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Biodegradation of plastics and its impact on environmental pollution-A review

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ABSTRACT

The most general term which is used for high molecular weight polymers of the organic nature is "Plastic" these polymers are obtained from different derivatives of petroleum and hydrocarbon. The utilization of plastic is rising gradually. Tons of the plastic goods are being manufactured by thousands of the plastic factories. The plastic made goods are the most widely utilized by the people in whole world due to cheapness and convenience. Due to non-biodegradable nature with few exceptions, plastic reason many hazardous and negative effects on environment. The main reason of the pollution is the disposal of plastic wastes. Many animal and plant species are already documented to be threatened and extinct due to human activities impacts. The recent strategies for degradation of polymers are usually chemical, photo, thermal, and biological procedures. Many steps are essential to be taken by the governments department and non government organizations in order to regulate the plastic trade and to bring improvements in waste management system. Producing the community awareness regarding environment, alternative methods of disposal, mechanism managing wastes, establishment of the incineration mechanisms and drop-off-areas, facilities of plastic recycling and use of biodegradable polymers and strategies along with the facilities of industrially controlled biodegradation are also recommended in order to ensure healthy environment. This review demonstrates the biodegradable plastics and classification of plastics mechanisms and microorganisms involved in biodegradation, the involved in biodegradation.

Keywords: Biodegradation, Mechanisms, Microorganisms, Polymers, Environment

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INTRODUCTION

Plastic used has been observing since 1970's (Williamson, 2003). The utilization of plastic is rising gradually. It is observed 500 billion plastic per annum are used. (Spokas, 2008). Tons of the plastic goods are being manufactured by thousands of the plastic factories. The plastic made goods are the most widely utilized by the people in whole world due to cheapness and convenience (Stevens, 2002). Due to non-biodegradable nature with few exceptions, plastic reason many hazardous and negative effects on environment (Adane and Muleta, 2011). The main reason of the pollution is the disposal of plastic wastes. Many animal and plant species are already documented to be threatened and extinct due to human activities impacts (Hasson *et al.*, 2007; Flores, 2008; Macur and Pudlowski, 2009; Xing, 2009).

TYPES OF PLASTICS

Plastic used has been observing since 1970's (Williamson, 2003). The utilization of plastic is rising gradually. It is observed 500 billion plastic per annum are used. (Spokas, 2008). Tons of the plastic goods are being manufactured by thousands of the plastic factories. The plastic made goods are the most widely utilized by the people in whole world due to cheapness and convenience (Stevens, 2002). Due to non-biodegradable nature with few exceptions, plastic reason many hazardous and negative effects on environment (Adane and Muleta, 2011). The main reason of the pollution is the disposal of plastic wastes. Many animal and plant species are already documented to be threatened and extinct due to human activities impacts (Hasson *et al.*, 2007; Flores, 2008; Macur and Pudlowski, 2009; Xing, 2009).

Table 1: Types of plastic their examples and uses.

Plastics types	Examples	Applications
Thermoplastics	PET or Polyethylene Terephthalate, Low-density polyethylene (LDPE) and High-density polyethylene (HDPE), Expanded polystyrene (EPS) PVC or Polyvinyl chloride Polycarbonate	Thermoplastics are changed form of plastic and it can be modified into different shapes on cooling or heating, it has ability of reversible, reshaping and reheating
Thermosets	Polyurethane (PUR), Silicone, Phenolic, Epoxy, Acrylic, Vinyl ester.	Thermosets is a permanent chemical change upon heating, and cannot be re-melt or reform.

The use of the bio-based biodegradable plastics is also observed to be increasing with the passage of time in packaging, health and the agriculture, but the plastic industries contribution is low. Furthermore the proper safety of environment and effective waste management are necessary (Rujnić-Sokele and Pilipović, 2017). According to studies, various natural microbes like fungi and bacteria species possess striking abilities for the rapid degradation of fossil and bio-based fossil based polymers which are biodegradable by the production and secretion of certain enzymes and exo-products (Ghosh *et al.*, 2013).

The significant enzymes secreted by microbes which are responsible for the biodegradation of polymer include cutinases, lipases, and proteases (Muhamad *et al.*, 2015). Furthermore, the other enzymes for examples lipases and esterases which are secreted by Rhizopus species like *R. arrhizus, R. delemar*, *Candida cylindracea* and *Achromobacter* species have also been observed to be effective in biodegradation of complex polymers e.g. polyethylene adipate (Lam *et al.*, 2009). The utilization and applications of plastic made of biodegradable polymers is low commercially because of the multifaceted structure and low awareness regarding optimized environment for the rapid degradation (Rujnić-Sokele and Pilipović, 2017). There are many mechanisms adopted by microorganisms to mortify plastic polymers like the mechanism of making fragments of plastic and use them as a source of nutrition or by the indirect mechanism involving different enzymes. The major species of microbes which are greatly involved in the biodegradation of plastic and its polymers, includes different strains are *Penicillium simplicissimum*, *Pseudomonas fluorescens* and *P. aeruginosa* (Iram *et al.*, 2019).

Classification of Plastics on the Basis of Biodegradability

On the basis of biodegradability plastics are classified in to two major groups as; biodegradable plastics and non-biodegradable plastics (Figure 1).

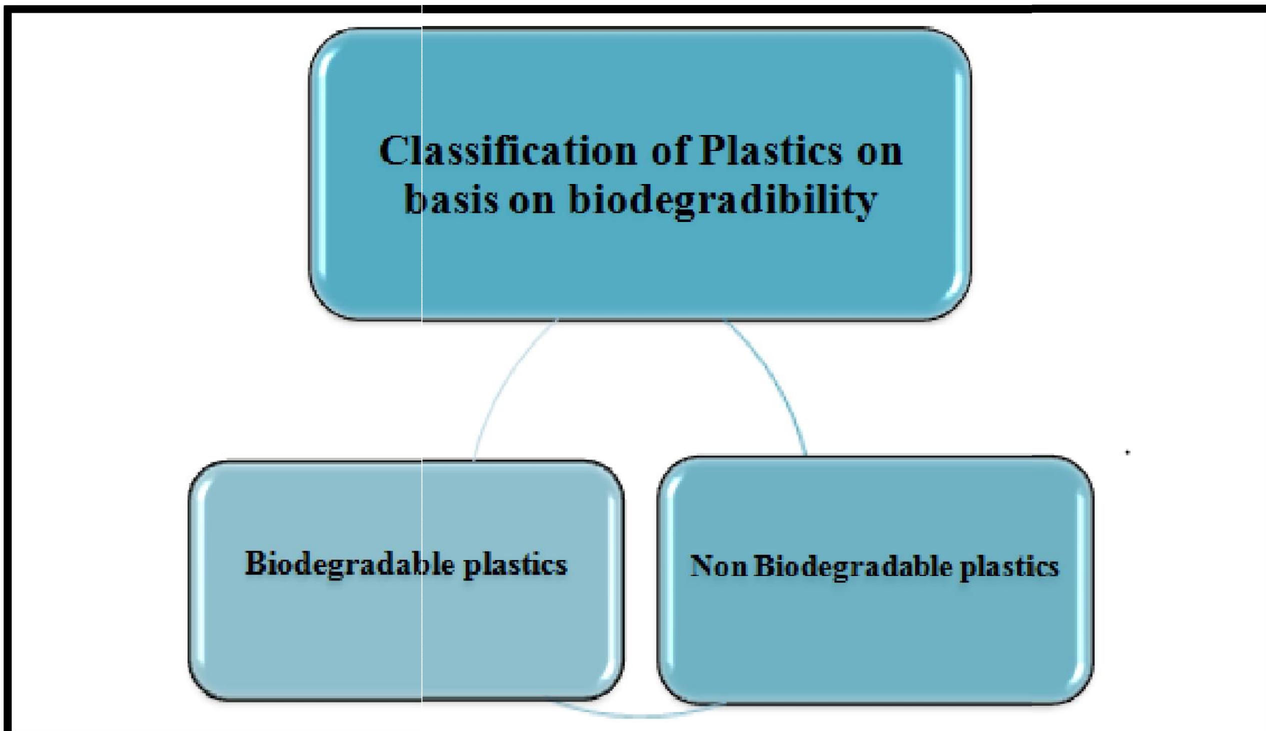

Figure 1: Classification of Plastics on basis of biodegradability

Plastics of biodegradable nature

The process involved in the plastic biodegradation involves hydrolysis (Ramli *et al.*, 2016). The main factors of the process of biodegradation are as; pretreatment nature, characteristics of polymer and type of microorganism. Furthermore, mobility, crystallinity, functional groups, molecular weight, tactility, chemical components and the nature of additives in plastics are vital features to judge in the degradation (Kabir *et al.*, 2020). During the process of degradation, the microbes produce and secrete enzymes and exo-chemicals which are involved in causing the disintegration of the plastic polymer and their complexes and convert them into small fragments or molecules known as the dimmers or monomers of plastics. These, small fragments are so tinier that they can be used as nutrition and energy source of microbes by passing through the bacterial semi-permeable (Alshehrei, 2017). Both mechanisms of aerobic and anaerobic reactions are involved in biodegradation (Szyszkowska and Galas, 2017).

Non-biodegradable plastics

It also includes both fossils and bio-based polymers. Mostly these plastics are synthetic and of fossil origin. These are obtained from the petrochemicals and hydrocarbon and their derivatives (Ghosh *et al.*, 2013). Due to high molecular weight they are stable and are not degraded by environment. These polymers are totally non-biodegradable or the rate of degradation is very low. The examples of non-biodegradable plastics are used PVC, PS, PP, PET, PE and PUR etc. Because of their wide use, littering, improper disposal and waste management they have been not degraded naturally in the ecosystem and become a major source of pollution (Krueger *et al.*, 2015).

BIODEGRADABLE PLASTICS AND THEIR CLASSIFICATION

Biodegradable plastics are classified as follows (Figure 2):

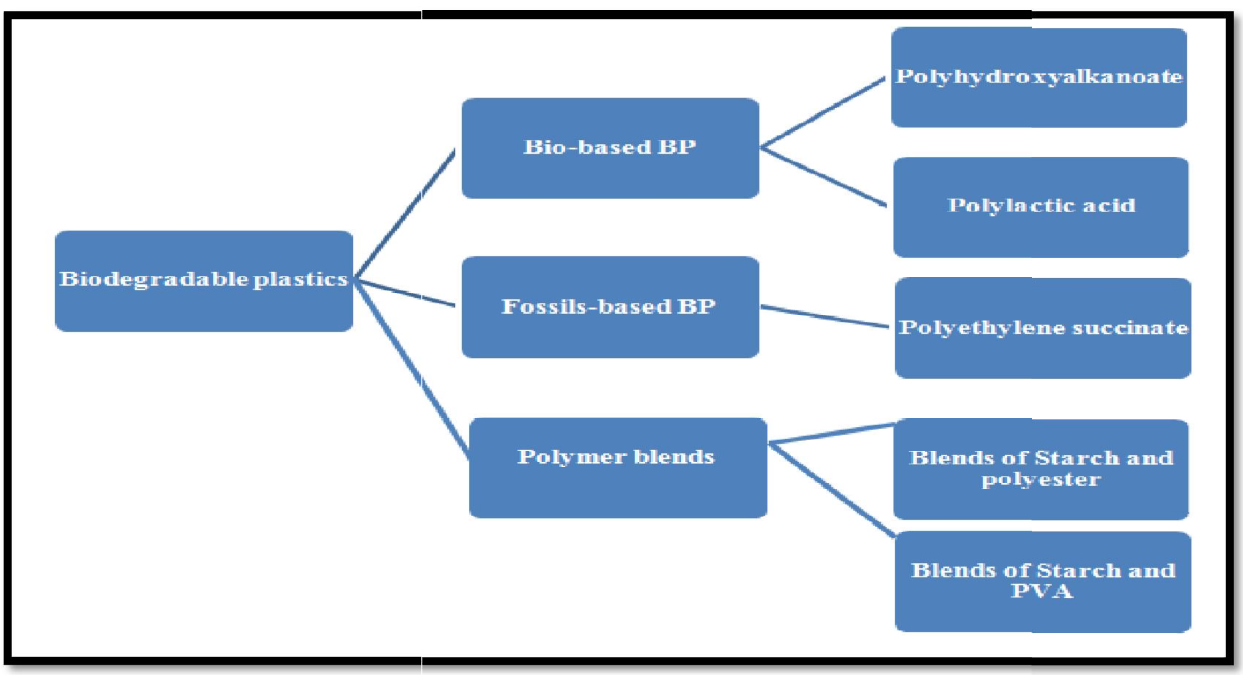

Figure 2: Categorization of Biodegradable polymers.

Biodegradable Plastics of Bio-Based Nature

These are derived from the resources which are renewable. They are very beneficial in many industrialized applications because of the capacity of complete degradation by the biological process (Lambert and Wagner, 2017). The examples of bio-based biodegradable plastics are cellulose and starch (Saini, 2017). The polymers of the starch and starch-based are classified as; starch-filled polymer and starch-based polymer. These are the polymers and degraded by various microbes i.e. fungi, bacteria and algae (Kasirajan and Ngouajio, 2012). The microorganisms like *Acidovorax faecilis*, *Variovorax paradoxus*, *P. lemoignei*, *Aspergillus fumigates* and *Comamonas* species are obtained from soil, noted to break up all the bio-based plastics under aerobic and anaerobic processes (Tiwari *et al.*, 2018). Polyhydroxyalkanoates **(**PHA) and Polylactic acid **(**PLA) are common bio-based biodegradable polymers (Elbanna *et al.*, 2004)

Polyhydroxyalkanoates (PHA)

PHA is biodegradable and bio-based polyester which is synthesized by the sugar and lipids fermentation by bacteria (Kenny *et al.*, 2008). It is used in pharmaceutical industries for the purpose of packaging of medical products because of biodegradable nature. Other uses include the items for service of fast food, packaging materials, disposable tools of medical use etc. The various species of bacteria degrade PHA readily such as Nocardiopsis, Bacillus, Cupriavidus and Burkholderia. Likewise the species of fungi includes Micromycetes and Mycobacterium which assimilate polymers of PHA (Boyandin *et al.*, 2013) in aerobic as well as anaerobic conditions.

Polylactic acid (PLA)

It is also bio-based biodegradable plastic which is derived from tapioca roots, corn starch, or sugarcane. It is used in medicines due to incorporation ability into animal and human bodies (Ikada and Tsuji, 2000). It can be degradation completely into hydrolytic by microbes. The species like *Bacillus licheniformis* and *Amycolatopsis* sp. isolated from soil, were observed to be involved in the PLA degradation (Anderson and Shive, 2012). A fungus, *Cryptococcus* sp. strain S-2 and its enzyme lipase also showed effective PLA biodegradation (Karamanlioglu *et al.*, 2017).

Fossil-based Biodegradable Plastics

It has been used in the packaging industry. These are used widely in pharmaceutical products packaging, packaging materials for makeup, food, and various chemicals. Different microbes are involved in their degradation but the process is too slow (Mir *et al.*, 2017).

Polyethylene Succinate (PES)

PES is thermoplastic polyesters produced by copolymerization of ethylene oxide and succinic anhydride carried out by poly-condensation of ethylene glycol and succinic acid. It is widely used in plastic industry for manufacture of agriculture films, coating agent in paper industry, and manufacturing of shopping bags. It is degraded by Pseudomonas species AKS2 which is mesophilic strain of bacteria (Tribedi and Sil, 2014).

Additionally, various mesophilic microorganisms, which have the PES degradation ability, are from the genera of *Paenibacillus* and *Bacillus*. Polycaprolactone is also a fossil-based polymer which is degraded by using aerobic as well as anaerobic microorganisms. It is degraded by microbial enzymes e.g. lipases and esterases (Karakus, 2016). *Aspergillus* sp. ST-01 which belongs to the fungal family has also been reported to degrade PCL efficiently into products such as succinic, butyric, valeric and caproic acid (Sanchez *et al.*, 2000)

Biodegradable Polymer Blends

It is cheaper in cost. Different types of biodegradable polymer blends which are starch-based are being manufactured like the starch/PVA blends and starch/polyester blends. These are completely biodegraded by action of microbial enzymes. The research trend on microbial mechanisms of degradation is increasing (Jayasekara *et al.*, 2005).

Starch/Polyester Blends

The blends of polyester and Starch are degradable due to their composition. Starch blends and polyester are very economical because starch is easily available, renewable and affordable. The speed of polyesters e.g. PCL degradation increases by increasing the concentration of starch. The polyesters thermoplastics can be used in genetic engineering and are versatile (Table 1). The microbial enzyme secreted by strains of *R. arrhizus* and *R. delemar* are involved in the hydrolysis of blends of polyester (Guarás *et al.*, 2017).

Starch/PVA Blends

PVA used in blends is aqueous soluble, fossil-based and biodegradable whose competitiveness increased by making a blend with starch. They have good properties of forming film and are used in packaging. Many microorganisms have been documented to be involved in the enzymatic hydrolysis of starch/PVA blends. Like the, depolymerase enzyme secreted by the strain *Alcaligenes feacalis* T1 is observed to degrade blends efficiently (Tokiwa *et al.*, 2009).

Microorganisms and the process involved in the biodegradation of plastics

The microorganisms especially species of bacteria and strains of fungi secretes enzymes extracellular that degrades different plastics including fossil and bio based plastics (Shah *et al.*, 2014). The microbes degrade polymers of plastic into Carbon dioxide and water through different mechanism of metabolism and action of enzymes. The enzymatic nature and its catalytic activity variety from species to species and depend on the type of strains. The strains of *Brevibacillus* spp. and *Bacillus* spp. are involved in the production of proteases which is involved in polymers degradation (Pathak, 2017).

The strains of different species of Fungi assimilates lignin contain the enzyme laccases that speed up aromatic as well as non-aromatic components by oxidation. The biodegradable as well as the non-biodegradable polymers including PHB, PHA, PET, PLA, PCL, PBS and PVC are documented to link with different microorganisms and their secreted enzymes (Muhamad *et al.*, 2015). The major types of microorganisms and their produced enzymes which are responsible for plastics degradation have been given in details in Table 2.

Table 2: Microbial enzymes and type of plastic degraded.

Sources	Microorganism	Enzyme	Type of plastic
Bacteria	Firmicutes	Unknown	PHB, PBS and PCL
	Clostridium botulinum, Rhizopus delemar, R. arrizus	Lipase	PCL, PBS, and PEA
	Brevibacillus borstelensis	Unknown	PET
	Pseudomonas stutzeri	Serine hydrolase	PHA
	Pseudomonas fluorescens, P. putida, Ochrobactrum sp.	Unknown	PVC
Fungi	*Penicillium funiculosum*	Unknown	PHB
	Aspergillus flavus	Glycosides	PCL
	A. niger	Catalase, protease	PCL
	Fusarium sp.	Cutinase	PCL
	Pestalotiopsis microspore, Curvularia senegalensisi, Fusarium solani	Serine hydrolase	PUR

The primary biodegradation process which is involved in the disintegration of plastic is the attachment of microorganism with the respective polymers and then colonization on the surface. The process of the hydrolysis of plastics which is based on enzyme-based involves the following steps: The first step involved in the degradation is the attachment of the enzymes with the substrate polymer and the hydrolytic division occurs. The oligomers, monomers and dimmers are formed after degradation which have low molecular weight and are then converted into carbon dioxide gas and water by the process of mineralization. Under, oxygen acts as acceptor of during electron acceptor aerobic conditions by bacteria which is followed by tinier organic compounds synthesis and finally end products carbon dioxide gas are formed. In the anaerobic conditions, the fragments of polymers are produced by microbes without oxygen. The electron acceptors used are the nitrate, manganese, iron, sulfate and carbon dioxide (Priyanka and Archana, 2011).

ACTORS AFFECTING BIODEGRADATION OF PLASTIC

There are different factors which affect the process of biodegradation like polymer properties of polymers, conditions of exposure, and the characteristics of enzyme (Figure 3). These factors are given below:

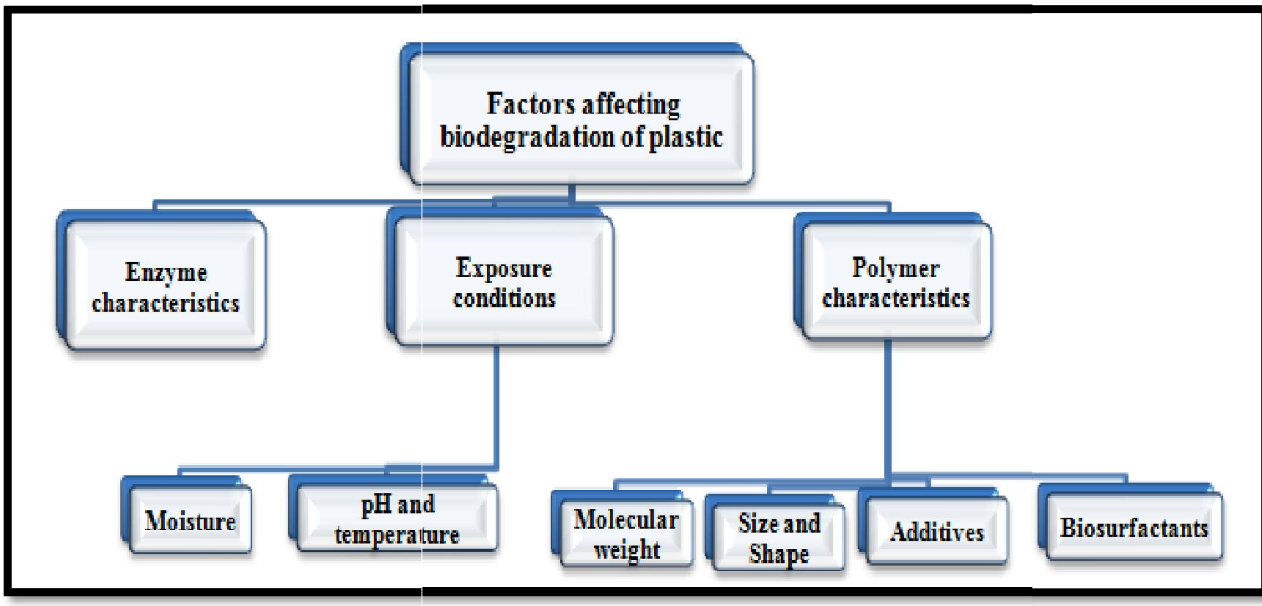

Figure 3: Factors effecting degradation of plastics

CONCLUSIONS

After all the survey of different literature, it can be concluded that the plastic and products of plastics use is unavoidable in our life. The need and demand of plastic is also increasing. The process of the production and the needs to management of plastic waste needs to be positively correlated by the adaptation of the bio and fossils based biodegradable materials to ensure the safety of the environment. The wide ranges of the species of microbes have effective and great potential of the degradation of the plastics biologically into simple components under aerobic as well as anaerobic conditions and mechanisms. There is a great demand and necessity to synthesize polymers which are biodegradable. Furthermore, the biodegradable compounds and their utilization must be improved in various industries by the facilities development for degradation and strategies for the control of littering to guarantee the sustainability and safety of natural environment.

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