Journal of Advanced Zoology
ISSN: 0253-7214
Volume 44 Issue S-5 Year 2023 Page 2606:2610

The importance of microbes in plastics degradation: A sustainable approach A Short Review

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Article History

Received:30/09/2023
Revised:15/10/2023
Accepted:30/10/2023

Abstract

Since the 1950s, plastics have been frequently utilized due to their affordability and durability. The widespread use of plastics poses a great risk to the environment. As plastics are non-degradable and have resistance to moisture, they get piled up in the environment, causing soil and water pollution. Global food chains are suffering due to the heavy use of plastic. Bioremediation is a technique that employs the use of living organisms, like microbes and bacteria, in the removal of contaminants, pollutants, and toxins from soil, water, and other environments. Using microorganisms to break down plastic and turns it into low molecular weight molecules, that are safe for the ecosystem is the most cost-effective and environmentally beneficial way to reduce the amount of plastic in the environment. Microorganisms degrade plastics by secreting metabolites such as polyhydroxyalkanoate depolymerases, which help in plastic breakdown. This review outlines the potential of different bacteria and fungi that can breakdown plastics and explains the general procedure of microbial biodegradation of plastics and also the different types of enzymes used by the microorganisms to degrade plastics.

Keywords: Plastic wastes, Environment, Bioremediation, Plastic degrading microbes.

Introduction:

Non-renewable sources like fossil fuels are used in the production of plastics. Extended carbon chains are bound with both inorganic and organic molecules in plastics. They are bound to hydrogen, sulfur, as well as nitrogen. Plastics are lightweight, affordable, and resistance towards moisture. They are also used in the packaging of various industrial goods (Fazakat & Hashmi, 2020). Plastics are artificial and semi-artificial materials that can be molded into a number of shapes and forms. Some of them are, polyurethane, polytetrafluoroethylene, polyvinyl chloride, polystyrene, polypropylene, polyethylene terephthalate , polyethylene, and polycarbonate. (Anani & Adetunji, 2021). The cumulation and disintegration of plastics is one of the most pervasive and persistent recent alterations to the surface of the planet. Recently, marine plastic trash has been meticulously ranked in accordance with trends in environmental degradation (Barone et al., 2020). Plastics aggregate on Earth's surface since they are unable to break down in the natural environment due to their massive molecular structure, resilience to microbial attack, and strong interactions with aromatic rings and halogen substituents. The soil becomes unproductive for farming because it clogs up the pores in the soil. When animals eat plastic or become entangled in it, they die, resulting in an immense negative impact on the ecology (Fazakat & Hashmi, 2020). Each year, about 350 million to 400 million plastics are been produced, out of which 5-13 million of plastics are thrown into the oceans which causes a negative effect on the marine ecosystem (Srikanth et al., 2022). Every year, the worldwide production of plastics increases by approximately 5% (Fazakat & Hashmi, 2020).

Plastics can be degraded in many ways like Photolysis, Thermal-oxidation and microbial degradation. In Photolysis, plastics are continuously exposed under the UV rays, which in turn breaks the complex polymer structure of plastic and turns its into a simple structure for degradation. In Thermal-oxidation, plastics are exposed to high temperature, but may led to the production of harmful gases. Thus, Biodegradation is the most cost-effective and eco-friendly than other methods. In biodegradation, microorganisms like, fungi and bacteria are used to degrade plastic (Srikanth et al., 2022). More than ninety different genera of microorganisms, including *Bacillus megaterium*, *Pseudomonas sp*., *Azotobacter sp*., *Ralstoniaeutropha sp*., *Halomonas sp*., and so on are used in the degradation of plastics (Fazakat & Hashmi, 2020). Cyanobacteria are also involved in the bioremediation of plastics from the marine bodies. Plastic acts as a carbon source for the microorganisms living in communities (Barone et al., 2020). The enzymes secreted by microorganisms lead to the breakdown of plastic by disassembling polymer chain and turning it into monomers and oligomers. These water-soluble molecules are then taken up by the microorganisms and gets degraded (Fazakat & Hashmi, 2020). The adoption of biodegradable polymers is also the best way for minimizing this plastic pollution. Due to the microbes' capacity to breakdown both organic and inorganic elements including lignin, starch, cellulose, and hemicelluloses, these biodegradable plastics can be broken down easily (Srikanth et al., 2022).

In this review our aim is to discuss about different types of microorganism used to degrade different types of plastics, mechanism of plastics degradation by microbes and factors affecting it, and a variety of microorganism-produced enzymes that have applications in bioremediation.

Types of plastics and their uses: - Every year, there has been a steady increase in the production of plastics due to its heavy utilization in day-to-day life. There are different types of plastics for different purposes. Due to its affordability and anti-corrosion properties plastics have become a part in our daily life. Different types pf plastics we mostly use are (Fazakat & Hashmi, 2020):

High Density Polyethylene (HDPE) which is used to make shopping bags, milk packaging, soap and detergent bottles, and pesticide bottles.

Polyethylene Terephthalate (PET) is mainly used to manufacture packaging material for food products such as fruit and drinks containers.

Low Density Polyethylene (LDPE) is used for the production of shopping bags, sandwich bags, and trashcan liners as well as food storage containers.

Polypropylene (PP) is used in the manufacture of toys, machine parts and food packaging. Clothes and houseware are also manufactured using PP.

Polyvinyl Chloride (PVC) is used in manufacturing medical devices, water pipes and wire & cable insulation.

Polystyrene (PS) is used in biodegradable plates and cups, instrument panels and car parts.

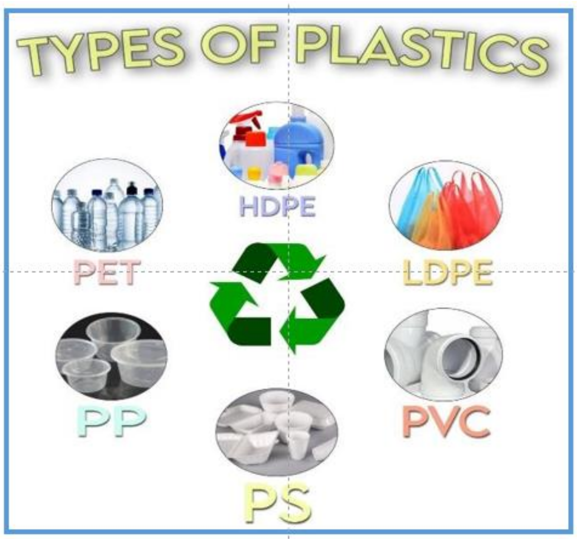

Figure 1. Different types of Plastics.

Mechanism of plastic biodegradation: With the help of bacteria and fungi, plastic can be degraded by changing its chemical composition, color, form, molecular mass, and tensile strength. Plastics can be degraded by enzymatic or non-enzymatic hydrolysis performed by microorganisms like fungi and bacteria. In addition to being partially aerobically (in presence of oxygen) digested in compost or soil, plastics can also be decomposed anaerobically (in absence of oxygen) in landfills or sediments (Fazakat & Hashmi, 2020).

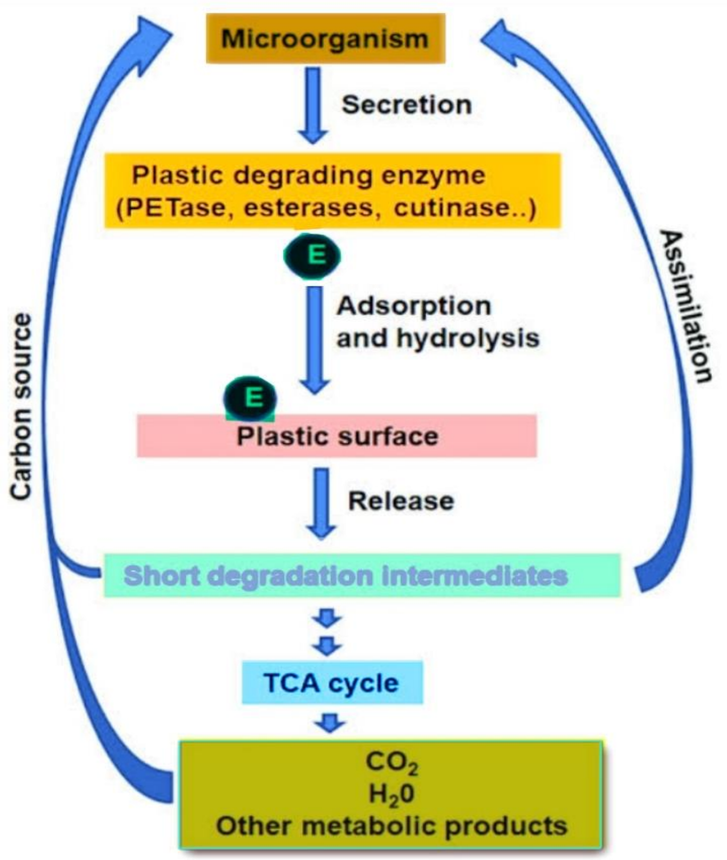

Figure 2. Mechanism pathway of Biodegradation of Plastic.

Aerobic biodegradation: Aerobic biodegradation also known as aerobic degradation occurs in the presence of oxygen. In the process the formation of biofilm is the first stage, during the biofilm production the microbial community gets established on the surface of the plastic. The next stage is depolymerization, in this stage microorganisms secret enzymes which initiates the depolymerization of polymer chains. Here, oxygen acts as an electron acceptor which helps in the depolymerization process. The enzymes Hydrolases and

Oxidoreductases are the main enzymes in this process. These enzymes break down the complex oligomer into water-soluble monomers. These monomers are then absorbed by the microbial cells as a carbon source. The final stage, is mineralization, or final biodegradation, in which the absorbed monomers are used in the metabolic processes of the microorganism, as a result carbon dioxide and water are released as end-products (Bher et al., 2022).

Anaerobic biodegradation: Anaerobic biodegradation also known as anaerobic degradation; it occurs in the absence of oxygen. In the initial stage, the microorganisms produce enzymes which help in the depolymerization of the polymer chains. Anaerobes uses carbon dioxide, sulfate, nitrate, iron and manganese as electron acceptor in this process (Fazakat & Hashmi, 2020). The enzymes digest the large oligomers into smaller water-soluble monomers. The organic addition results in more polymer chain swelling and opening as well as improved quorum sensing. This enhances the microbe's growth and consumption of the polymer chains. Methanogenesis is the last stage in the anaerobic degradation, in which the microbes continue to digest the polymer chains and acetate are converted into methane, which is released as an end-product. Carbon dioxide, water, and biomass are also released as an end-product (Quecholac-Piña et al., 2020).

Factors affecting biodegradation of plastics: There are a number of physical and chemical conditions which negatively influence the plastic degradation. The factors are:
Temperature: Increase in temperature negatively affects the process of biodegradation, high temperature decreases the enzymatic activity of the microorganisms. If the plastic has a high melting point it poses difficulty in the biodegradation process (Fazakat & Hashmi, 2020).
pH: Due to fluctuations in the environment's acidic and basic conditions, pH can also have an impact on the rate of biodegradation. The byproducts of microbial degradation also change the acid/base concentration of the surrounding environment, ultimately impacting on the proliferation of microbes and the pace of degradation (Fazakat & Hashmi, 2020).
Moisture: Due to the need for moisture for the growth and reproduction of microorganisms, the process of biodegradation can be affected by the amount of moisture. Therefore, increasing the moisture can improve the biodegradability (Fazakat & Hashmi, 2020).
Complex structure: In contrast to molecules lacking side chains, compounds containing side chains are more challenging to breakdown (Fazakat & Hashmi, 2020).
Molecular weight: Plastics having high molecular weight require more time degrade than plastic having less molecular weight (Fazakat & Hashmi, 2020).

Enzymes produced by microorganisms for plastic biodegradation: The plastic can be broken down by a number of enzymes that have active sites. Fungi like *Aspergillus flavus* and *Aspergillus niger* produce enzymes which degrade straight chain polyesters. Similarly, degradation pf PHB (Polyhydroxybutyrate) are done extracellular enzymes. Like this there are a number of enzymes which can degrade plastics and those are given below (Srikanth et al., 2022):

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Biodegradation of plastics using various Microorganisms: There are numerous microorganisms including various bacteria and fungus that contribute to the degradation of various plastics. Those microorganisms are as follows (Fazakat & Hashmi, 2020):

Microorganisms	Plastics
Clostridium botulinum	PCL
Pseudomonas putida, *Pseudomonas fluroscens*	PET, Polyethylene, LDPE, and plastics bags.
Aspergillus flavus	PCL and LDPE
Aspergillus niger	PCL and LDPE
Streptomyces spp.	LDPE
Bacillus amyloliquefaciens	LDPE

Conclusion:

We use plastics in our everyday life, because of its durability and cost-effectiveness, but as we can see that the accumulation of plastic in our environment is causing adverse effect to our ecosystem and the organisms living in it. Plastic accumulation not only causing problem in land, but also in seas, oceans, and other water bodies. Land animals as well as marine animals gets trapped into these plastics, and die. Plastic gets blocked in the intestine and gills of marine animals, as a result of which they die. There are various methods through which plastics can be easily degraded, among them the use of microorganism including bacteria and fungi, is the most eco-friendly and cheapest method. Microorganisms can degrade different types of plastics using different kinds of enzymes they secret. Although, not many microorganisms can properly degrade plastics, but research is still going on to enhance the ability of microbes to degrade plastic. Several methods, such mutagenesis, genome engineering, advanced computational modeling, computational genomics are being performed to modify the enzymes for bioremediation of plastics. These can lead to the reduction of plastic wastes from the environment.

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