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A Review on Microorganisms Involved in Biodegradation of Plastic

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Abstract

Wide use of plastics is leading towards the water and soil pollution which is of great concern. Plastics are considered as a threat to the environment because of their inability to degrade and thus accumulate in the environment causing increase in plastic waste. The cheapest and environmental friendly method to reduce the plastic waste is the use of microorganisms for degradation of plastic thus converting them into low molecular weight compounds which are not harmful for the ecosystem. This review describes the research carried out in last two decades to explore the potential of various microorganisms to degrade plastic. It also explains various types of plastic that are being produced as well as their common uses. The general mechanism involved in biodegradation process along with the factors affecting are discussed in this paper. There is a need to isolate and characterize the microorganisms as well as the enzymes involved in degrading plastic.

Keywords: Plastic waste; Biodegradation; Plastic degrading microbes

Introduction

Plastics are produced from non-renewable source i.e. fossil fuels. They are long chain polymers of carbon bonded with other organic or inorganic elements and also with nitrogen, hydrogen and sulphur. They are light weight, non-biodegradable and can resist moisture. Plastics are non-metallic and can be moulded into any desirable form. They are used in packaging industry including cosmetics, food and pharmaceuticals etc. [1]. Worldwide about 57 million tons of plastic waste is being generated each year. Due to resistance of plastic to microbial attack, large molecular mass, strong bonds with halogen substitutions and aromatic rings, plastics are unable to breakdown easily in the natural environment and are main reasons of accumulation in the biosphere at a large scale without deterioration and results in environmental pollution. In solid waste management, there is a major focus on plastic waste and it has become a threat to the global ecosystem due to its resilience against degradation [2].

There is increase of almost 5% in production of plastics each year throughout the world [3]. Plastic waste accumulates in the nature and causes harm to the environment because of its inability to degrade. In the soil it clogs the pores and makes it unsuitable for agricultural purposes. Animals die by swallowing the plastic or by being trapped in it and it cause huge negative impact on ecosystem.

Environmental pollution due to plastic waste is considered as major issue and to solve this problem during last three decades various techniques including chemical and biological degradation have been studied. The use of enzymes and microorganisms for the purpose of degradation is classified as the biodegradation method [4].

Plastics are being widely used because of the resilience and low cost. But it has now become a source of pollution and major problem in management of solid waste [5,6]. It also affects the natural resources by contaminating the soil and causing negative impacts on water quality [7-9].

Plastic waste was tripled in 1990s and rapidly increasing in the marine environment [10]. In 1993, there was 107 million tons demand for plastic and in 2000 it increased to 146 million tons. There is growth rate of 15% per annum in plastic industry of Pakistan [11]. Plastic waste is being generated rapidly worldwide. 1 million tons, 4.5 million tons and 16 million tons of plastic waste is contributed by UK, China and India, respectively. Reliability, versatility and competitiveness of plastic materials has been increasing since past 5 decades and it has become a substitute for metal, wood and leather materials because of the physical properties, durability and flexibility. Resilience and accumulation in the environment are the reasons it poses threat to the environment. The recycling of plastic waste is an alternative solution. But expensive processes are used for collection and sorting the waste [12]. Only 5% of plastic bags are recycled out of 1 trillion which are being dumped in US per annum. Bioremediation can be one of the potential tools for the plastic waste management and reduce adverse impacts on environment [9,11,13].

Microorganisms over 90 genera can degrade plastic from bacteria to fungi including *Bacillus megaterium, Pseudomonas sp., Azotobacter, Ralstoniaeutropha, Halomonas sp.*, etc [14]. There are certain microbial species that are associated with the degradation of materials. The enzymatic activities of microbes cause the degradation of plastic by breaking down the chain of polymers and converting them into monomers and oligomers. These water-soluble products are metabolized after being absorbed by the microbial cells. Carbon dioxide and water are produced as a result of aerobic metabolism and as a result of anaerobic metabolism, water, carbon dioxide and methane are produced as end products [15]. Monomers formed by breaking down the polymers can easily be accumulated and degraded by the microbial cells [16].

The aim of this review paper is to:

- Describe different types of plastic and their usage.
- General mechanism pathway involved in the microbial degradation of plastic and factors affecting it.
- Identify the various microbes capable of degrading plastic.

Types of Plastics and their Uses

There is increase in production of plastics because of the wide application. There are various types of plastics which can be used for different purposes. Their insulating and anti-corrosion properties make them suitable to be widely used in daily life. Different types of plastics and their uses are listed in the Table 1 given below:

Sr. No.	Types	Common Uses
1	High Density Polyethylene (HDPE)	Milk containers, Bottles of soaps and detergents, grocery bags and pesticide containers.
2	Polyethylene Terephthalate (PET)	It is commonly used in bottles, jars and carpet fibre etc.
3	Low Density Polyethylene (LDPE)	Used in liners for trashcan, containers for storing food like sandwich bags and grocery bags.
4	Polypropylene (PP)	Lunch box, syrup bottles packaging of food. It is also used in fabrics, yarns and nursery pots.
5	Polyvinyl Chloride (PVC)	It is used in pipes and food packaging.
6	Polystyrene (PS)	It is used in disposable cups, boxes, packing foam and plastic cutlery.
7	Other types of plastics	Many types of plastic are used to make food containers.

Table 1: Types and uses of plastics.

Biodegradation of plastic

Biodegradation of plastic involves change in the chemical structure, color, shape, molecular mass and tensile strength of the plastic with the help of microbes. It includes enzymatic or non-enzymatic hydrolysis of bacteria and fungi or other microorganisms [17].

The origin of plastic, its chemical structure and the environmental conditions for degradation affect the process of biodegradability. The other factors include production, chemical composition, processing of plastic and application conditions which influence the mechanical nature of these substances. Plastics can be degraded aerobically (with oxygen) in nature and anaerobically (without oxygen) in landfills or sediments and also in compost or soil by partial aerobic degradation [18].

Aerobic biodegradation

This process is also known as aerobic degradation and plays an important role in decontamination of hazardous substances present in waste sites. Oxygen is used by the microbes involved in aerobic degradation as an electron acceptor and organic compounds arebrokendownintosmalleroneswiththereleaseofcarbondioxideandwaterasby-products [19,20].

Anaerobic biodegradation

The microorganisms involved in anaerobic degradation decompose the organic chemicals in the absence of oxygen. It is also important in decontamination of hazardous substances present in waste sites. Carbon dioxide, Sulfate, Nitrate, Iron and Manganese are used by anaerobic bacteria as electron acceptors. Methane is also produced as a by-product along with carbon dioxide, water and biomass [18].

Mechanism of plastic biodegradation

Microbes involved in biodegradation of plastic secrete extracellular enzymes to convert the long chain into monomers outside the cells. The mechanism pathways for aerobic and anaerobic biodegradation are given in the Figure 1:

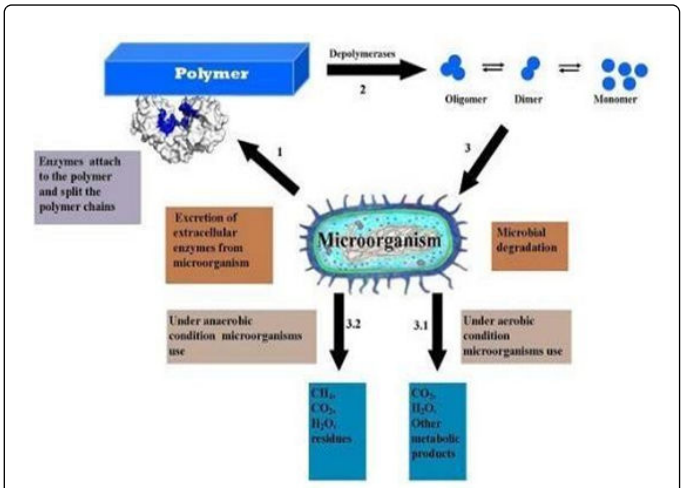

Figure 1: Mechanism pathway for aerobic and anaerobic biodegradation [17].

Steps involved in biodegradation of plastic

The biodegradation of plastic includes the following steps:

- Attachment of microorganisms to plastic surface.
- Plastic acts as source of carbon for the microorganisms. Biofilm is formed on the surface and colonization starts.
- Microorganisms then release extracellular enzymes which get attached to the surface.
- The long chain of polymers is broken down to monomers by the action of enzymes.
- Molecules are transported to the cytoplasm of microbial cells during metabolism.

- Plastic is completely degraded and releases carbon dioxide, water and other metabolites [17,21].

Microbes, if hydrophilic, can attach to the plastics' surface. After getting attached to the surface microbes grow by using plastic as carbon source. Compounds with low molecular weight like monomers, oligomers are formed by microbial degradation of compounds with high molecular weight. These compounds can also get diffused in the microbial cells [4,22].

Factors Involved in biodegradation of plastics

There are various factors which affect the process of biodegradation. Chemical and physical characteristics are important and play an important role in biodegradation. Compounds with side chains are difficult to degrade as compared to the compounds without side chains. Similarly, it is also difficult to degrade high molecular weight compounds. The other factors include temperature at which plastic melts morphology and crystallinity. If melting temperature is high, then it will be hard to degrade the plastic. The amorphous compounds can easily be degraded as compared to crystalline one. All these factors must be kept in mind before initiating the process of plastic biodegradation [23].

Listed below are the physical and chemical characteristics which affect the biodegradability of plastics:

- Presence of functional groups responsible for hydrophobicity (hydrophobic degradation is slower than hydrophilic).
- Morphology of plastic.
- Density and molecular weight of plastic.
- Presence of bonds which can easily be broken like amide or ester bonds.
- Molecular composition.
- Complexity in the structure e.g. Branches in long chains.
- Hardness.
- Physical form e.g. Powder, films etc [20,21,24].

There are certain exposure conditions upon which biodegradability also depends:

Moisture: The process of biodegradation can be influenced by the moisture content because of its requirement for microbial growth and reproduction. Therefore, the biodegradability can be enhanced by providing enough moisture [25].

pH and Temperature: pH can also influence the rate of biodegradation as it changes the acidic and basic conditions of the environment. Products formed as a result of biodegradation also alter the pH of the environmental eventually affecting the growth of microorganisms and rate of biodegradation. Similarly, biodegradability is affected by the melting temperature of plastics. High melting temperature of plastics make the process of biodegradation difficult and enzymatic activities of microbes are decreased with increase in temperature [25].

Enzymes

Various enzymes have active sites and are able to degrade the plastic. For instance, *A. flavus* and *A. niger*, two fungal species produced enzymes which quickly degraded straight chain polyesters [26]. The degradation of Polyhydroxybutyrate (PHB) is done by the specific mechanism of extracellular enzymes known as depolymerase produced by the microbes [27].

Research on plastic biodegradation

The use of bioplastics and fossil-based plastic is increasing in the world. The utilization of biodegradable plastics can be beneficial if the waste is properly managed and strategies for litter control are established [28]. PET is a non-biodegradable thermoplastic which accumulates in the environment. *Ideonella sakaiensis* 201-F6, a novel bacterial strain, was identified to degrade PET and use it as carbon and energy source. The bacterial strain converts the PET into two monomers (ethylene glycol and terephthalic acid) which are not harmful for the environment [29]. There is a need to optimize the biodegradation process of PET for environmental friendly applications. In another study, microbial consortia containing *Pantoea spp.* and *Enterobacter spp.* were used to degrade LDPE [30]. Researchers have identified microorganisms to convert waste of plastic processing i.e. organic styrene into PHA. *P. putida* NBUS12, is isolated which can efficiently degrade styrene [31]. *Achromobacter xylosoxidans* is a bacterial strain which is able to degrade high- density polyethylene (HDPE) [32]. Another thermophilic bacterium *Anoxybacillus rupiensis* Ir3 (JQ912241), was isolated from soil polluted by hydrocarbon in Iraq to degrade aromatic compounds by utilizing them as a carbon source [33]. Extensive research has been going on around the world to develop the processes to degrade plastics which will result in proper management of plastic waste and protect our environment from the hazards of plastic pollution. Few studies from the literature have been described in Table 2 in which different microorganisms were used to degrade the plastic:

Sr. No.	Microorganisms	Plastics	References
1.	*Clostridium botulinum*	PCL	[25,34]
2.	*Pseudomonas fluorescens Pseudomonas putida Ochrobactrum (Genus)*	PET	[35,36]
3.	*Aspergillus flavus*	PCL	[25]
4.	*Aspergillus niger*	PCL	[25]
5.	*Pseudomonans putida*	Polythene and plastic bags	[37]
6.	*Sreptomyces, Aspergillus niger, Pseudomonas, Aspergillus flavus*	LDPE	[38]
7.	*Bacillus Amyloliquefaciens*	LDPE	[38]

Table 2: Literature reported on biodegradation of plastic using various microorganisms.

Future Prospects

Use of biodegradable plastic is most innovative and environmental friendly method to eliminate the plastic pollution. Biodegradable plastic can be used in packaging industry, health and agriculture industry. They can be efficiently degraded in the environment with the help of microorganisms. The microorganisms which are able to degrade the plastic should be isolated and screened to test their degrading potential. Characterization of microorganisms at molecular level is also needed. There are some extracellular enzymes that have capability to degrade plastics. There is a need to characterize these enzymes and also identify the genes responsible for enzymes. Then these genes can be used to improve the biodegradability of other microorganisms. After field application, microorganisms with efficient degrading potential should be multiplied to degrade plastics at larger scale.

Conclusion

It is concluded that plastic is widely used in our daily life for packaging our goods due to its quality and durability. However, its accumulation in the ecosystem is a great threat. Marine animals die due to blockage in their intestines and gills caused by plastics. In the literature, various methods are present to degrade the different types of plastics. The cheapest method to degrade plastic is the biodegradation using microorganisms (bacteria or fungi). It is the eco-friendly and cheap methods as compared to others. Extracellular enzymes like depolymerase, lignin peroxidase are excreted by microbes help in process of degradation. Various microorganisms have been reported in the literature that are capable of degrading plastic. Further investigation is needed to characterize those microbes as well as enzymes involved.

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