

Plastics: Impact on the Environment, Sources, and Remedial Solutions Using Microbes.

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ABSTRACT

Plastic is one of the most widely used and essential materials worldwide, owing to its stability, durability, lightness, requiring low maintenance, transparency, and being cheap. It is the centre of attention as compared to other known materials. Equipped with a vast number of desired properties, plastic facilitates application in various industries, also used for commercial and agricultural purposes. But most plastics are not degraded easily, and they require many centuries for their complete decomposition. As a result, plastics accumulate rather than decomposing in landfills or naturally. Its disposal is causing significant harm to various ecosystems, namely terrestrial, marine, air, and water. The worldwide plastic production attained 460 million tons in the year 2022 and is expected to double by 2035 and quadruple by 2050. The present article comprehensively summarizes the microorganisms that are able to degrade a variety of generally used synthetic plastics, like polyethene, polystyrene, polypropylene, polyvinyl chloride, polyurethane, and polyethene terephthalate. Bacterial, fungal and algal species offer efficient biodegradation pathways. Despite these developments, the rate of microbial degradation is lower, and the efficiency of microbes strongly depends on factors like the polymer type, physicochemical properties, composition of microbial community, enzyme activity, and factors like salinity, temperature, pH, etc. The development of extensible, cheaper techniques for building bioplastics and increasing the potential of microbes will prove to be helpful for the wider utilization of this technique in overcoming pollution caused by microplastics. Researchers in various fields, like synthetic chemists, process engineers, and microbiologists, should work collectively to create a more sustainable society by generating environmentally friendly polymers.

Keywords: Environment, microorganisms, synthetic plastics, biodegradable, environment-friendly, durable.

1. INTRODUCTION

Plastics are extensively used all over the globe due to their beneficial properties, namely being versatile, transparent, light in weight, durable, resistant to chemicals and serving as an integral part of human life [1, 2]. Due to their unique qualities, they are used in various applications, like packaging, home goods, automobile parts, shopping bags, and wrappers, etc. But it is due to these properties that they have become the maximum contributors to environmental degradation [3-9]. The disposal of it is causing remarkable harm to varied ecosystems, namely, terrestrial, marine, air, and water. The worldwide plastic production reached 460 million tons in 2022 and is expected to double by 2035 and quadruple by 2050 [10]. 18% of global plastic is produced in Europe, North America (19%), China produces about 28% of the total global plastic, the rest of Asia (21%), Africa (7%), and Latin America (4%) [11]. In the human body, the entry

of these conventional plastics/microplastics (fragments of plastic with dimensions less than 5 mm) occurs via inhalation, ingestion, and skin contact [12]. Plastics remain persistent in the environment due to their resistance to degradation and the presence of different types of chemical additives. Additives, namely flame retardants, UV stabilizers, and plasticizers although enhance the properties of plastics but at the same time increase their persistence in the ecosystem and their toxicity [13]. Exposure for a long time can have detrimental effects on DNA of human beings, and there is an increase in the tendency of chronic diseases like cancer and infertility [14]. During 1950-2018, around 6.3 billion tonnes of plastic have been produced worldwide, out of which only 9% and 12% have been recycled and incinerated [15].

Conventional plastics are polymers of repeating monomers mainly derived from petrochemicals. Commonly used plastics are polyethene, polypropylene, polyvinyl chloride, polystyrene, polyethene terephthalate, and polyurethane [16]. Low-density polyethene and bioplastics such as PLAs and PHAs are extensively used in plastic bags, while conventional plastics like PET are extensively used in the textile industry and as food packaging. There is a quicker accumulation of one-time use plastic waste, used mainly for packaging of food and drink products, than waste from costlier items like laptops, televisions, and automotive parts [17].

Due to excessive production of plastic, in 1950, 2 million tonnes were produced, which has increased to 400 million tonnes in the year 2022, resulting in pollution of the environment and contamination [18-20]. Although there is advancement in recycling techniques and adoption of circular strategies, to date, there is not much reduction in plastic waste being landfilled, incinerated, or discarded as such into the atmosphere, which, in turn, causes degradation of aquatic ecosystems [21-23].

After they enter the environment, they undergo various physical, chemical, and biological transformations that ultimately break them into microplastics [24, 25]. These microplastics are prevalent in all marine ecosystems, including groundwater [26, 27], wetlands [28], rivers and lakes [29], seas and oceans [30], and even in glaciers [31].

Due to their persistent nature, smaller size, and tendency to adsorb and transport toxic substances [32], the existence of microplastics is a cause of concern. Despite increasing awareness in public and political attention, most of the waste from plastic is still not being properly recycled [33]. In 2019, around 22% of plastic was not managed properly or directly released into the environment [34].

Having a high surface area and hydrophobicity [35, 36], microplastics can also transport other pollutants, like heavy metals and prevalent organic pollutants. The presence of plasticizers in them causes an increase in their surface hydrophilicity and affects biofilm formation [37, 38]. As a result, two items that are prepared from the same starting polymeric material may degrade at different rates due to the presence of different additives and environmental exposure.

In the past few decades, bioplastics have often been used as eco-friendly alternatives to synthetic plastics. However, their degradability in aquatic systems is not sufficiently understood and is frequently overstated in the public domain [39, 40]. While bioplastics are generally biodegradable, this does not hold universally, as the presence of additives and composite formulations can change their degradation potential and cause ecotoxicological risks, mainly when these materials release non-polymeric materials during breakdown. Apart from that, bioplastics currently face economic and technical constraints related to production scalability and high costs, which restrict their widespread acceptance. So, there is a need for clearer communication, regulatory alignment, and further material optimization so that bioplastics can be accepted globally.

More attention should be given to the degradation processes that generate MPs and not on the documentation of microplastics and their environmental impacts. In recent times, chemical and thermal degradation techniques have been used for microplastic degradation. However, these techniques are associated with various disadvantages, like being costly, less efficient, and the production of toxic by-products [41-43].

Biodegradation by microorganisms, such as bacteria, fungi, and microalgae, mainly leads to the breakdown of the polymer into oligomers, dimers, and monomers, as well as CO₂ and H₂O [44]. Compared to physical and chemical degradation, microbial degradation is cost-effective, environmentally friendly, and sustainable. In terms of “green” initiatives, it holds great potential for its widespread application [45]. Highly efficient strains of bacteria are being utilized in degrading MPs and are known to occur in diverse habitats, namely, municipal landfills, polluted soil, sludge, mangroves, marine sediments, wastewater, compost, and regions under extreme climates [46-47]. *Sporosarcina globispora* and *Bacillus cereus* isolates from mangrove sediments have been identified as efficient candidates for PP degradation [48]. Bacterial strains, namely *Pseudomonas aeruginosa*, *Bacillus megaterium*, and *Rhodococcus ruber*, tend to degrade thermoplastics PE and PET [49].

Fungal strains like *Penicillium chrysogenum*, *Fusarium solani*, *Aspergillus tubingensis*, *Aspergillus fumigatus*, *Pestalotiopsis microspore* *Cladosporium*, and *pseudocladosporioides* demonstrated degradation potential for polyurethane [50]. *Rhizopus arrhizus* and *Aspergillus niger* have shown biodegradation towards polypropylene, on the other hand, *Humicola insolens* and *Penicillium* sp. are effective in causing degradation of polyethylene terephthalate [51].

Algae species are highly potent candidates for the biodegradation of polymers and mainly for MPs degradation. Microalgae make use of CO₂ from the atmosphere for growth and live well under photoautotrophic conditions [52]. Microalgae show their tendency for degradation of polymers using their toxins and enzymes; they can survive under different environments and require only limited carbon sources [53-54].

Microorganisms can cause break down of MPs. Bacteria, algae and fungi, use precise metabolic pathways to degrade MPs [55-57]. Degradation processes involve enzymes that are produced by these microorganisms. Certain bacterial species cause hydrolysis of plastic polymers into smaller biodegradable components [58-59] by releasing extracellular enzymes. Algal species initiate the breakdown of synthetic plastics by secreting specific oxidative enzymes. Fungi secrete ligninolytic enzymes for the degradation of different types of plastics [60]. In the same way, bacterial species produce hydrolases, like esterases and lipases, which break down bonds in plastics into simpler monomers [61, 62]. Microplastic biodegradation is still in its infancy, and a few plastic-degrading microorganisms and enzymes have been discovered to date. There are a few comprehensive reviews reported in this field [63-68]. Some important research has been done in the past two years [69-80] and more sincere efforts are further required in this direction for efficient degradation of plastics involving microbes.

CONCLUSION

Plastics are considered one of the most important materials in our lives, with unique properties, such as being cheap, chemically versatile, and durable. Being widely used, however, due to improper waste management and a low recycling rate, has caused the amassing and degradation of the environment and has become a significant threat to human health. To reduce global plastic pollution, coordination among

nations is the need of the hour to reduce plastic consumption, increase rates of reuse, collection of waste, and efficient recycling, and introduce safe disposal systems.

Apart from that, biodegradation involving microbes is coming up as a promising, sustainable approach for overcoming plastic pollution. Bacterial, fungal and algal species offer efficient biodegradation pathways. Despite these developments, the rate of microbial degradation is lower, and the efficiency of microbes strongly depends on factors like the polymer type, physicochemical properties, composition of microbial community, enzyme activity, and factors like salinity, temperature, pH, etc. The development of extensible, cheaper techniques for building bioplastics and increasing the potential of microbes will prove to be helpful for the wider utilization of this technique in overcoming pollution caused by microplastics.

FUTURE PROSPECTS

To overcome the difficulties in the disposal of plastic waste, one of the most eco-friendly and safe ways is to utilize bioplastics in packaging items, health industry, agriculture, in therapeutics and fishery material. Presently, synthetic plastics are a great danger to the environment, mainly due to the lack of good waste management strategies and clutter control. Further, stress should be given to their biodegradation and recycling in a balanced way to make their reuse possible. There exists a great need to develop new microbes for the degradation of synthetic polymers. Researchers in various fields, like synthetic chemists, process engineers, and microbiologists, should work collectively to create a more sustainable society by generating environmentally friendly polymers.

LIST OF ABBREVIATIONS:

Polyethylene (PE)
Polypropylene (PP)
Polyvinyl chloride (PVC)
Polystyrene (PS)
Polyethylene terephthalate (PET)
Polyurethane (PU)
Low-density polyethylene (LDPE)
Polylactic Acid (PLA)
Polyhydroxyalkanoates (PHAs)
Microplastic (MP)

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