



Plastic Degrading Microbes: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author BS designed the paper, made literature searches, author SAS wrote first draft of the manuscript and author OKR made review and corrected. All authors read and approved the final manuscript.

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ABSTRACT

Plastic accumulation is the vital cause of environmental pollution and is an ever-increasing ecological threat. The sustainable use of synthetic polymers is one of the major challenges of the twenty-first century. The conventional techniques employed to degrade plastic in the environment are inadequate as it releases harmful by-products. One of the solutions for reducing the plastic pollution is biodegradation of plastic by using microorganisms. In the present review, we have analysed the potential of plastic degrading microbes reported by different investigators.

Keywords: Plastic; biodegradation; bacteria; fungi; actinomycetes.

1. INTRODUCTION

Plastic is a synthetic material made up of elements extracted from the fossil fuel resources which has several valuable uses. During the 19th and 20th centuries, most of the industrial and technological revolutions are made possible due

to the plastic. Over the span of 30 years, usage of plastic materials (polybutylene terephthalate (PBT), polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyurethane (PUR)) is invariably seen in industries belonging to food, clothing, shelter, transportation, medical and construction, since

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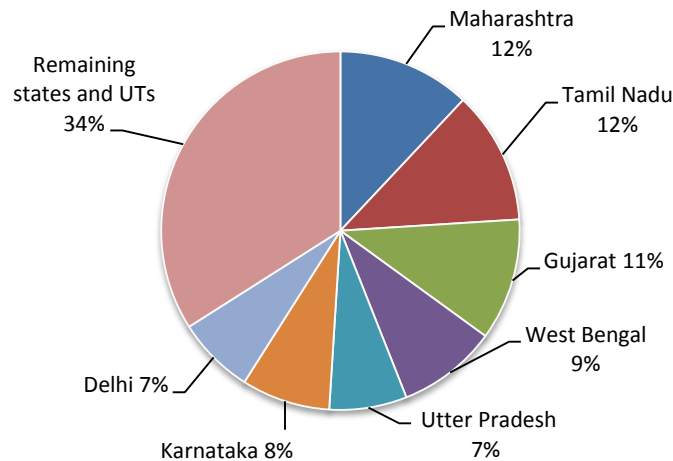


Fig. 1. States contributing to total plastic waste generation in India

Source: Central Pollution Control Board, Annual Report (2018-19)

they are of lightweight, low in cost, durable and unbreakable [1]. It is estimated that all over the world, annual waste generation due to plastic is about 57 million tons [2].

Low density polyethylene (LDPE) is one of the major sources of environmental pollution. Polyethylene is a polymer formed by long chain ethylene monomers. The utility of polyethylene is expanding worldwide at a rate of 12% per annum and each year synthetic polymers are produced approximately 140 million tonnes (MT). Since, large amount of polyethylene is getting accumulated in the environment, their disposal evokes a major ecological issue.

In India, with the ever-increasing population and urbanization, waste management has become a major challenge. Approximately 65 MT of municipal solid wastes (MSW) are produced per year, which includes plastic, organic waste, wood, paper, glass, etc. Plastic waste contributes 5% of municipal waste generating as much as 3.3 million metric tonnes annually [3]. Of the total plastic production, LDPE accounts for 60 per cent, and the polythene carry bags which are non-degradable are the most commonly found solid waste. The extensive use of shopping bags (made of polythene) by the public is become an ever-increasing environmental issue in India. The municipal and garbage sites are mostly dumped with greater quantity of this waste material which is highly recalcitrant. In India, the states majorly contributing to total plastic waste generation are Maharashtra Tamilnadu, Gujarat, West Bengal, Uttar Pradesh, Karnataka and Delhi as shown in the Fig. 1.

Plastic pollution in soil poses a serious threat to human, plant and animal life, since very small amount of the discarded plastic is treated in waste facilities, larger quantities are reaching landfills where in the decomposition process lasts up to 1000 years, and during this period the toxic chemicals gets absorbed in the soil and water sources making them unfit for sustainable use.

2. DEGRADATION OF PLASTIC

Plastic degradation involves various treatments of physical, chemical and biological factors. Physical factors involve heat and radiations, chemical factors include acids and alkalis and biological factors are using microbes like bacteria, fungi and actinomycetes. Based on the nature of the causative agents, degradation of polymer is classified as thermal degradation, photo-oxidative degradation, mechano-chemical degradation, catalytic degradation, ozone-induced degradation, and biodegradation [4]. The conventional techniques employed to degrade plastic in the environment are inadequate as it releases harmful by-products.

The most abundant plastic waste materials discarded in landfills are the plastic bags (69.13%) which are made up of low density polyethylene (LDPE) [5]. LDPE is amorphous in nature (10-30 methyl (CH₃) groups per 1000 C atoms) and composed of butene, hexene, and octene. The branching system in LDPE chains makes more accessible and susceptible to attack due to the presence of more tertiary carbon atoms at the branch sites. In LDPE material, the

physical arrangement of the polymer chains and the vinylidene content have shown to be directly related with the polymer oxidation which makes it more biodegradable [5].

3. MICROBES AND THEIR ROLE IN PLASTIC BIO-DEGRADATION

Microbes are omnipresent in biosphere, and their presence influence the environment in which they grow. The effects of microbes on their environment can be beneficial or harmful. The most important role of the microbes on earth is their ability to decompose the organic matter and recycle the primary elements (carbon (C), oxygen (O), and nitrogen (N)) that make up all living systems.

Plastic biodegradation is breakdown of complex polymer into simpler monomers which depends on various factors like morphology, substrate availability, molecular weight of the polymers and surface characteristics [6,7,8]. The microbial role is very crucial in degradation of plastic and different microorganisms degrade different plastic groups. A scientific study revealed that in mangrove soil, some of the microorganisms have potential to degrade plastic [9]. Works on LDPE found that bacterial isolates of *Bacillus* and fungal isolate of *Aspergillus* sp. were the highest degraders [10]. Similar studies have also been reported by various investigators [11,12,13,14,15] as shown in Table 1.

The natural and synthetic plastics are associated with/degraded by microorganisms like bacteria, fungi, actinomycetes and *saccharomonospora*. The seventeen genera of bacteria and nine genera of fungi are found to degrade plastic [20,21,22].

3.1 Bacteria

The isolates of bacteria found to be involved in plastic degradation are *Azotobacter* sp, *Bacillus megaterium*, , *Ralstonia eutropha*, *Pseudomonas* sp., *Halomonas* sp. [22], *B. brevis* [23], *A. delafieldii* [24], *P. amyloiticus* [25], *B. pumilus* [26], *B. petrii* [27], *P.aeruginosa* [28], *Shewanella* sp. [29]. Further, *Bacillus brevis*, a thermophilic bacterium, has been isolated from soil with Poly Lactic Acid-degrading properties.

Studies on bacterial degradation of polyethylene have revealed the potential of *Arthrobacter* sp., *Acinetobacter baumannii*, *A. Viscosus* sp., *Bacillus amyloliquefaciens*, *Pseudomonas* sp., *B. Thuringiensis*, *Cereus, pumilus*, *Mycoides*, *Staphylococcus cohnii*, *Pseudomonas fluorescens*, *Xylosus* sp., *Micrococcus luteus*, *M. Lylae*, *Rahnella aquatills*, *Flavobacterium* sp., *Paenibacillus macerans*, *Ralstonia* sp., *Delftia acidovorans*, *R. erythropolis*, *P. aeruginosa* [30] and *B. brevies* [31] in plastic biodegradation. The bacterial species identified from the polythene bag samples were *Bacillus*

Table 1. Efficiency of microbes in plastic degradation

Microbes	Plastic type	Microbial Source	Efficiency of Degradation (%)	References
<i>Bacillus cereus</i>	Polyethylene (PE)	Dumping Soil	2.40-7.20	[16]
<i>Pseudomonas putida</i>	Milk Cover	Garden Soil	75.30	[17]
<i>Streptomyces</i> sp	LDPE	Garbage Soil	46.70	[11]
		Dumpsite	46.20 and 29.10	[18]
		Sludge Sewage		
		Household	31.40 and 16.30	[18]
	Natural and Synthetic	Garbage Dumpsite		
<i>Pseudomonas</i> sp	Polyethylene	Textile Effluent Drainage Site	39.70 and 19.60	[18]
	Plastic and Polythene	Mangrove Soils	20.54 and 8.16	[9]
<i>Aspergillus glaucus</i>	Plastic and Polythene	Mangrove Soils	20.80 and 7.26	[9]
<i>Micrococcus luteus</i>	Plastic Cups	Forest Soils	38.00	[19]
<i>Masoniella</i> sp	Plastic Cups	Forest Soils	27.40	[19]

sp., *Diplococcus* sp., *Pseudomonas* sp., *Streptococcus* sp., *Staphylococcus* sp., *Micrococcus* sp., and *Moraxella* sp. The bacterial species of *B. cereus* and *S. globispora* isolated from sediments of mangroves in Malaysia were able to grow on media infused with polypropylene which showed degradation potential of 12% and 11% respectively in 40 days by weight loss method [32].

3.2 Fungi

In recent years fungal strains like *Aspergillus versicolor*, *A. flavus* [33], *Chaetomium* sp. [34], *Mucor circinellodis* sp., have been reported for plastic degradation. The predominant fungal species identified in degradation of polythene bags are *A. niger*, *A. cremeus*, *A. nidulans*, *A. ornatus*, *A. candidus*, *A. glaucus* and *A. flavus* [9].

Many studies on plastic degradation by fungal species have reported the species of *P. lilacinus* [35], *F. moniliforme* [36], *A. flavus* [37], *T. aurantiacus* [38], *P. verrucosum*, *T. album*, [39] and *Aspergillus* sp. [40]. Further, the two genera of *Penicillium roqueforti* and *Tritirachium album* are known to degrade polylactic acid (PLA). It was reported [41] that PVC is degraded by *A.niger*, polyesters and polyhydroxybutyrates (PHBs) are subjected to degradation by various fungal genera like *Acremonium*, *Mucor*, *Cladosporium*, *Debaryomyces*, *Paecilomyces*, *Fusarium*, *Pullularia*, *Emericellopsis*, *Eupenicillium*, *Penicillium*, *Verticillium* and *Rhodospiridium*. Polycaprolactone (PCL) and Polyesteracetals (PEA) are degraded by *Aureobasidium*, *Aspergillus*, *Cryptococcus*, *Chaetomium*, *Rhizopus*, *Fusarium*, *Thermoascus* and *Penicillium*. Fungi like *Aspergillus terreus*, *Aspergillus flavus*, *Alternaria solani*, *Aspergillus fumigates* and *Spicaria* sp., have been isolated from plastic dumped soil [42].

3.3 Actinomycetes

Actinomycetes found to degrade polylactic acid (PLA). A strain of *Amycolatopsis* sp. has shown to reduce 60% of the PLA film (100mg) in liquid culture at 30°C after 14 days. There are several actinomycetes species known to degrade Polybutylene succinate (PBS), PCL and PLA viz., *Amycolatopsis* sp. [43], *Amycolatopsis* sp. [44], *Saccharothrix* [45], *Kibdelosporangium aridum*, *Actinomadura keratinilytica* [46], *Amycolatopsis thailandensis* [47], *Streptomyces*

bangladeshensis [48], *Streptomyces thermoviolaceus* subsp. *Thermoviolaceus* [49].

4. MECHANISM OF BIO-DEGRADATION

Bio-degradation of plastics is brought about by the activity of the microbial enzymes through cleavage of polymer chain into monomers and oligomers, which are water soluble and get easily absorbed and metabolized by the microbial cells. Biodegradation method of polymers is classified with the use of microbes and enzymes [50].

The polythene degradation starts with the microbial attachment to its surface. Several wood degrading fungi and actinobacteria (*Streptomyces badius*, *Streptomyces setonii*, *Streptomyces viridosporus*) are found to produce extracellular enzymes (peroxidases, lactase and oxidases) which lead to degradation of polythene [51]. Various microorganisms produce degrading enzymes [52] that detect polymers as a main source of the organic compound [53]. The ability of the species of *Aspergillus* and *Pseudomonas* isolated from plastic dumped site to degrade low density polyethylene was studied by SEM and FTIR analysis which revealed that the polythene degraded by fungi has become fragile and its surface has porosity. This infers that the fungus adhering to the inert surface of polythene and utilizing polythene as the sole source of carbon and energy, which is why the decreasing weight of LDPE films is observed [51].

Further, the qualitative and quantitative analysis methods for biodegradation include zone of clearance method, weight loss method, Fourier transform infra-red spectrometer (FTIR) and scanning electron microscopy (SEM) analysis which are analysed by broad-range of parameters such as substrate weight loss, polymer chemical structure, variations in the mechanical properties and the percentage emission of carbondioxide [54].

6. CONCLUSION

The polluted environment containing plastic wastes can be cleaned easily with the inclusion of microbes without causing any detrimental effect to the environment. Plastic biodegradation is an eco-friendly, beneficial and also cost effective approach for plastic waste management. However, there are no reports on any practical application of microbes for plastic degradation at field conditions. Hence, more studies may be taken up for bringing out a

package of practise for efficient management of plastic pollution. In this direction, Environmental Management and Policy Research Institute (EMPRI) has initiated research studies to screen the microbes from various sources to formulate a microbial product for plastic biodegradation.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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