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# Degradation of Synthesised Plastic-Polystyrene by Micro and Macro Organism

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***Abstract:*** *Polymers with a molecular mass greater than that of synthetic or semi-synthetic organic solids are utilized as industrial inputs to create plastics. Because of the rising usage of plastics and the need to have a capacity for disposing of plastic waste, the need for biodegradable plastics has developed to a significant extent in recent years. The issue with plastics is a result of its non-biodegradability, the closure of landfills, and the worsening issues with land and water contamination. Due to the significant environmental issues that plastics are producing, producers are compelled to create materials that are kinder to the environment. Moreover, the metabolic alterations they undergo and their interaction are crucial. This overview essay has been modified as a result in order to highlight and make an impact on the importance of macro and microorganisms in the biodegradation of polystyrene polymeric compounds. The review talks on the dangers of plastics, how they degrade, and what influences how they degrade. Polymers are broken down by microbes. Degradation of Polystyrene by Bacteria, Fungal, Insects, and Possible Enzymes for Biodegradation of Polystyrene*

**Keywords**: Biodegradation, Microorganisms, polystyrene, bacteria, fungi, insects and degrading enzymes

## 1. INTRODUCTION

Long-chain polymers formed from petrochemical or natural sources like lignin, starch, and biopolymers are regarded as plastics. Presently, plastic is the main hazard in our immediate environment, despite its importance in day-to-day activities. In terms of stability, plastic is leading but very tough to degrade and depolymerize; therefore, it is persistent in the environment and contributes to a variety of hazards (Khan & Majeed, 2019). The yearly production of plastic has increased since 1960 by 8.7 percent, thereby playing an important role in the transformation of the industry into an enterprise with a multibillion-dollar market across the globe (Smith et al., 2018).

Recently, there has been a dramatic increase in the production of plastic, particularly in the past fifteen years. An estimated three hundred and thirty-five million tons of plastic were produced in 2016, while by 2050, twenty-six billion tons of garbage plastic will be manufactured, as predicted statistically, but those that will finally end up in landfills as well as ecospheres will be more than half, resulting in major degradation of the environment (Rodrigues *et al*., 2019; Ru *et al*., 2020).

The metric tons of plastic produced all over the world are close to 300 million each year (Bratovcic, 2019); more than half are utilized at a time, while within a year they are also discarded, but close to ten percent of the plastic waste is accounted for by recycling (Garcia and Robertson, 2017). But the negative impact of plastic utilization is greater than its importance (Bratovcic, 2019). The waste generated is an important environmental problem as a result of its inability to biodegrade, thereby posing a danger to the health of creatures in aquatic and terrestrial environments (Chae and An, 2017). The plastic trash is gradually fractured into microplastics (MPs) or nanoplastics (NPs) through abrasion, mechanical weathering, photolysis, and degradation by microbes, thereby resulting in the ubiquity and environmental persistence of plastic pieces (Hou *et al*., 2021).

Polystyrene (PS) is a general synthesized polymer that is formed from the monomer styrene (vinyl benzene). It's usually applied in the production of food packaging, disposable boxes, laboratory ware, disposable cups, and materials for packaging, while it's also useful in electrical applications (Akere *et al*., 2021). This is attributed to stiffness, lightweightness, and thermal insulation. Extruded (XPS) and expanded polystyrene are the two major varieties of polystyrene, but they both primarily vary in density. The brand name for polystyrene is Styrofoam, and it is a commonly utilized plastic with a yearly production of millions of tons (Machona *et al*., 2022). Slowly, polystyrene fractures into nano-plastics, and this is dangerous to ecosystems and the environment, including biota, while the economy and human health are not left behind**.** The stomach composition of different creatures like turtles, dolphins, whales, earthworms, and birds has been discovered to contain residues of plastic (Meaza *et al*., 2021).

Polystyrene is divided into four different types of products, and this depends on its various applications: general-purpose polystyrene (GPPS), oriented polystyrene (OPS), high-impact polystyrene (HIPS), polystyrene foam, and expanded polystyrene (EPS) foam (Ho et al., 2018)**.** Polystyrene is a very stable polymer with a high molecular weight and a strong hydrophobic property, which is responsible for its being highly resistant to biodegradation (Ho et al., 2018). The polystyrene carbon-carbon backbone specifically plays a vital role in resistance to enzyme cleavage through the processes of oxidation as well as reduction.

There are possible health challenges for humans, provided there is whole-body swallowing of fish and other marine species that consume minimal concentrations of polystyrene**.** Exposure to styrene for a long period of time can cause neurotoxic effects like weariness and nervousness, as well as difficulties sleeping. Hematological situations like low platelets and hemoglobin levels may also occur, while there are also likely occurrences of cytogenetic effects like abnormalities in lymphatic systems, carcinogenic challenges, and chromosomal effects, also known as cytogenetic situations (Machona *et al*., 2022). This review investigates the breakdown of polystyrene by micro and macroorganisms by evaluating the roles of bacteria, fungus, insects, and enymes produced by those microbes in the polystyrene degradation process.

## 2. The Dangers of Plastics

In 2010, approximately 5–13 million plastic tons entered the water, thereby responsible for plastic bits worth trillions floating in the marine ecosystem (Amaral-Zettler *et al*., 2020). Plastics contribute to environmental pollution while also affecting the health of wildlife. The ingestion of plastic by marine organisms that mistakenly take it for food is another challenge. More than two hundred and sixty species, consisting of turtles, fish, invertebrates, seabirds, and mammals, mistakenly ingest litters of plastic with the thought that it is food, thereby causing starvation, feeding impairment, ulcers, body movement impairment, body harm, distortion, and death (Rodrigues *et al*., 2019).

Throughout the plastic production process, plastic is blended with antioxidants and chemical additives (bisphenol A, phthalates, and polybrominated diphenylethers). The aforementioned additives are poorly bonded to these plastic polymers, and this is responsible for their escape after fragmentation of plastic during ingestion or environmental factors, mainly by aquatic creatures. The chemicals mentioned above are dangerous, carcinogenic, and poisonous, while they also disrupt the secretion of endocrine in animals as well as humans (Rodrigues *et al*., 2019). Also, there is a possibility for the emission of dioxins by PVC plastics during production or combustion, and they are known carcinogens and disruptors of the immune and reproductive systems (Chandra, 2015).

As a result of the hydrophobicity characteristics of plastic, they can absorb and also concentrate pollutants like polyaromatic hydrocarbons (PAH), polychlorinated biphenyls, metal ions, organochlorine pesticides, and pharmaceutical products that are then directly or indirectly released in animals that feed on products from plastics (Rodrigues *et al*., 2019)**.** The large concentrations in terrestrial areas find their way into drainage, and with time, they will be responsible for drainage blockage while also causing flooding (Lebreton & Andrady, 2019).

The plastic surface, dubbed the "Plastisphere" by Amaral-Zettler, has offered a home for bacteria. The surfaces of the plastic are colonized by microorganisms, and this result in biofilm formation, which assists other organisms (microalgae, microscopic fungi, plants, and mammals) to flourish. The accumulation of biomass causes bio-fouling of the plastic, which thereby increases some microplastics density and forces them to sink into the pelagic or benthic zones while also altering the habitat of the open ocean and thereby facilitating invading microbe's migration from one area to another (Caruso, 2020). As a result of the large volume of isolation from marine microplastics that affected several species, Vibrio, a bacterium genus, has recently received a lot of interest (Parthasarathy *et al*., 2019).

Microplastics are also discovered in the diet of humans, and this occurs as a result of eating seafood, especially mussels (Reed, 2015). Presently, pollution caused by plastic is a major challenge in our ecosystem, and it is important to urgently address it. Burning, landfill dumping, ocean dumping, and recycling are traditional systems of disposing of them, but they only help with approximately ten percent of the plastic trash generated and are still in need of development. Therefore, it is essential that there be a quick evolution of natural decomposers so as to give room for enzymes that will be helpful in the decomposition of these xenobiotic substances**.** Plastics are broken down and decomposed into metabolic products through the activity of enzymes, and the final substances formed after the activity of microbes have little or no environmental impact (Fesseha & Abebe, 2019; Khan & Majeed, 2019).

## 3. Biodegradation

The process by which microorganisms alter the structure and composition of the chemicals introduces into the environment by metabolic or enzymatic action is regarded as biodegradation (Urbanek *et al*., 2018). The polymers are attacked by microbes through attaching as well as colonizing the surface of the polymer with the formation of biofilm, followed by the secretion of extracellular enzymes and plastic polymer depolymerization to low-weight molecular compounds, microbial uptake, and utilization of low-molecular compounds for growth and inorganic constituent production (mineralization) (Alshehrei, 2017; Fesseha & Abebe, 2019; Zumstein *et al*., 2018).

Through a number of both biotic and abiotic processes, plastic that enters the marine environment is initially divided into microplastics and nanoplastics. A greater surface area is provided for microbial colonization and biofilm production on microplastics as a result of the loss of physical integrity that increases the plastics surface area (Urbanek *et al*., 2018). After fifteen days of contact with the maritime environment, there is a report of plastic bag formation by biofilm. In polyethylene and biodegradable plastic bags deployed in shallow benthic and pelagic habitats, the number of biofilms rose considerably within 33 days (Urbanek *et al*., 2018).

Through a process called de-polymerization, microbes can breakdown plastics containing hydrolysable linkages through the hydrolysis of enzymes. The chain bond of plastic polymers is cleaved by enzymes to form oligomers as well as monomeric units, which are further converted into components that are water-soluble (Montazer *et al*., 2020). The plastic biodegradation process methodology includes biofragmentation, assimilation, biodeterioration, and mineralization, although this process may only apply to polyesters, polyurethanes, and polyamides and not polyolefins like PE, PP, and PS.

The pre-existing environmental conditions have a significant influence on the degradative processes and products produced by these plastic polymers. As microbial biomass, water, and carbon dioxide are produced during biodegradation, aerobic bacteria are principally in charge of this process under aerobic conditions. In anoxic and hypoxic conditions, bacteria play a major role in the decomposition of plastic, generating water, carbon dioxide, methane, and microbial biomass (Shah et al., 2008).

Based on the makeup of the polymer, plastic is categorized as either biodegradable or non-biodegradable. Polylactic acid (PLA) and polyhydroxyalkanoates (PHA), two types of plastic biopolymers, are generated from microorganisms or starch, respectively. Biodegradable polymers include polymer blends like those between polyester and starch or polyvinyl alcohol and starch, respectively. According to Khan and Majeed (2019) and Rana (2019), nonrenewable resources are the source of other biodegradable polymers, including polycaprolactone (PCL) and polyethylene succinate (PES).

The microbial breakdown of biodegradable plastic has been the subject of several reports. Studies on plastics, the majority of which are classified as non-biodegradable, are still ongoing, though. According to Urbanek et al. (2018), polymers mostly derived from nonrenewable energy sources include polyethylene, polypropylene, polyvinyl chloride, polystyrene, polyterephthalate, polyurethane, and polyamides.

### 3.1. Factor affecting plastic biodegradation

Many factors influence polymer breakdown, such as the type of microbe, exposure to environmental conditions, and polymer characteristics (Chandra, 2015). Research has indicated that the degree of biodegradability of a plastic polymer is mainly dictated by its hydrophobicity or hydrophilicity, molecular weight and density, morphology and structural complexity, molecular composition and type of bond, plastic's hardness and physical forms, kinds of additives and plasticizers, and the presence of functional groups (Alshehrei, Yuan et al., 2020).

Significant environmental elements that affect polymer breakdown include UV light, humidity, heat, chemicals, and wave action. These variables either influence the growth and metabolic processes of the residing microorganisms, changing the rate at which the microorganisms degrade, or they seriously damage and age the plastics, weakening their bonds and speeding up the plastics' degradation and bioavailability for degradative microorganisms (Yuan et al., 2020).

## 4. Mechanism of biodegradation

A microbe adhering to the polymer surface, polymer use as a carbon source, and polymer decomposition are the three stages of polymer biodegradation. According to Dansom et al. (2018), microorganisms adhere to polymer surfaces and release enzymes to degrade them, thereby obtaining energy for growth. The breakdown of large polymers produces low molecular weight molecules called monomers and oligomers. Following their internal diffusion, certain oligomers may be absorbed in the habitats of bacteria (Zeenat et al., 2021).

## 5. Bacteria degradation of Polystyrene

There are currently no known enzymes that specifically interact with polystyrene, an aromatic thermoplastic having a C-C backbone. Several microbial strains and a consortia were able to break down polystyrene using it as the only carbon source, despite the fact that its biodegradation rate is slower than that of organic materials (Ho et al., 2018).

Two bacteria that were isolated from mangrove sediments, Bacillus cereus and Bacillus gottheilii, decreased the weight of polystyrene granules by 7.4% and 5.8%, respectively, in less than 40 days (Auta et al., 2017). According to Johnson et al. (2018), Cupriavidus necator H16 converted polystyrene into biodegradable polyhydroxyalkanoates.

Pseudomonas and Bacillus species revealed degrading potential in brominated high impact PS (Mohan et al., 2016). The biodegradation mechanism and relevant enzymes have not been identified, despite the discovery of bacteria capable of biodegrading polystyrene. The process of polystyrene decomposition has not been understood.

## 6. Fungi degradation of Polystyrene

*Cephalosporium sp*. and *Mucor sp*. have been found to be capable of degrading polystyrene. Over half of the polystyrene molecular weight was reduced by the strains of *Gloeophyllum trabeum* DSM 1398 and *Gloeophyllum striatum* DSM 9592. According to Krueger et al. (2015), polystyrene may be depolymerized by the brown rot fungus Gloeophyllum trabeum and the white rot fungi *Pleurotus ostreatus, Phanerochaete chrysosporium*, and *Trametes versicolor* when they were coupled with lignin.

However, Aspergillus sp., Penicillium sp., and Fusarium sp. were identified for their capacity to degrade polystyrene foam (Umamaheswari and Murali, 2013). Hyphae from Curvularia species had adhered to and punctured the polymer's structure (Motta et al., 2009). According to Oviedo-Anchundia et al. (2021) there is also a breakdown of polystyrene by species such as Geomyces and Mortierella. Krueger et al. (2017) found that Gloeophyllum trabeum facilitated the surface oxidation of polystyrene sheets.

## 7. Polystyrene degradation by Insects

Traditional methods of getting rid of used plastic include chemical recycling, landfilling, and burning; however, none of these solutions can solve the fundamental issue of environmental pollution. Gabriel et al. (2019) suggest that biodegradation is a great way to address this issue. Malachová et al. (2020) found that prior studies on the biodegradation of plastic had demonstrated the ability of some bacteria and fungi to break down plastic components.

More and more insect larvae, including Tenebrio molitor L., Galleria mellonella L., Zophobas atratus Fab., Tenebrio obscurus Fab., Plodia interpunctella Htibner, Tribolium castaneum Herbst, Lasioderma serricorne F., Rhyzopertha dominica F., and Sitophilus oryzae L., have been found to be able to consume, degrade, and mineralize plastics in recent years (Lou et al., 2020; Yang et al., 2020; Wang et al., 2020).

In the meantime, insects consume more plastic than bacteria and fungi that have been isolated from trash, sewage sludge, and soil (Peng et al., 2020). Further studies have been conducted on three insect larvae: the superworm (larvae of Zophobas atratus Fab.), the greater wax moth (Galleria mellonella L. larvae), and the yellow mealworm (Tenebrio molitor L. larvae). Our studies and the literature indicate that all three insects have the potential to ingest and degrade PS (Brandon et al., 2021).

By suppressing the gastrointestinal microorganisms of snails, Song et al. (2019) showed that snails are capable of degrading polystyrene on their own. They also showed that there is a connection between gut microbes and the biodegradation of polystyrene by observing the alterations in the gut microbiome following polystyrene consumption. The same is true for beetle larvae; it has been demonstrated that Plesiophthalmus davidis and Uloma sp. can break down polystyrene, but there aren't many reports about how well they can break down polyethylene (Kundungal et al., 2021).

For the past five years, there has been a lot of reporting on the biodegradation of polystyrene foam, also known as Styrofoam. According to Yang et al. (2015a,b), gut microbe suppression studies indicate that polystyrene can be depolymerized and mineralized into $H_2O$ and $CO_2$ by Tenebrio molitor larvae in less than 24 hours. Many investigators have attested to the frequency of gut microbe-dependent polystyrene depolymerization and biodegradation in T. molitor (Yang et al., 2018a, b, 2021). Members of the darkling beetle species, such as Tenebrio obscurus (Peng et al., 2019) and Zophobas atratus (Peng et al., 2020b), have also shown the same pattern of PS biodegradation.

Pseudomonas aeruginosa strain DSM 50071 (Kim et al., 2020) was recovered from Z. atratus, whereas Exiguobacterium sp. strain TY2 was obtained from the intestine of T. molitor larvae (Yang et al., 2015b). The mass reduction rates in the bacterial cultures were significantly slower than those in the larvae's stomach, indicating that the digestive tracts are where synergetic biodegradation takes place. Furthermore, Achatina fulica (Song et al., 2020) and Galleria mellonella larvae (Lou et al., 2020) were found to have a restricted extent pattern of PS depolymerization in their digestive tracts. PS depolymerization in the snails was not inhibited by antibiotic suppression with oxytetracycline, indicating the presence of PS-degrading enzyme(s).

## 8. Potential Polystyrene degrading enzymes

Potential lipases, esterases, and oxidative enzymes that degrade polystyrene have been suggested by several researchers (Przemieniecki et al., 2020). Alkane hydroxylases may disrupt the PS main-chain C-C bonds in acidic or alkaline environments because C-C bonds lose stability in alkaline environments (Xu et al., 2019). Nevertheless, allowing large styrene groups to occupy the active site might prevent the enzyme from breaking C–C bonds.

The gut bacterial population of mealworms (Tenebrio molitor) was found to have increased activity of the enzymes galactosidase, acid phosphatase, glucuronidase, naphthol-AS-BI-phosphohydrolase, leucine arylamidase, and alkaline phosphatase, according to Przemieniecki et al. (2020). According to Yang et al. (2015), there may be PS depolymerase enzyme activity in nature because there are recognized depolymerase enzyme types that work on long-chain alkane groups or polymers with aromatic residues.

Finding the enzymes that possess the functional ability to depolymerize at the gene, amino acid, or DNA sequence level and figuring out the degradation processes and mechanisms involved are the two key obstacles that need to be overcome before PS can be biodegraded effectively. In addition, the monomer styrene produced by PS depolymerization is easily broken down into precursors of the tricarboxylic acid cycle through the styrene catabolism pathways found in a variety of bacteria, such as Pseudomonas, Rhodococcus, Xanthobacter, and Nocardia (Danso et al., 2019).

## 9. CONCLUSION

Plastics play a critical role in providing for our everyday requirements. Owing to its superior quality, its application is constantly growing, and its deterioration is starting to raise serious concerns. A variety of microorganisms are important to the many processes that occur in the natural environment when plastics break down. Future attempts to biodegrade plastic materials will be aided by our understanding of the synergy among those bacteria. The hydrophobic surfaces and high molecular weight of the plastic materials make it difficult for bacteria to form long-lasting biofilms and break them down into tiny molecular oligomers.

Although there are various plastic-degrading technologies on the market, the most widely used, least expensive, and environmentally safe approach uses microorganisms to break down plastic. Through a complicated enzymatic mechanism, the bacterium releases extracellular enzymes to degrade the plastic; however, further research is required. A deeper understanding of the microbial population participating in material attack would be possible with the application of molecular techniques to identify certain groups of bacteria involved in the degradation process. Research should concentrate on genomes and proteomics since there is currently a deficiency in the molecular characterisation of effective plastic-degrading bacteria, which could hasten breakdown.

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