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Role of Microorganisms in the Biodegradation of Plastics

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Abstract— The abundant growing accumulation of plastic wastes has become a severe environmental and social issue. As plastic remains in the environment for decades and centuries, it is very important to develop innovative approaches for the disposal of plastic wastes. Much of the recent research is mainly focussed on the identification of microorganisms and microbial enzymes that can degrade plastic waste. This probably offers new biological treatment strategies for plastic degradation. The current review mainly discusses the role of various microorganisms in the biodegradation of plastics.

Key words: Plastic waste, environmental issues, plastic degradation, microorganisms

INTRODUCTION

Plastic is the most versatile synthetic 'manmade' substance created out of the fossil fuel resources that enabled most of the industrial and technological revolutions of the 19th and 20th centuries. About 8300 million metric tons of plastic were produced throughout the world of which 79% of this production is accumulated in the environment [1]. According to some authors, it is estimated that an accumulation of about 12,000 Mt will be in landfills or in the natural environment by 2050 which represents an annual accumulation of ~339 Mt [1]. The development of an efficient degradation process is the need of the hour to avoid this huge annual accumulation.

The indiscriminate usage of polythene (as shopping bags) by the people is becoming an environmental problem. 60% of the total plastic production accounts for LDPE (Low–density polyethylene) and non-biodegradable polythene carry bags are the most widely found solid wastes in municipal and garbage sites. Plastic materials owing to their widespread applications in a variety of sectors *viz.*, clothing, food, constructions, medical, and transportation, etc have gained enormous importance during the last 25 years [2, 3]. This could be due to their low cost, less weight, unbreakable nature, and extreme durability [2, 3]. Petroleum-based materials (polypropylene and polythene) are the main constituents of the plastics. These materials called resins exhibit high resistance to

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degradation and hence remain years together in their original form in landfills [3]. Production of plastics has grown significantly in the last 3 decades averaging 10% annual growth rate. A general estimate of worldwide plastic waste generation is annually about 57 million tons [3]. Plastic materials however, have several disadvantages, the most important one being that they do not breakdown and hence accumulate in the environment. Due to their buoyancy, long-term persistence, and ubiquity in the marine environment, plastic waste poses a variety of hazards to marine life also [4]. **Table 1** shows the uses of different synthetic plastics.

Table 1 Uses of various synthetic plastics [5]

Plastic	Use
Polyethylene	Polyethylene is used in food packing films, milk and water bottles, toys, plastic bags, irrigation and drainage pipes, motor oil bottles and so on.
Polypropylen e	The use of polypropylene is mostly in manufacturing of car batteries, drinking straws, medicine bottles, bottle caps, bumpers, disposable syringes, carpet backings, car seats.
Polycarbonate	Polycarbonate is mainly used in making of lens in glasses. It is also used in making of sunrooms and verandas, roofs of green houses, sky lights. It can also be used in making street lights, lights of cars, nozzles on paper making machinery, safty visors, baby bottles and house wear.
Polyvinyl chloride	This is mostly used in electricity pipes, shoe soles, garden hoses, automobile shoe covers, shower curtains, visors, bottles, rain coats and so on.
Nylon	Football helmets, windshield wipers, water hose nozzles, small bearings, racehorse shoes, speedometer gears, ink, rain wear, cellophane, parachute fabrics are manufactured with Nylon or Polyamides
Polystyrene	Polystyrene is mostly used in packing materials, laboratory ware, disposal cups , also in certain electronic.
Polytetra flouro ethylene (PTFE)	PTFE is used in coating on non-stick kitchen utensils, such as saucepans and frying pans. PTFE is used in various industrial applications such as electronics and bearings and also in specialized chemical plant.
Polyethylene terephthalate (PET)	PET is used in pillow and sleeping bag filling, peanut butter jars, carbonated soft drinking bottles, textile fibers, processed meat packets.

The Public also have gained enough knowledge regarding the undegradable nature of discarded plastic waste and their environmental concerns. Discarded plastics, besides being highly visible are a rapidly increasing percentage of solid waste in landfills, resistant to biodegradation leading to pollution, which is harmful to the natural environment [3]. Scientists are focussing their attention on finding out remedies towards the undegradable nature of plastics and found that microorganisms play an immense role in the biodegradation of plastics owing to their ability to degrade organic and inorganic material [3]. Microorganisms produce certain extracellular enzymes and thereby breakdown complex polymers into simpler molecules to further use them as carbon and energy sources [6-8] Kambe et al. (1999) [9] have studied that a bacterium isolated from soil can make use of polyester polyurethane to meet its carbon and nitrogen requirements. The potentiality of microbes in plastic degradation can be attributed to their ability to hydrolyze ester bonds by producing specific enzymes called esterases [9]. A bacterium, *Comamonas acidovorans* TB-35 degraded plastics by producing enzymes called PUR esterases (polyester-poly urethane degrading enzyme. Another bacterium, *Alcaligenes faecalis* was studied for its ability to produce polycaprolactone depolymerase, an enzyme capable of degrading polycaprolactone (PCL) [10]. Webb et al. (2000) [11] have studied the fungal colonization and biodeterioration of plasticized polyvinyl chloride in *in-situ* and *ex-situ* conditions and suggested that microbial succession may occur during the long periods of exposure in *in-situ* conditions. The authors have also identified *Aureobasidium pullulans*, fungi, some yeast, and some yeast-like fungi such as *Kluyveromyces* spp *and Rhodotorula aurantica*. The Incidence of marine and mangrove bacteria accumulating polyhydroxy-alkanoates on the mid-west coast of India has been reported by Rawte et al. (2002) [12]. Rohindra et al. (2003) [13] have studied the microbial degradation of PCL (polycaprolactone)- PUB (poly vinyl butyral) blends. Kathiresan (2003) [14] has revealed that the high diversity of microorganisms in mangrove soil is capable of degrading plastics, although at a slower rate.

Unless if it is petroleum-derived synthetic polymer the remaining biodegradable plastic polymers when discarded in the environment can be degraded by non-biological and biological processes. Polyethylene can be exposed to ultraviolet light, thermal heating, and treatment with acidic or basic substances as initiators or by photo-oxidation.

Microorganisms in the Biodegradation of plastics

There are many microorganisms (especially of bacterial and fungal origin) that have a mechanism to degrade large and complicated hydrocarbons into simpler biomolecules. They are in particular Gram-positive and Gram-negative as well as a few species of fungal origin like *Aspergillus* species. Other species of microbes like *Streptococcus*, *Staphylococcus*, *Micrococcus* (Gram-negative), *Moraxella* and *Pseudomonas* (Gram-positive) and species of fungi (*Aspergillus glaucus* and *Aspergillus niger*) are also involved in the biodegradation system [14]. In addition, *Bacillus megaterium*, *Ralstonia eutropha*, *Azotobacter*, *Halomonas* species are involved in the breakdown method [15]. Raaman et al. (2013) [16] studied the ability of fungi in plastic degradation (commercial polythene carry bags of low-density polyethylene (LDPE)) by isolating and identifying fungi from polythene pollution sites around Chennai. They found that *Aspergillus japonicus* exhibited a degradation potential of 11% while that of *Aspergillus niger* 5.8%. Russell et al. (2011) [17] reported the ability of

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endophytic fungi in the degradation of polyester polyurethane (PUR), a synthetic polymer. Endophytes are microorganisms living in inner plant tissues and play important role in the decomposition of plants after the death of host tissue. These endophytic fungi are also able to degrade complex lignocellulose polymers suggesting that these organisms should be screened for their ability to degrade plastic which is also a complex polymer [17]. Two *Aspergillus* species (*Aspergillus japonicus* and *Aspergillus terreus*) isolated from mangrove soil of Niger delta were studied for their ability to degrade LDPE (Low-density polyethylene) and HDPE (high-density polyethylene) films [18]. These organisms are also capable of utilizing the degraded plastic as a carbon source. **Table 2** shows the list of some plastic degrading microbes.

Table 2 Plastic degrading microorganisms

Microorganism	Polymer degraded	Reference
Alcaligenes faecalis	Polycaprolactone (PCL)	[10]
Thermomonspora fusca	BTA-co-polyester	[19]
Aureobasidium pullulans	Dioctyl adipate (DOA) Plasticized Polyvinyl chloride	[11]
Pseudomonas chlororaphis *Pseudomonas putida AJ* *Ochrobactrum TD* *Pseudomonas fluorescens B-22* *Aspergillus niger van Tieghem F-1119*	Polyvinyl chloride	[20] [21] [22]
Brevibacillus borstelensis *Rhodococcus rubber* *Penicillium simplicissimum YK*	Polyethylene	[23] [24] [25] [26]
Rhizopus delemar *Penicillium roquefort, Amycolatopsis sp, Bacillus brevis*	Polylactic acid	[27] [28]
Pestalotiopsis microspore	Polyurethane	[17]
Comomonas acidivorans	Polydiethylene adipate	[17]
Trichoderma sp. *Aspergillus terreus* and *Chaetomium globosum*	Polyurethane	[29], [30]
Clostridium botulinum, C. acetobutylicum, Streptomyces sp. SNG9	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)	[31] [28]
Clostridium botulinum and *Alaligenes faecalis*	Polycaprolactone	[32]
Cladosporium Cladosporioides, X epiculopsis graminea, and *Penicillium griseofulvum* and the plant pathogen *Leptosph aeria* sp. *Agaricus bisporus* and *Mara smius oreades*	Polyurethane	[33]
Plerotus ostreatus	Oxo-biodegradable plastic bags and green Polyrthylene	[34]

Conclusion and Future Prospects

Indiscriminate usage of plastic is causing big havoc to the environment. The recalcitrant nature of plastic towards biodegradation is mainly responsible for the increased environmental burden. Microorganisms owing to their ability to degrade organic and inorganic materials created interest among the scientific community to search for potential microbes capable of degrading plastic waste. Microorganisms with their ability to produce a variety of extracellular enzymes (depolymerases) found to play a key role in plastic degradation. Till date, a large number of plastic-degrading microbes and enzymes have been identified from the environment. However, there is little knowledge regarding the mechanism of the breakdown of plastics by these enzymes. More studies are needed to understand the mechanism of degradation by microbial enzymes and ways to improve the efficacy of enzymes for effective biodegradation. Approaches such as rational protein engineering and directed evolution could improve the stability and activity of depolymerases.

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