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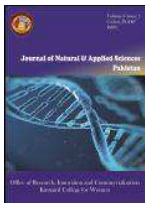

BIODEGRADATION OF SYNTHETIC AND NATURAL PLASTICS BY MICROORGANISMS: A MINI REVIEW

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Abstract
The use of plastic has increased intensively in daily life due to their durability, light weight, easy availability and inexpensiveness. The countries which generate plastic the most include China the lead producer of plastic waste 23.9%. The environmental pollution caused by plastic is evident from the amount of plastic that has accumulated in environment. There are health hazard of plastic on wildlife too. One problem is ingestion of plastic by marine life who mistake it as food. A biotechnological approach is becoming popular now which is biodegradation of plastics using microbes. Microbial degradation of plastics means breaking down plastic polymers into its monomers and oligomers by microorganisms. The mechanism of biodegradation of plastic involves bio-deterioration, bio-fragmentation, assimilation and mineralization. The major factors that affect the process of microbial biodegradation depends on polymer characteristics and environmental conditions. Different microbial strains are capable of degrading different types of plastic like *Brevibacillus spp., Bacillus spp.* which secrets proteases to degrade polyethylene. The need for biodegradation of plastic and biodegradable plastic has assumed increasing importance to resolve plastic pollution.

1. Introduction

The use of plastic has increased intensively in daily life due to their durability, light weight, easy availability and inexpensiveness (Sil, 2015). The problem that occurs is that they are not highly stable and not easily degraded, thus accumulating in our environment causing pollution (Vijaya & Reddy, 2008).
Plastics can be defined as long chain polymers, which could be naturally occurring or synthetic (Ghosh et al. 2013). The polymers like starch, lignin, chitin etc. are natural plastics while synthetic plastics are commonly derived from petrochemical like polyethylene, polystyrene, silicone, nylon etc. (Narwal, & Guta, 2017).
The countries which generate plastic the most include China the lead producer of plastic waste 23.9%. Whereas, Europe is on second rank accounts for 21.5% global plastic production (Plastics Europe, 2015). It is estimated that 500 billion to 1 trillion plastic bags are used in one year (Singh, Mir & Sharma, 2018).
Most of the plastic used is inert, which due to improper waste management and uncontrolled

littering accumulates in our environment, leading to ecological and health related problems (Comăniță et al. 2016). Given the environmental and health related problems associated with plastic, the use of microorganism to degrade plastic is being sought in to resolve plastic pollution. The rationality of microbial degradation in terms of environmental safety, impact of plastic on environment and life, mechanism of biodegradation of natural and synthetic plastic are focused in this review.

2. Impact Of Plastic On Environment And Life

The environmental pollution caused by plastic is evident from the amount of plastic that has accumulated in environment. According to estimates around 10% of global municipal waste is plastic (Lebreton & Andrady, 2019). Not only environment is polluted, there are health hazard of plastic on wildlife too. One problem is ingestion of plastic by marine life which mistake it as food. According to one report, over 260 species, including turtles, invertebrates, fish, mammals, and seabirds, ingested or became entangled in plastic rubbish (Ivar do Sul and Costa, 2014). Consequently, it impaired their movement and feeding, reduced reproductive output, cuts, ulcers and death too (Thompson, Moore, Saal, & Swan, 2009). There is a potential transfer of plastic and pollutants along the food chain harming humans as well (Santillo et al., 2017).

3. Microbial Biodegradation Of Plastic

Since plastic pollution has become a problem for environment, it has become imperative to resolve this problem. Conventional approaches like incineration, landfills, dumping into oceans are non-sustainable from environmental viewpoint (Abdel-Shafy & Mansour, 2018). So a biotechnological approach is becoming popular now which is biodegradation of plastics using microbes. Biodegradation of plastic through microorganisms is brought about by the enzymatic action of microbes like bacteria, fungi, yeast etc. into metabolites like H2O, CO2, CH4, biomass etc. (Sheel, & Pant, 2018).

4. Mechanism Of Biodegradation Of Plastic By Microorganisms

Microbes degrade synthetic and natural plastics through enzymatic hydrolysis, where they secrete extracellular enzymes (Shah et al. 2014). The biodegradation could be through aerobic process on anaerobic depending on environmental factors and type of microbe (Gu, 2003). The process of microbial biodegradation initiates with the attack of microbe towards plastic (Shah, Hasan, Hameed & Ahmed, 2008). Then the plastic is converted into monomers through different enzymes, converting them into water-soluble and membrane permeable molecules. This process is called as depolymerization (Alshehrei, 2017). The mechanism of biodegradation of plastic involves bio-deterioration, bio-fragmentation, assimilation and mineralization. Firstly, the microorganism attach to the plastic surface, alters its physical and chemical properties, followed by polymer breakdown (bio-fragmentation) through enzymatic cleavage. Various hydrolyses enzymes such as proteases, ureases, esterases or proteases catalyze the break-down of different bonds of polymer (Loredo-Treviño, Gutiérrez-Sánchez, Rodríguez-Herrera & Aguilar, 2011). Through assimilation the fragmented polymer is taken-up by microbes which is mineralized into CO2, H2O, CH4, etc. (Tokiwa et al. 2009; Singh and Sharma 2008).

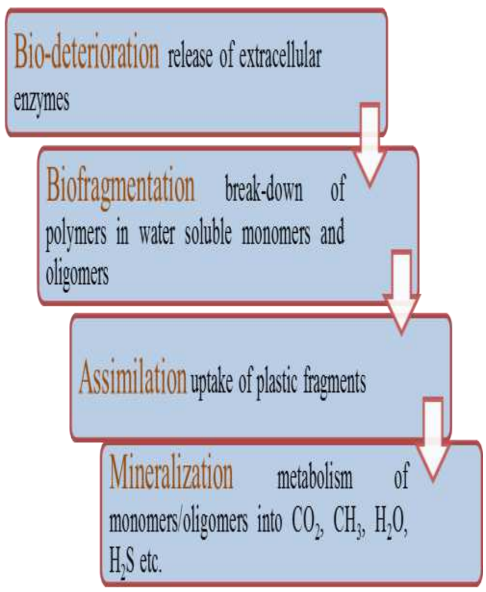

Figure 1. The process of biodegradation by microorganisms

5. Factors Affecting Biodegradation Of Plastic

The major factors that affect the process of microbial biodegradation depends on polymer characteristics and environmental conditions. Polymer characteristic includes morphology, functional group, flexibility, additives, molecular weight, cross-linking, co-polymers, crystalline structure, and blend (Varjani & Upasani, 2017). Whereas, exposure conditions such as pH, temperature, moisture, UV radiations, bio-surfactants, hydrophobicity and enzymes determines microbial activity (Kijchavengkul, & Auras, 2008).

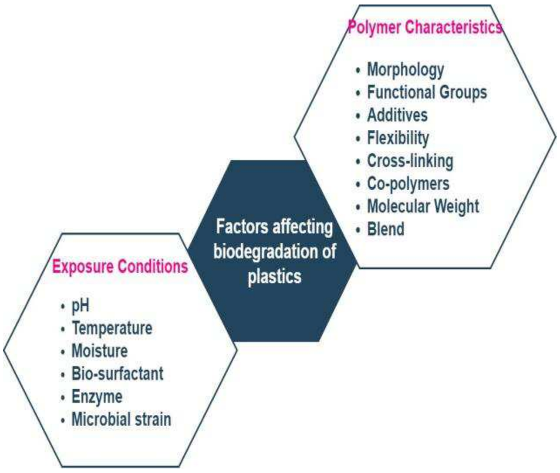

Figure 2. Factors affecting the process of biodegradation of plastics by microorganism

6. Biodegradation Of Synthetic Plastic By Microorganisms

Different microbial strains are capable of degrading different types of plastic like *Brevibacillus spp., Bacillus spp.* which secrets proteases to degrade polyethylene (Webb, *et al*, 2000). Fungu *A. pullulans* is capable of utilizing polyvinyl chloride (PVC) as a carbon source by secreting esterase enzyme (Sivan, 2011). Polycaprolactone (PCL) which is a synthetic plastic is easily degraded by bacterium *Alcaligenes faecalis* and *Clostridium botulinum* and fungal strain *Fusarium* (Pathak & Navneet, 2017). Polylactic acid (PLA) degradation has been reported by *Bacillus brevis* which is a thermophilic bacteria (Caruso, 2015).

Brevibaccillus borstelensis and *Rhodococcus ruber* have a capacity to degrade the CH2 bonds in polyethylene plastic and use it as a sole carbon source (Hadad, Geresh, & Sivan, 2005).

In one study, the co-relation of UV radiations on biodegradation of Low-Density Polyethylene (LDPE) using *Aspergillus spp.* and *Lysinibacillus spp.* were monitored. The results showed 29.5% rate of biodegradation of UV-irradiated LDPE while 15.8% for non-UV-irradiated films (Esmaeili, 2013).

In one research, researchers screened 250 samples of Polyethylene Terephthalate (PET) plastic contaminated site. They isolated a bacteria *Ideonella sakaiensis* that demonstrated the ability to degrade PET completely after 6 weeks at temperature 30 °C. Two key hydrolases were identified, PETase and METHase which works simultaneously to depolymerize PET. Firstly, PETase break down PET into mono (2-hydroxyehyl) terephthalic acid (MHET), followed by METHase hydrolyzing METH into terephtalic acid and ethylene glycol (Yoshida, 2016).

7. Biodegradation Of Natural (Bio) Plastic

The natural plastic or bio-based plastic is biodegradable and bio-compatible (non-toxic) as well. One class of bioplastic is polyhydroxyalkanoates (PHAs) which are biodegradable polyesters (Shimao, 2011). Polyhydroxy Butyrate (PHB) is one type of bio-plastic which is synthesized by microorganisms in response to physiological stress, like nutrient limitation in order to prevent starvation (Sharma & Dhingra, 2016). The representative species of bacteria capable of degrading PHAs include *Burkholderia, Bacillus, Cupriavidus and Nocardiopsis* (Boyandin et al. 2013).

Lee *et al.* researched on degradation of PHB by 105 fungi isolated from natural habitats and lichens. Out of which 41 fungal strains showed PHB degradation by forming clear zones below and around fungal colonies (Lee, Gimore, & Huss, 2015).

Recently, a new enzyme depolymerase was isolated from *Burkholderia cepacia* DP1which played role in the hydrolysis of PHA. The enzyme was active at pH range 6-10 and temperature 35-55 °C (Azami, 2019).

Another biodegradable bio-plastic is polylactic acid (PLA) which is derived from corn starch, sugarcane or tapioca roots, which is widely used in medicines s (Ikada and Tsuji 2000). *B. licheniformis* and *Amycolatopsis sp* showed the ability to degrade PLA in soil (Fukushima et al. 2009; Anderson & Shive 2012).

8. Conclusions

The importance of plastic in or daily life is immense but the impact it is making on our environment, marine life and health cannot be ignored. Microbial biodegradation has evolved to be effective in reducing the plastic quantity as well as environmental impact. The microbes degrade plastic via metabolic processes into simpler forms. Further, characterization of microbial enzymes at molecular level is required so that process of degradation could be enhanced.

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