the word bioplastic can refer either to bio-based plastics synthesized from biomass and renewable resources such as Poly(lactic acid) (PLA) and Polyhydroxyalkanoate (PHA) or plastics produced from fossil fuel including aliphatic plastics like Polybutylene succinate (PBS), which can also be utilized as a substrate by microorganisms (Table 1) (Tokiwa et al., 2009; Mekonnen et al., 2013). For instance, utilizing starch as a renewable resource in production of packaging bioplastic resulted in a lower consumption of non-renewable

energy resources (–50%) and therefore less greenhouse gas emissions (–60%) when compared to the polystyrene packaging (Razza et al., 2015).

In 2014, 1.7 million tons of bioplastics were produced throughout the world (European Bioplastic, 2015). The production of bioplastics is expected to reach 6.2 million tons in 2018 (Mostafa et al., 2015) (Fig. 1). In 2012, PLA and starch-based were the most utilized bioplastics by 47 and 41% of total consumption, respectively (Mostafa et al., 2015). Moreover, Polyhydroxybutyrate (PHB) bioplastics got the attention of the scientific community due to their low CO₂ emission (Mostafa et al., 2015).

Although bioplastics are considered to be environmental friendly materials, they also have some limitations such as high production cost and poor mechanical properties. High production cost drawback can be managed by utilizing the low cost of renewable resources such as agricultural wastes (Jain and Tiwari, 2015). Among the bio-based plastics, Poly(lactic acid) (PLA) reveals optimum properties including high tensile strength and modulus. Poly(hydroxyalkanoates) (PHAs) are their commercial competitors although they lack some optical and mechanical properties when compared to PLAs (Tabasi and Ajji, 2015).

Accumulation of plastic wastes in the environment forces industry to produce a sustainable and a biodegradable type of a plastic (Pathak et al., 2014). The term biodegradation involves biological activity. The biodegradation of polymers consists of three important steps: (1) Biodeterioration, which is the modification of mechanical, chemical, and physical properties of the polymer due to the growth of microorganisms on or inside the surface of the polymers. (2) Biofragmentation, which is the conversion of polymers to oligomers and monomers by the action of microorganisms and (3) Assimilation where microorganisms are supplied by necessary carbon, energy and nutrient sources from the fragmentation of polymers and convert carbon of plastic to CO₂, water and biomass (Lucas et al., 2008). The important factors that affect the plastic's biodegradation in the environment are the chemical structure, the polymer chain, crystallinity and the complexity of polymer formula. In fact, the specific functional groups are selected by enzymes and can be processed. Generally, polymers with a shorter chain, more amorphous part, and less complex formula are more susceptible to biodegradation by microorganisms. Moreover, the environment, in which the polymers are placed or disposed of, plays as a key factor for their biodegradation. The pH, temperature, moisture and the oxygen content are among the most significant environmental factors that must be considered in biodegradation of polymers (Massardier-Nageotte et al., 2006; Kale et al., 2007b).

Previously, the non-biodegradability of synthetic plastics resulted in the accumulation of millions of tons of plastic wastes (Pathak et al., 2014). However, by developing bioplastics as a substitute material for conventional plastics, certain applications have become mandatory for the production of real biodegradable polymers (Eubeler et al., 2009). Therefore, the main objectives of this review paper are to summarize the biodegradation of bioplastics in different environments and to discuss the activity of the microorganisms that are responsible for their degradation.

2. Biodegradation of bioplastics under different environmental conditions

Many studies were conducted to investigate the biodegradability of bioplastics under different environmental conditions, such as soil, compost, marine and other aquatic environments. Among these environmental conditions, mostly soil and compost were taken into account due to their high microbial diversity (Anstey et al., 2014). Although most of the plastic wastes are disposed of in landfills, the

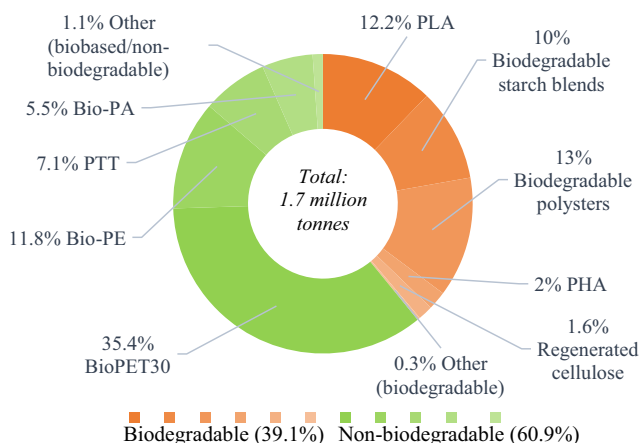


Fig. 1. Global production of bioplastics 2014 (by material type) (European Bioplastic, 2015).

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