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A review on bioplastic and its composites

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Abstract
Innovations in food packaging systems will help meet the evolving needs of the market, such as consumer preference for "healthy" and high-quality food products and reduction of the negative environmental impacts of food packaging. Emerging concepts of active and intelligent packaging technologies provide numerous innovative solutions for prolonging shelf-life and improving the quality and safety of food products. There are also new approaches to improving the passive characteristics of food packaging, such as mechanical strength, barrier performance, and thermal stability. The development of sustainable or green packaging has the potential to reduce the environmental impacts of food packaging through the use of edible or biodegradable materials, plant extracts, and nanomaterials. Active, intelligent, and green packaging technologies can work synergistically to yield a multipurpose food-packaging system with no negative interactions between components, and this aim can be seen as the ultimate future goal for food packaging technology. This article reviews the principles of food packaging and recent developments in different types of food packaging technologies. Global patents and future research trends are also discussed.

Keywords: Bioplastic and its composites

Introduction
The interest in the development of bioplastics has been increasing in food packaging industries in recent years for the purpose of safe and secure food packaging. Within the term bioplastics, (a) bio-based and (b) biodegradable plastics, but bioplastics can also fulfill both of these criteria. Bio-based plastics are typically made from renewable sources by the action of living organisms (Jamshisian *et al.*, 2010) [21]. They can be polysaccharides (e.g., starches, such as thermoplastic starch; cellulose, such as regenerated cellulose; pectin, and chitin), proteins (e.g., wheat gluten, wool, silk, casein and gelatin), lipids (e.g., animal fats, plant oils), or products of microorganisms (e.g., polyhydroxyalkanoate (PHAs) such as poly (hydroxybutyrate) (PHB)). Furthermore, bio-based plastics can also be chemically synthesized from bio-derived products (e.g., poly (lactic acid) (PLA), poly (butylene succinate) (PBS), and poly (trimethylene terephthalate) (PTT)) (Harrison *et al.*, 2018) [18]. Bio-based plastics, as part of an expanding circular bio-economy, can be designed to be either totally converted to CO_2 within a short span of time (Karan *et al.*, 2019), or contribute to carbon capture and storage through integration into non degradable long term infrastructure which includes plastic-based municipal water and sewer piping, building and roofing materials and road surfaces (Brukner *et al.*, 2018) [10]. Bioplastics can be obtained from different renewable sources such as vegetable oil, corn starch, potato starch, fibers obtained from pineapple, jute, hemp, henequen leaves and banana stems (Siracusa *et al.*, 2008) [47]. Bioplastics can also be made using microorganisms and sometimes various nanometer-sized particles especially carbohydrate chains (polysaccharides). The new technological goal for efficient and sustainable development will be the use of raw materials that can be renewed and used in the manufacture of biodegradable plastics. Over the past 20 years, bio-based polymers that are made from different proteins are used for purposes like the formation of films and coatings for food packaging applications. The bioplastics can be used for minimally processed fruits, vegetables, organic products, and dairy products. Some of the protein-based films and packages posses' low to moderate mechanical properties when compared to those of the traditional synthetic plastic films (Baldwin *et al.*, 2011) [6]. The main aim of introducing bioplastics is to emulate the life cycle of biomass, which includes the conservation of renewable fossil resources,

CO_2 production, and water (www.european-bioplastic.org). Meanwhile, there is a huge demand to explore the other suitable microorganisms and plants that are available for the production of bioplastics.

2. Bio-based Plastics

Currently, bioplastics are produced from agricultural crop-based feedstocks, carbohydrates and plant materials. Next-generation microalgae-based bioplastics production can theoretically address many of these issues, as they can be located on non-arable land. This expands global photosynthetic capacity, can be seen as a much-needed technology assisted reversal of desertification and increases our ability to convert CO_2 into feedstocks for bioplastics. The composting process depends on many factors, such as the chemical structure of the polymer, its length and branching, the presence of functional groups, the molar mass, hydrophobicity/hydrophilicity, crystallinity, presence of additives and contaminants, type of microorganisms or enzymes, and conditions of the environment (temperature, oxygen, humidity, pH, light, pressure, and presence of the compounds accelerating decomposition, e.g., salts or metals) (Musioł *et al.*, 2011) [36]. Micro-algae systems can also use saline and/or wastewater and enable effective recycling of nutrients (e.g., nitrogen and phosphorous) in contained systems, thereby reducing eutrophication and reliance on energy-intensive chemical fertilizers. Unlike fossil-based plastics, microalgae-based bioplastics can be designed for biodegradability in natural as well as industrial composting settings. Although biodegradable fossil-based polymers such as polybutylene adipate terephthalate and polycaprolactone exist (Bastos, 2018) [7], their production from petrochemicals precludes them from being CO_2 neutral. Internationally, microalgae systems also offer the technical capacity to support distributed production, while locally they offer the potential to enable regional communities to be more self-sufficient and provide significant new market opportunities (SDG, Decent Work, and Economic Development). If strategically developed, these systems can, therefore, provide sustainable solutions and make a significant contribution to a number of problems that occur due to the use of synthetic plastics. The molecular complexity of plant and bacterial biomass provides a greater source of natural bio-based polymers as well as monomeric feedstocks for bioplastic production. The major monomers and polymers can be sourced from higher plant crops, microalgae and cyanobacteria. However, the packaging technology must maintain the balance between food protection and other issues, including the costs of energy and materials, heightened social and environmental awareness, and stringent regulations on pollutants and disposal of municipal solid waste (Marsh and Bugusu, 2007) [30].

Various natural and synthetic biodegradable polymers are used in the packaging field. In view of the polymers origin, they can be classified as natural, synthetic, and modified natural polymers (Kulkarni *et al.*, 2012) [27].

From an environmental point of view, the classification is based on the origin of raw material: from renewable resources (i.e., of biological origin), and nonrenewable/fossil resources (i.e., oil, natural gas, and coal) (Rydz *et al.*, 2015) [41] (Fig. 1). This entry focuses on the main biodegradable natural, microbial and synthetic polymers and their properties and potential applications in the field of food packaging.

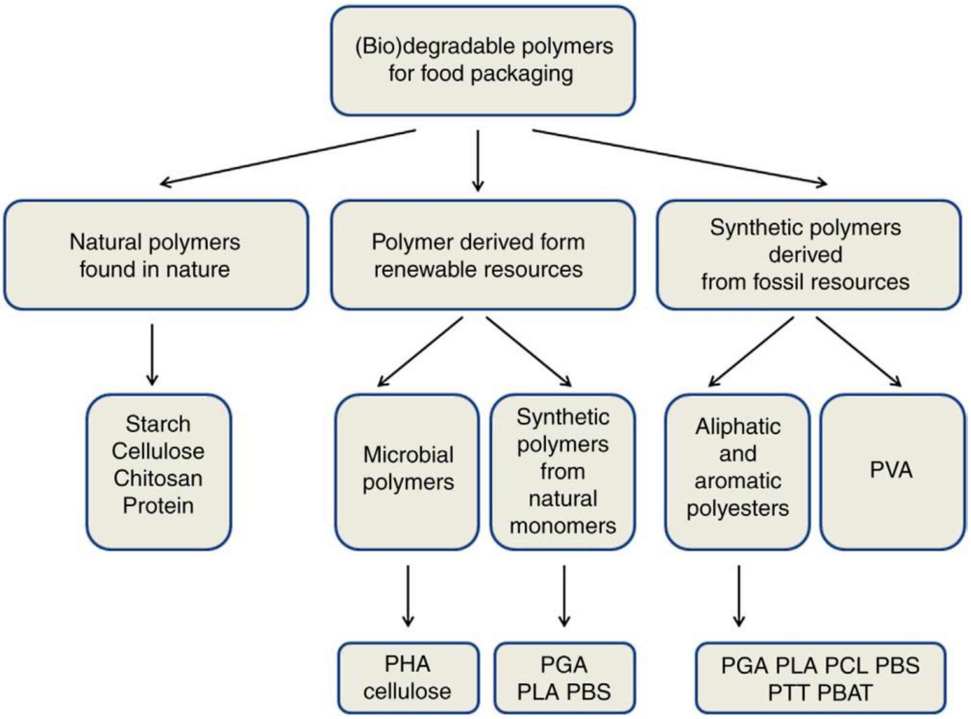

Fig 1: Classification of Biodegradable polymers for food packaging applications

2.1. Natural Polymers

All natural polymers are biodegradable due to their natural origin because for each action of a polymerase, there is depolymerase that can catalyze the degradation which aids to maintain the balance of nature (Khemani and Scholz, 2012; Rydz *et al.*, 2015) [24, 41]. Natural products and their derived compounds have a major impact in the food packaging industry. The advantageous properties of these polymers are their biodegradability, supplementary nutritional food value, incorporated antimicrobial and antioxidant properties, renewable origin, relatively low cost, prevalence, and the fact that they have no negative impact on the environment like a traditional plastic material.

2.1.1. Starch

Starch is a polymeric carbohydrate produced by many plants as a reserve material in the form of granules of different shapes like polygons, spheres, platelets, and sizes from 0.5 µm to 175 µm. Its molecule is composed of two types of polymers of d-glucose: amylose (20%–30%) and amylopectin (70%–80%). Depending on the source, the proportion of amylose and amylopectin differs. It is considered as one of the promising biopolymer materials due to biodegradability, nontoxicity, availability, and renewability. Starch film was manufactured by injection molding, extrusion applications, blow molding, film blowing, and foaming were used for packaging applications (Jabeen *et al.*, 2015) [20]. Starch-based films showed very low permeability to oxygen at relatively low humidity, moreover they are tasteless, odorless, and colorless (The *et al.*, 2009) [49]. Generally, starch film is brittle in food packaging materials, common plasticizers such as sorbitol, xylitol, and glycerol are used. Starch can also be plasticized by genetic and chemical modification or blending with materials like poly (vinyl alcohol) (PVA), poly (*ε*-caprolactone) (PCL), and others. Thermal and mechanical properties of thermoplastic starch depend on the content of these polymers in the blended plastic (Lu *et al.*, 2009) [49]. Thermoplastic starch is a mixture of starch and glycerol after the gelatinization process. It is hydroscopic; therefore this material is not suitable as packaging for high-moisture and liquid food products. However, it has good oxygen-barrier properties. Starch-based thermoplastic materials were used for food wrappings and cups, plates, and other food containers (Rejak *et al.*, 2014; Lopez *et al.*, 2015) prepared packaging bags from thermo-compressed films based on thermoplastic starch modified with talc nanoparticles.

2.1.2. Chitosan

Chitosan (CS) is a linear nontoxic polycationic polysaccharide consisting of β-(1→4)-linked 2-amino-2-deoxy-d-glucose (d-glucosamine) and 2-acetamido-2-deoxy-d-glucose (*N*-acetyl-d-glucosamine) units. Commercially it is prepared by chemical *N*-deacetylation of chitin, which is a component of shells from marine crustaceans (shrimp, oysters, crabs, lobsters, and Antarctic krill). The degree of deacetylation and the molar mass of the polymer is one of its most important chemical characteristics, which could influence the manner of its use. Moreover, chitosan has different properties, biological roles, and biodegradability depending on the relative proportions of *N*-acetyl-d-glucosamine and d-glucosamine residues. As a packaging material, CS has many valuable features. The polymer is entirely or partially soluble in water, has the ability to form films without the use of other additives, and it is resistant to heat. CS has good permeability to oxygen and carbon dioxide and excellent mechanical properties. Furthermore, it also has antimicrobial activity and can therefore be used to extend the shelf life of food and as a component of biodegradable edible films for food. Storage conditions have a high impact on the properties of the film. Stress on the film increases with the rise of temperature from 4° C to 30° C and may cause it to break.

2.1.3. Whey Protein

Whey proteins (WP) are capable of molding into flexible films, and due to moderate moisture permeability, good oxygen barriers, and good biodegradability they are used as raw material for producing edible films, biodegradable films, or materials for biodegradable packaging (Ramos *et al.*, 2012; Wang *et al.*, 2013) [40, 29]. These films have additional quality of being flexible, odorless, tasteless, and depending on the purity of the proteins and their composition, may have different transparency. It is also considered that whey proteins are one of the most common and least expensive raw materials used in the preparation of edible films. Plastic films formulated with the use of WP are biodegradable and have a high barrier to oxygen (Bugnicourt *et al.*, 2010) [11]. It can be used as a coating on paper and also on plastic substrates with polymers such as polypropylene (PP), poly (vinyl chloride), and low-density polyethylene (LDPE). The coatings showed good mechanical properties and visual properties, such as excellent gloss and transparency (Ozdemir and Floros, 2008) [37]. Whey protein-based coatings blended with plasticizers have high barrier properties and moderate moisture permeability (Popovic *et al.*, 2012; Verbeek and van den Berg, 2010) [39, 57]. WP coatings films blended with commercial biodegradable Bio-Flex, based on polylactide-stereo block co-polyester, for application as completely biodegradable packaging were investigated. The tests showed that a whey protein-based layer can improve oxygen barrier properties. Moreover, blending WP with Bio-Flex does not affect the rate of its biodegradation (Cinelli *et al.*, 2014) [14].

2.2. Synthetic/Artificial Biopolymers

Genetic engineering by manipulation of biosynthetic enzymes offers unique opportunities to create non natural analogues of biopolymers and gives the possibility for further polymer modification (Kim *et al.*, 2015) [29] (Fig. 2).

Different composition units depend not only on the carbon source and type of microorganisms, but also on the dilution rate, the carbon to nitrogen ratio, time, and temperature (Hartmann *et al.*, 2004; Kim *et al.*, 2007) [25].

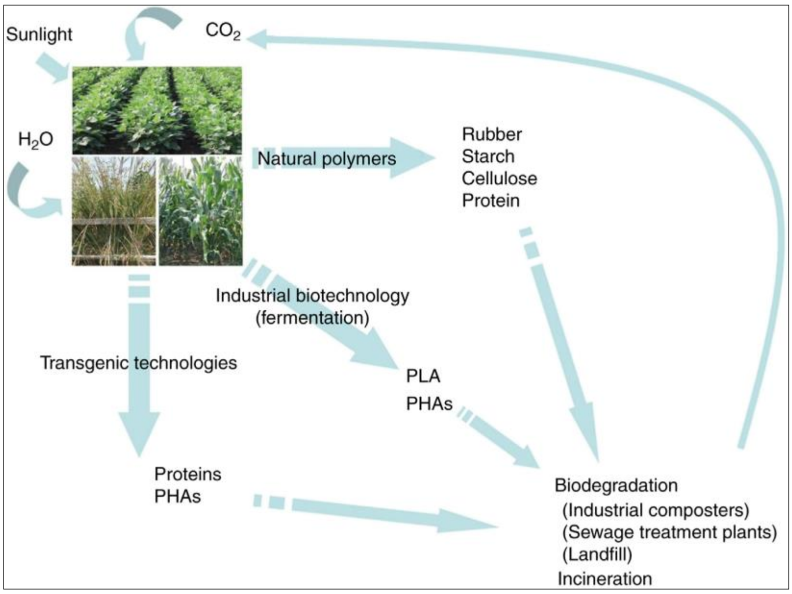

Fig 2: Polymers from Renewable Resources. Originally published in Mooney, B.P., 2009

2.2.1. Polyhydroxyalkanoates

Polyhydroxyalkanoates belong to the group of polyesters naturally produced by microorganisms as a carbon storage source. A wide variety of mechanical properties, from hard crystalline to elastic, are some of the main advantages of PHA and the properties depend on the compositions of monomers (Bugnicourt *et al.,* 2014) [14]. Many investigations were conducted in terms of PHA chemistry, biosynthesis, properties, and potential applications. PHAs are biodegradable and as such they can be used as food packaging that should be disposal with contamination from food after consumption.

Low moisture vapor permeability, in comparison with low-density polyethylene, is also offered by PHAs. This feature is very useful in packaging applications. Another important representative of PHAs are PHB copolymers: poly (hydroxybutyrate-*co*-hydroxyvalerate) (PHBV), poly (hydroxybutyrate-*co*-hydroxyhexanoate) (PHBHx), poly (hydroxybutyrate-*co*-hydroxyoctanoate) (PHBO), poly (hydroxybutyrate-*co*-hydroxyoctadecanoate) (PHBOd), and poly (3-hydroxybutyrate-*co*-4-hydroxybutyrate) (P3HB4HB). A certain amount of those copolyesters have attracted industrial interest and were commercialized. The possibility to influence the composition of PHA copolymers during fermentation allows obtaining a material with the desired properties (Avérous and Pollet, 2012) (Table 1). Biodegradable bottles, containers, sheets, fibers, and coatings can be prepared using PHA. Low values of water vapor permeability coefficient for PHA are similar to that of poly (ethylene terephthalate) (PET) (Koller, 2014) [26]. This factor has a significant impact during the selection of packages for food when desiccation or water inflow is inadvisable.

2.2.2. 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. The lactic acid monomers are either directly polycondensed or undergo ring opening polymerization of lactide resulting in formation of PLA pellets (Modi, 2010) [32]. 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 biobased polymer commercialized on a large scale and can be shaped into injection moulded objects, films and coatings (Rasal *et al.,* 2010) [42]. PLA has replaced high-density polyethylene, low-density polyethylene (LDPE), polyethylene terephthalate and PS as packaging material.

2.3. 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). 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) [32]. 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. PHB is used in bulk shrink packaging and flexible intermediate bulk containers. PHB is similar to isotactic polypropylene (iPP) with respect to melting temperature (175–180°C) and mechanical properties. 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. 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.

2.3.1. 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.

2.3.2. 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. PCL is obtained by ring-opening polymerization of ε-caprolactone with suitable catalysts (Bohlmann, 2005) [8] (Fig. 3). The resulting PCL is a semi-crystalline polymer with a softening point temperature that is between 59–64°C and $Tg = -60$°C. It is manufactured under the trade names Tone (Union Carbide, USA), CAPA (Solvay, Belgium), and Placeel (Daicel Chemical Ind., Japan).

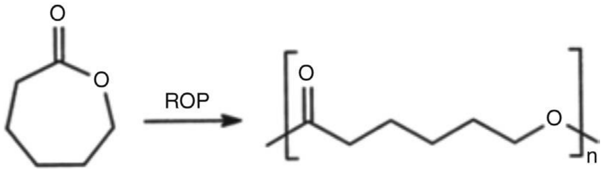

Fig 3: Ring-Opening Polymerization of ε-Caprolactone.

3. Application of Bioplastic in Food packaging
The primary challenge facing the food industry in producing bioplastic packaging,
Currently, is to match the durability of the packaging with product shelf-life. Alone or working in combination, environmental temperature, relative humidity, presence of active bacterial and spoilage microorganisms, ultraviolet exposure, etc. are the usual modes of degradation in food quality and spoilage. These factors that cause deterioration of the food product are also factors that influence the rate of degradation of the bioplastic material, and special care must be taken to develop bioplastic materials which address these concerns.

3. Biodegradation of bioplastics
The non-biodegradability of synthetic plastics resulted in the accumulation of millions of tons of plastic wastes (Pathak *et al.*, 2014) [38]. 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) [15]. 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) [4]. Although most of the plastic wastes are disposed of in landfills, the biodegradation of bioplastics in landfills have not been studied much yet. Therefore, the biodegradation of bioplastics in compost, soil and aquatic environments are particularly discussed here.

3.1 Compost
A huge amount of plastic wastes is disposed of in landfills which eventually lead to generation of greenhouse gases and leachate. Therefore, other solid waste management methods including composting or recycling are considered to be more preferable for the recovery of plastics. Composting is a process in which the organic matter is converted to CO2 and a soil-like material (humus) by activity of a mixed group of microorganisms. As defined by the American Society for Testing and Materials (ASTM), compostable plastic is ''a plastic that undergoes degradation by biological processes during composting to yield carbon dioxide, water, inorganic compounds, and biomass at a rate consistent with other known compostable materials and leaves no visually distinguishable or toxic residues" (ASTM D6400-04, 2004). It was studies that the presence of meal-based filler enhances the rate of biodegradation compared to pure bioplastic, which was attributed to the high concentration of soluble sugars in meal-based fillers (Anstey *et al.*, 2014) [4]. The presence of corn in PLA/corn bioplastics seemed to enhance the biodegradation in compost since corn was a highly biodegradable material. Thus, microorganisms degraded the material and the PLA fraction more efficiently (Sarasa *et al.*, 2009) [45]. The PLA pots in association with poultry feather fibers (PFF) showed a higher rate of deterioration than those of the pure PLA which might be related to the other components used in molding and extrusion processes of the PLA pot production that inhibited the biodegradation (Ahn *et al.*, 2011) [3]. Renewable resources can be employed to produce bioplastics. For instance, cellulose acetate (CA) bioplastics can be produced from agricultural wastes. In recent work, it was reported that the biodegradation of CA bioplastics from low cost fiber flax and cotton linters was 44 and 35%, respectively, after 14 days of composting. Some bioplastics in markets are labeled as 100% biodegradable. However, their potential for composting has not been verified. In a relevant study, the biodegradability of two different samples of sponge cloth bioplastics (sample A and B), which were widely used for cleaning the surfaces, were composted. The results showed that the sample B had a biodegradability of more than 80%, whereas sample A slightly biodegraded indicating that the biodegradability of bioplastics could strongly be attributed to the type of the environment and also to the chemical structure of the polymer.

3.2. Soil
Since plastic wastes are also widely disposed of in soil environments, investigating their changes and influences in this particular environment should also be discussed. Mainly, soil environments contain a vast biodiversity of microorganisms, which enable the plastic biodegradation to be more feasible with respect to other environments, such as water or air. Many studies investigated the biodegradability of PHA and PLA bioplastics and this topic seemed to be more popular than the biodegradability of other bio or petroleum based bioplastics. In a recent work, in order to improve the biodegradability of bioplastics, the blending of other biodegradable materials was investigated. It was reported that, the biodegradation of PHB/PPW-FR (potato peel waste fermentation residue) biocomposite was more efficient than the sole PHB since PPW-FR fibers reduced the crystallinity of PHB biocomposite (Wei *et al.*, 2015) [60]. In another study, adding the empty fruit bunch (EFB) fibers increased the rate of PLA biocomposite biodegradation (Harmaen *et al.*, 2015) [17]. The biodegradation of PLA bioplastics in a real soil environment under Mediterranean

real field conditions was studied throughout an 11 months period. The biodegradation process was very slow although the cellulose which was utilized as the positive control was completely degraded. This might be correlated to the lower temperature of the systems under real conditions and duration of the experiment.

In fact, these bioplastics require higher temperature and longer time to be effectively degraded (Rudnik and Briassoulis, 2011) [35].

3.3. Aquatic systems

The plastic wastes were found to be largely accumulated evenly in deep marine environment. Due to their semi-permanent stability in a marine ecosystem, the plastic wastes potentially result in marine pollution, which can have impacts on marine animals (*Volova et al.,* 2010; Sekiguchi *et al.,* 2011) [58, 46]. Therefore, bioplastics which are considered as biodegradable polymers in the environment, can also be used to develop a sustainable environment even in marine and aquatic systems. The researchers suggested that in order to understand the biodegradation of bioplastics in marine habitats, the test methodology should include six different habitats (supralittoral, eulittoral, sublittoral benthic, deep sea benthic, pelagic and buried in the sediments). It was found out that the degradation in pelagic habitat was more efficient with respect to eutrophic habitat. In addition, the authors also suggested that the highest biodegradation could be achieved at the interface of water-sediment since the environmental conditions at the interface supported the activity of plastic-degrading microorganisms (Tosin *et al.,* 2012) [53]. In another work, in order to compare the biodegradability of bioplastics under laboratory and real conditions, the biodegradation of PHB and PHBV bioplastics in sea water under both static and dynamic conditions was studied. The laboratory (static) incubation was conducted in batch flasks containing natural seawater at 21°C while the dynamic incubation was performed in an open system with continuous seawater flow at temperature between 12 and 22 °C and pH ranged from 7.9 to 8.1. For both bioplastics, the weight loss percent was the same under both static and dynamic conditions although the weight loss was less under dynamic conditions rather than the static one. This might be attributed to the fact that the dynamic condition was more realistic, which provided nutrient supply limitation and the temperature change of sea water. In addition, addition of sediments was studies to understand its effects on biodegradation. It was investigated that the sediments could have a favorable effect on biodegradation, however, no definite correlation could be determined (Thellen *et al.,* 2008) [50].

The water temperature can also have a significant influence on biodegradation of bioplastics. It was reported that the rate of PHA films biodegradation was different in various periods of the year 1999 and 2000 due to the changes in weather temperature. In addition, different sea waters might have played a substantial role in biodegradation, depending on the existing bioplastic-degrading microorganisms. The degradation of PCL, PBS and PHB biopolymers in three different sea water types was investigated by measuring their strength retention. The findings showed that the strength retention changed in different sea water environment, which might be attributed to the different bioplastic-degrading microorganisms available in these three particular sea waters types (Sekiguchi *et al.,* 2011) [46].

Another parameter, which can alter the degree of biodegradation in marine water is the shape of the polymer. It was stated that the PHA films were degraded faster than PHA pellets because of their larger surface area. Furthermore, a larger polymer/water interface also facilitated the attachment of microorganisms to the surface of the polymer (Volova *et al.,* 2010) [58]. This pattern was also observed for PHA films in tropical soil environments in another work as well (Boyandin *et al.,* 2013) [9].

3.4 Bioplastic degrading microorganisms

More than 90 types of microorganisms including: aerobes, anaerobes, photosynthetic bacteria, archaebacterial and lower eukaryotic are responsible for the biodegradation and catabolism of bioplastics. These microorganisms can be found extensively in soil or compost materials Kumaravel *et al.,* 2010; Accinelli *et al.,* 2012) [28, 2]. Enzymes which can be either intracellular or extracellular, are responsible for enzymatic degradation of bioplastics. Depolymerases which can be obtained from bioplastic-degrading microorganisms were investigated as enzymes play a significant rule in bioplastics biodegradation. (Tokiwa and Calabia, 2004; Chua *et al.,* 2013) [51, 13]. Many studies have been conducted on depolymerase purification from bioplastic-degrading microorganisms. Intercellular depolymerase from *Rhodospirillum rubrum* were investigated as PHB-degrading enzymes (Tokiwa and Calabia, 2004) [51]. The depolymerase enzyme responsible for PCL degradation was isolated from *Streptomyces thermoviolaceus subsp. Thermoviolaceus* 76T-2 (Chua *et al.,* 2013) [13]. Other enzymes such as lipase from *Alcaligenes faecalis,* estrase from *Comomonas acidivorans* and serine from *Pestalotiopsis microspora* were also produced that involved in bioplastic biodegradation (Trivedi *et al.,* 2016) [55].

According to the literature, the biodiversity of bioplasticdegrading microorganisms was not the same under different environmental conditions.

Although bio-based plastics such as PLA produced from renewable resources can be degraded in different microbial environments, the biodegradation of petroleum-based bioplastics such as PES depends on the resource (source of water) on which it is located (Tezuka *et al.,* 2004) [48]. Also, the distribution of PBS bioplastic-degrading microorganisms in soil environments is not comparable to other bioplastics including PCL (Abe *et al.,* 2010) [1]. It was reported that the fungal species in soil or compost had a more tendency to degrade Mater-Bi (MB) starch based bioplastics (Accinelli *et al.,* 2012) [2]. In a relatively previous study, the PHB-degrading fungal strains were isolated from soil compost, garden soil, hay compost, farm hay, cotton boll fallen leaf, living leaf, plant root, ceiling pipe, pond, shower stall and air. Bacteria species able to biodegrade different biopolymers such as, *Stenotrophomonas, fungi species like Penicillium, Aspergillus, Thermomyces, Fusarium, Clonostachys, Verticillium, Lecanicillium, cladosporium, Mortierella* and *Doratomyces* and *actinobacteria*

species including *Streptomyces* were all isolated from compost environments. Co-culture of different microorganisms may enhance the biodegradation of bioplastics. In fact, the other microorganism may help the biodegradation by utilizing the intermediates of bioplastics biodegradation by the main microorganism.

4. Present applications

Bioplastics such as PLA, PHB, PHA, starch are being used in many commercial products. Chitosan materials are used in Biodegradable food wrap. Among the most bioplastics PLA is considered as frequently used bio plastic. Although advanced research needs to be carried out in bioplastics some of the bioplastics are used as packaging material in fresh fruit and vegetable packaging and can also be used in packaging of food materials like noodles, pasta and bakery items.

5. Conclusion

The current application of use of bioplastics in the packaging of both short-shelf life as well as long-shelf life products are gaining importance among the consumer. However, several advancements are in progress in the bio-based packaging materials which have resulted in their use for packaging in MAP based food packaging. It is also clear that bio-based packaging materials offer a versatile potential use in the packaging industry however, researches need to be performed in certain storage tests on packaging machinery.

6. References

1. Abe M, Kobayashi K, Honma N, Nakasaki K. Microbial degradation of poly (butylene succinate) by Fusarium solani in soil environments. Polym Degrad Stab 2010;95:138-143.
2. Accinelli C, Saccà ML, Mencarelli M, Vicari A. Deterioration of bioplastic carrier bags in the environment and assessment of a new recycling alternative. Chemosphere 2012;89:136-143.
3. Ahn HK, Huda MS, Smith MC, Mulbry W, Schmidt WF, Reeves JB III. Biodegradability of injection molded bioplastic pots containing polylactic acid and poultry feather fiber. Bioresource technology 2011;102:4930-4933.
4. Anstey A, Muniyasamy S, Reddy MM, Misra M, Mohanty A. Processability and biodegradability evaluation of composites from Poly (butylene succinate)(PBS) bioplastic and biofuel co-products from Ontario. Journal of Polymers and the Environment 2014;22:209-218.
5. ASTM D6400-04. Compostable Plastics 1. Annu. B. ASTM Stand 2004, 4-6.
6. Baldwin EA, Hagenmaier R, Bai J. Edible coatings and films to improve food quality. CRC Press 2011.
7. Bastos Lima MG. Toward multipurpose agriculture: food, fuels, flex crops, and prospects for a bioeconomy. Global Environmental Politics 2018;18:143-150.
8. Bohlmann GM. General characteristics, processability, industrial applications and market evolution of biodegradable polymers. Handbook of Biodegradable Polymers, Rapra Technology Ltd, Shawbury, UK 2005, 183-212.
9. Boyandin AN, Prudnikova SV, Karpov VA, Ivonin VN, Đỗ NL, Nguyen TH, Volova TG. Microbial degradation of polyhydroxyalkanoates in tropical soils. International Biodeterioration & Biodegradation 2013;83:77-84.
10. Bruckner M, Giljum SG, Fischer S. Tramberend and J Borner. The global crop land footprint of the non-food bio economy 2018.
11. Bugnicourt E, Schmid M, Nerney OM, Wild F. Whey-layer: the barrier coating of the future. Coat Int 2010;43:7-10.
12. Cano AI, Cháfer M, Chiralt A, González-Martínez C. Physical and microstructural properties of biodegradable films based on pea starch and PVA. Journal of Food Engineering 2015;167:59-64.
13. Chua TK, Tseng M, Yang MK. Degradation of Poly (ε-caprolactone) by thermophilic Streptomyces thermoviolaceus subsp. thermoviolaceus 76T-2. *AMB Express* 2013;3:8.
14. Cinelli P, Schmid M, Bugnicourt E, Wildner J, Bazzichi A, Anguillesi I, Lazzeri A. Whey protein layer applied on biodegradable packaging film to improve barrier properties while maintaining biodegradability. Polym Degrad Stab 2014;108:151-157.
15. Eubeler JP, Zok S, Bernhard M, Knepper TP. Environmental biodegradation of synthetic polymers I. Test methodologies and procedures. Trends in Analytical Chemistry 2009;28:1057-1072.
16. Guilbert S, Gontard N. Agro-polymers for edible and biodegradable films: review of agricultural polymeric materials, physical and mechanical characteristics. In Innovations in food packaging. Academic Press 2005, P263-276.
17. Harmaen AS, Khalina A, Azowa I, Hassan MA, Tarmian A, Jawaid M. Thermal and biodegradation properties of poly (lactic acid)/fertilizer/oil palm fibers blends biocomposites. Polymer Composites 2015;36:576-583.
18. Harrison JP, Boardman C, O'Callaghan K, Delort AM, Song J. Biodegradability standards for carrier bags and plastic films in aquatic environments: a critical review. Royal Society open science 2018;5:171-792.
19. Hartmann R, Hany R, Geiger T, Egli T, Witholt B, Zinn M. Tailored Biosynthesis of Olefinic Medium-Chain-Length Poly [(R)-3-hydroxyalkanoates] in Pseudomonas putida with Improved Thermal Properties. Macromolecules 2004;37:6780-6785.
20. Jabeen N, Majid I, Nayik GA. Bioplastics and food packaging: A review. Cogent Food & Agriculture 2015;1:1117749.
21. Jamshidian M, Tehrany EA, Imran M, Jacquot M, Desobry S. Poly-Lactic Acid: production, applications, nanocomposites, and release studies. Comprehensive reviews in food science and food safety 2010;9:552-571.
22. Karan H, Funk C, Grabert M, Oey M, Hankamer B. Green bioplastics as part of a circular bioeconomy. Trends in plant science 2019.
23. Katiyar V, Tripathi A, Patwa, Kotecha P. Environment Friendly Packaging Plastics. Polymers for Packaging Applications 2014, 115.
24. Khemani K, Scholz C. Introduction and overview of degradable and renewable polymers and materials. Degrad Polym Mat 2012, 1114.
25. Kim HW, Chung MG, Rhee YH. Biosynthesis, modification, and biodegradation of bacterial medium-chain-length polyhydroxyalkanoates. The Journal of Microbiology 2007;45:87-97.
26. Koller M. Poly (hydroxyalkanoates) for food packaging: Application and attempts towards implementation. Applied food biotechnology 2014;1:3-15.
27. Kulkarni Vishakha S, Butte Kishor D, Rathod Sudha S. Natural polymers–A comprehensive review. International Journal of Research in Pharmaceutical and Biomedical Sciences 2012;3:1597-1613.

28. Kumaravel S, R Hema, Lakshmi R. Production of polyhydroxybutyrate (bioplastic) and its biodegradation by Pseudomonas lemoignei and Aspergillus niger. Journal of Chemistry 2010;7: S536-S542.
29. Lee SH, Kim MN. Isolation of bacteria degrading poly (butylene succinate-co-butylene adipate) and their lip A gene. International Biodeterioration & Biodegradation 2010;64:184-190.
30. Marsh K, Bugusu B. Food packaging—roles, materials, and environmental issues. Journal of food science 2007;72:R39-R55.
31. Miles C, DeVetter L, Ghimire S, Hayes DG. Suitability of biodegradable plastic mulches for organic and sustainable agricultural production systems. HortScience 2017;52:10-15.
32. Modi SJ. Assessing the feasibility of poly-(3-hydroxybutyrate-co-3-hydroxyvalerate)(PHBV) and poly-(lactic acid) for potential food packaging applications (Doctoral dissertation, The Ohio State University) 2010.
33. Mooney BP. The second green revolution? Production of plant-based biodegradable plastics. Biochemical Journal 2009;418:219-232.
34. Mostafa NA, Farag AA, Abo-dief HM, Tayeb AM. Production of biodegradable plastic from agricultural wastes. Arabian journal of chemistry 2018;11:546-553.
35. Rudnik E, Briassoulis D. Degradation behaviour of poly (lactic acid) films and fibres in soil under Mediterranean field conditions and laboratory simulations testing. Industrial Crops and Products 2011;33:648-658.
36. Musioł M, Rydz J, Sikorska W, Rychter P, Kowalczuk M. A preliminary study of the degradation of selected commercial packaging materials in compost and aqueous environments. Polish Journal of Chemical Technology 2011;13(1):55-57.
37. Ozdemir M, Floros JD. Optimization of edible whey protein films containing preservatives for mechanical and optical properties. Journal of Food Engineering 2008;84:116-123.
38. Pathak S, Sneha CLR, Mathew BB. Bioplastics: its timeline based scenario & challenges. Journal of Polymer and Biopolymer Physics Chemistry 2014;2:84-90.
39. Popovic S, Pericin D, Vastag Z, Lazic V Popovic L. Pumpkin oil cake protein isolate films as potential gas barrier coating. Journal of Food Engineering 2012;110:374-379.
40. Ramos ÓL, Silva SI, Soares JC, Fernandes JC, Poças MF, Pintado ME, *et al.* Features and performance of edible films, obtained from whey protein isolate formulated with antimicrobial compounds. Food Research International 2012;45:351-361.
41. Rydz J, Sikorska W, Kyulavska M, Christova D. Polyester-based (bio) degradable polymers as environmentally friendly materials for sustainable development. International journal of molecular sciences 2015;16:564-596.
42. Rasal RM, Janorkar AV, Hirt DE. Poly (lactic acid) modifications. Progress in polymer science 2010;35:338-356.
43. Rhim JW, Park HM, and Ha CS. Bio-nanocomposites for food packaging applications. Progress in polymer science 2013;38:1629-1652.
44. Sam ST, Nuradibah MA, Chin KM, Hani N. Current application and challenges on packaging industry based on natural polymer blending. In *Natural Polymers*. Springer, Cham 2016, P163-184.
45. Sarasa J, Gracia JM, Javierre C. Study of the biodisintegration of a bioplastic material waste. Bioresource technology 2009;100:3764-3768.
46. Sekiguchi T, Saika A, Nomura K, Watanabe T, Watanabe T, Fujimoto Y, Kanehiro H. Biodegradation of aliphatic polyesters soaked in deep seawaters and isolation of poly (ε-caprolactone)-degrading bacteria. Polymer degradation and stability 2011;96:1397-1403.
47. Siracusa V, Rocculi P, Romani S, Dalla Rosa M. Biodegradable polymers for food packaging: a review. Trends in Food Science & Technology 2008;19:634-643.
48. Tezuka Y, Ishii N, Kasuya KI, Mitomo H. Degradation of poly (ethylene succinate) by mesophilic bacteria. Polym degrad stab 2004;84:115-121.
49. The DP, Debeaufort F, Voilley A, Luu D. Biopolymer interactions affect the functional properties of edible films based on agar, cassava starch and arabinoxylan blends. Journal of Food Engineering 2009;90:548-558.
50. Thellen C, Coyne M, Froio D, Auerbach M, Wirsen C, Ratto JA. A processing, characterization and marine biodegradation study of melt-extruded polyhydroxyalkanoate (PHA) films. Journal of Polymers and the Environment 2008;16:1-11.
51. Tokiwa Y, Calabia BP. Review degradation of microbial polyesters. Biotechnology letters 2004;26:1181-1189.
52. Tokiwa Y, Calabia B, Ugwu C, Aiba S. Biodegradability of plastics. International journal of molecular sciences 2009;10:3722-3742.
53. Tosin M, Weber M, Siotto M, Lott C, Degli-Innocenti F. Laboratory test methods to determine the degradation of plastics in marine environmental conditions. Frontiers in microbiology 2012;3:225.
54. Tripathi AD, Srivastava SK, Yadav A. Biopolymers: potential biodegradable packaging material for food industry. Polymers for Packaging Applications 2014, 153.
55. Trivedi P, Hasan A, Akhtar S, Siddiqui MH, Sayeed U, Khan K. Role of microbes in degradation of synthetic plastics and manufacture of bioplastics. Journal of Chemical and Pharmaceutical Research 2016;8:211-216.
56. Vaverková MD, Adamcová D. Biodegrability of bioplastic materials in a controlled composting environment. Journal of Ecological Engineering 2015;16:721-730.
57. Verbeek CJ, van den Berg LE. Extrusion processing and properties of protein-based thermoplastics. Macromolecular materials and engineering 2010;295:10-21.
58. Volova TG, Boyandin AN, Vasiliev AD, Karpov VA, Prudnikova SV, Mishukova OV, Dũng VV. Biodegradation of polyhydroxyalkanoates (PHAs) in tropical coastal waters and identification of PHA-degrading bacteria. Polym Degrad Stab 2010;95:2350-2359.
59. Wang Y, Xiong YL, Rentfrow GK, Newman MC. Oxidation promotes cross-linking but impairs film-

forming properties of whey proteins. Journal of food engineering 2013;115:11-19.
60. Wei L, Liang S, McDonald AG. Thermophysical properties and biodegradation behavior of green composites made from polyhydroxybutyrate and potato peel waste fermentation residue. Industrial Crops and Products 2015;69:91-103.