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Review Article

Microbial Degradation of Plastic Waste: A Review

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ABSTRACT

Plastics are light weighted, durable, corrosion resistant materials, strong, and inexpensive. Scientists have reported many adverse effects of the plastic in the environment and human health. Nowadays biodegradable plastics are considered as the environmental friendly. The plastic polymers as such at room temperatures are not considered as toxic. The toxic properties are found in plastics, when heat is released from the food material in which they are covered and then they produce serious human health problems. This review article covers the list of plastics and their applications, plastic degrading efficiency by microbes and their involvement to degrade the plastic waste.

Keyword: Plastic; biodegradation; microorganisms; pollution

INTRODUCTION

Plastics are polymers derived from petrochemicals which are further synthetically made from monomers by some chemical processes to produce these long chain polymers [1]. Plastics are light weight, low cost, highly durable and are of high strength. In our daily life the plastics are available in various forms such as nylon, polycarbonate, polyethylene-terephthalate, polyvinylidene chloride, Urea formaldehyde, polyamides, polyethylene, polypropylene, polystyrene, polytetraflouro ethylene, polyurethane and polyvinyl chloride [2].

The annual production of plastics has doubled over the past 15 years to 245 million tonnes [3]**.** Production of plastic has increased from 204 million tonnes in 2002 million tonnes in 2013, representing a 46.6 % increase [4]. During the past three decades, plastic materials are widely used in transportation, food, clothing, shelter construction, medical and recreation industries, fishing nets, packaging, food industry and agricultural field [5].

Under the natural condition degradable or non-degradable organic materials are considered as the major environmental problem, *e.g.* plastics. The accumulation of these plastic wastes created serious threat to environment and wild life [6]. The environmental concerns include air, water and soil pollution. The dispersal of urban and industrial wastes contaminates the soil. The soil contaminations are mainly made by human activities [7]. Environmental pollution is caused by synthetic polymers, such as wastes of plastic and water-soluble synthetic polymers in wastewater [8].

Many animals die of waste plastics either by being caught in the waste plastic traps or by swallowing the waste plastic debris to exert ruinous effects on the ecosystem [9]. Some of the plastic products cause human health problems because they mimic human hormone. Vinyl chloride is classified by the International Agency for the Research on Cancer (IARC) as carcinogenic to humans [10]. It has also shown to be a mammary carcinogen in animals. PVC is used in numerous consumer products, including adhesives, detergents, lubricating oils, solvents, automotive plastics, plastic clothing, personal care products (such as soap, shampoo, deodorants, fragrances, hair spray, nail polish) as well as toys and building materials. [11] Styrene is classified by IARC as possibly carcinogenic to humans and is shown to cause mammary gland tumours in animal studies. It also acts as an endocrine disrupter [12]. BPA has been linked with premature birth, intrauterine growth retardation, preeclampsia and still birth [13]. It has also been noted that prolonged exposure to BPA shows a significant effect on the sex hormones (progesterone) in females [14]. Burning plastics usually produce some noxious gases like furans and dioxins which are dangerous greenhouse gases and play an important role in ozone layer depletion. In fact, dioxins cause serious problems in the human endocrine hormone activity, thus becoming a major concern for the human health [15, 16]. Dioxins also cause very serious soil pollution, causing a great concern for scientific community worldwide. Phthalates and Bisphenol A are closely related in thyroid causing dysfunction in humans.

CATEGORIES AND CLASSIFICATION OF PLASTICS

Based on their, thermal properties, designing properties and their degradable properties the plastics are classified into various types. Different types of plastic and their applications are listed in Table 1.

Table 1: Types of plastic and their applications

Types	Applications	References
Polyethylene terephthalate (PET)	Drink bottles, peanut butter jars, plastic films, microwavable packaging	[17]
Polylactic acid (PLA)	A biodegradable thermoplastic that can be converted into a variety of aliphatic polyesters derived from lactic acid	[18]
Polyetherimide (PEI)	(Ultem) A high-temperature, chemically stable polymer that does not crystallize	[18]
Phenolics (PF) or (phenol)	High-modulus, relatively heat-resistant and excellent fire resistant polymer used for insulating parts in electrical fixtures, paper laminated product (e.g., Formica) and thermally insulation foams	[18]
Polyvinyl chloride (PVC)	Plumbing pipes and guttering, shower curtains, window frames, flooring	[17]

Polyethylene (PE)	Wide range of inexpensive uses including supermarket bags, plastic bottles	[17]
Polyvinylidene chloride (PVDC)	Food packaging	[18]
Low-density polyethylene (LDPE)	Outdoor furniture, sliding, floor tiles, shower curtains, clamshell packaging	[18]
Polyamides (PA)	Fibers, tooth brush bristles, fishing line, under- the-hood car engine mouldings	[18]
Polypropylene (PP)	Bottle caps, drinking straws, yogurt containers, appliances, car fenders (bumpers) plastic pressure pipe systems	[17]
Polycarbonate/ Acrylonitrile butadiene styrene (PC/ABS)	A blend of PC and ABS that creates a stronger plastic. Used in car interior and exterior parts and mobile phone	[17]
Polystyrene (PS)	Packaging foam, food containers, plastic tableware, disposable cups, plates, cutlery, CD and cassette boxes	[17]
Melamine formaldehyde (MF)	One of the aminoplasts used as a multi colorable alternative to phenolics Bio degradable and heat-resistant thermoplastic composed of modified corn starch	[18]
Acrylonitrile butadiene styrene (ABS)	Electronic equipment cases (e.g., computer monitors, printers, keyboards) drainage pipe	[18]
High impact polystyrene(HIPS)	Refrigerator liners, food packaging, vending cups	[18]
Polyester (PES)	Fibers, textiles	[18]
Nylon	Small bearings, speedometer gears, windshield wipers, water hose nozzles, football helmets, race horse shoes, cell phone.	[18]
Polytetrafluoro ethylene (PTFE)	Electronics bearing, nonstick kitchen utensils.	[19]
Polymethyl methacrylate (PMMA)	Contact lenses, glazing, aglets, florescent light diffusers, rear light covers for vehicles.	[20]
Urea formaldehyde (UF)	Wood adhesive and electrical switch housings	[20]
Poly etheretherketone(PEEK)	Strong chemical and heat resistant thermoplastic biocompatibility allows for use in implant application and aerospace moulding	[20]

CLASSIFICATION OF PLASTICS ACCORDING TO THEIR THERMAL PROPERTIES

Based on their thermal properties they are classified into two types. They are thermoplastics and thermoset plastics.

Thermoplastics

Thermoplastics are plastics which can be hardened and softened by repeated heating and cooling process. They are also considered as non-biodegradable plastics. Breaking of double bonds produces thermoplastics. Polyethylene (PE), Polypropylene, polystyrene, polyvinyl chloride and polytetrafluoroethylenes are examples of thermoplastics.

Thermoset plastics

Thermoset plastics have highly cross-linked structures whereas thermoplastics are linear solids. Here chemical changes involved are irreversible but cannot be recycled. Phenol formaldehyde polyurethanes are examples of thermoset plastics.

classification of plastic according to their designing properties

Based on their designing properties they are classified into electrical conductivity tensile strength, degradability, durability and thermal stability.

Classification of plastics according to their degradability properties

Based on their chemical properties the plastics are differentiated into degradable and nondegradable polymers. Normally nonbiodegradable plastics are synthetic plastics and they have a usual repeat of small monomer with very high molecular weight. But the degradable plastics are made up of starch and they have less molecular weight.

INVOLVEMENT OF MICROORGANISMS FOR DEGRADATION OF PLASTICS

The microorganism's role is very important for plastic degradation. The different types of microbes degrade different groups of plastics. The microbial biodegradation has been at accepted and process still underway for its enhanced efficiency. Table 2 shows the list of microorganisms and their plastic degrading efficiencies.

Table 2: Table showing different microbes and their plastic degrading efficiencies

Microorganisms	Types of plastics	Source of the microbes	Degradation Efficiency	Reference
Bacillus cereus	polyethylene	Dumpsite soil.	7.2-2.4%	[62]
Pseudomonas putida	Milk cover	Garden soil	75.3%	[63]
Streptomyces sp	LDPE	Garbage soil	46.7%	[64]
Pseudomonas sp	Natural and synthetic polythylene	Sewage sludge dumpsite	46.2% and 29.1%	[65]
Pseudomonas sp	Natural and synthetic polythylene	Household garbage dumpsite	31.4% and 16.3%	[65]
Pseudomonas sp	Natural and synthetic polythylene	Textile effluent drainage site	39.7% and 19.6%	[65]
Pseudomonas sp	Polythene and plastic	mangrove soil	20.54% and 8.16	[66]

Aspergillus glaucus	Polythene and plastic	mangrove soil	20.80% and 7.26%	[66]
Micrococcus luteus	Plastic cup	Forest soil	38%	[67]
Masoniella sp	Plastic cup	Forest soil	27.4%	[67]
Pseudomonas sp and *bacillus cereus*	Polythene carry bags	Plastic dumping sites	12.5%	[68]
Aspergillus niger and *Streptococcus lactis*	Polythene bags and plastic cups	Medicinal Garden soil, Sewage Water Soil, Energy Park soil, Sludge Area soil, Agricultural Soil	12.25% and 12.5% respectively	[69]
Rhodococcus ruber (C208)	Branched low-density (0.92 g cm−3) polyethylene	Not specified	7.5%	[70]
Phanerochaete chrysosporium and *Pseudomonas aeruginosa*	Polythene carry bags	Plastic dumping sites	50% and 35% respectively	[71]
Aspergillus niger, Pencillium pinophilum	Powdered LDPE	Not specified	5% and11.07% respectively	[72]
Aspergillus oryzae leads	High density polyethylene films	High density polyethylene (HDPE) film buried in soil	72%	[73]
Streptomyces KU8, *Pseudomonas sp* and *Aspergillus flavus*	Low density polyethylene powder	Garbage soil dumped site	46.16% 37.09% 20.63	[74]
Eight *Streptomyces* strains and two fungi, *M. rouxii* NRRL 1835 and Aspergillus flavus	Disposable plastic films	Nile River Delta	28.5% and 46.5% Respectively.	[75]

Pseudomonas stutzeri	Low density polythene and polythene	soil from the plastic dumping site	73.38% reduction	[76]
Arthrobacter sp. and *Pseudomonas* sp	High-density polyethylene (HDPE)	dumped sites	12% and 15%	[77]
Brevibaccillus borstelensis strain 707	Branched low-density polyethylene	Soil	11%	[78]
Psedumonas sp.			20.54 ± 0.13	[79]
Aspergillus glaucus	Polythene bags and plastic cups	Mangroves rhizosphere soil	28.80 ± 2.40 %	
Serretia marscence	Polythene carry bags	Polythene dumping site	22%	[80]
Bacillus cereus	LDPE and BPE 10	Municipal compost yard	17.036%	[81]
Aspergillus versicolor and *Aspergillus sp*	LPDE in the powdered form	Sea water	4.1594 g/L	[82]
Staphylococcal species	(LDPE)	Not specified	22%	[83]

Microorganisms such as bacteria, fungi and actinomycetes degrades both natural and synthetic plastics [21]. The richness of microbes able to degrade polythene is so far limited to 17 genera of bacteria and 9 genera of fungi [22]. Microbial degradation of plastics is caused by oxidation or hydrolysis using microbial enzymes that leads to chain cleavage of the large compound polymer into small molecular monomer by the metabolic process [23]. The microbial species associated with the degrading materials were identified as bacteria, fungi, actinomycetes sp. and *saccharomonospora* genus [24, 25]. The microorganism's growth is influenced by several factors including the availability of water, redox potential, temperature carbon and energy source [26]. Microorganisms secreted by both exoenzymes and endoenzymes that are attached to the surface of large molecular substrate and cleave in to smaller segments [27, 28]. Recently reported, degrading enzymes are produced by several microorganisms [29]. Microorganisms recognize polymers as a source of the organic compounds [30].

Bacteria

Microorganisms such as *Bacillus megatserium*, *Pseudomonas* sp., *Azotobacter sp.*, *Ralstonia eutropha*, *Halomonas* sp., etc are used to degrade plastics [25]. In addition, *Bacillus brevis* 93**)** [31]**,** *Acidovorax delafieldii* BS-3[32], *Paenibacillus amyloticus* TB-13 [33]**,** *Bacillus pumilus* 1-A [34]**,** *Bordetella petrii* PLA-3 [35]**,** *Pseudomonas aeruginosa* PBSA-2 [36]**,** *Shewanella* sp. CT01 [37] are examples of bioplastic degrading bacteria[37]. In addition to these strains, a thermophilic bacterium, *Bacillus brevis*, with PLA-degrading properties has been isolated from soil.

In past years polyethylene degrading bacteria has been reported such as, *Acinetobacter baumannii, Arthrobacter* spp*, Viscosus spp*, *Pseudomonas* spp*, Arthrobacter viscosus*, *Bacillus amyloliquefaciens, Thuringiensis, Mycoides, Cereus, pumilus, Staphylococcus* *cohnii, Xylosus spp, Pseudomonas fluorescens, Rahnella aquatills, Micrococcus luteus, Lylae, Paenibacillus macerans*, *Flavobacterium* spp, *Delftia acidovorans, Ralstonia* spp *Rhodococcus erythropolis, Pseudomonas aeruginosa* [38] and *Bacillus brevies* [39]The microbial species that identified from the sample polythene bags tested were *Bacillus sp., Staphylococcus sp., Streptococcus sp., Diplococcus sp.,Micrococcus sp., Pseudomonas sp. and Moraxella sp.* The microbial species are associated with the degrading materials were identified as bacterial genus like (*Pseudomonas, Streptococcus, Staphylococcus, Micrococcus, Moraxella*) [40, 25].

Fungi

The growth of many fungi can also cause small-scale swelling and bursting, as the fungi penetrate the polymer solids. In recent years fungal strains have been reported for p;astic degradation such as *Aspergillus versicolar* [41], *Aspergillus flavus* [42], *Chaetomium* spp [43] *Mucor circinellodies* species etc. The polythene bags were degraded by some fungal species identified such as, *Aspergillus niger, A. ornatus,nidulans, A. cremeus, A. flavus, A. candidus and A. glaucus* were the predominant species. The microbial species are associated with the degrading materials were identified fungi (*Aspergillus niger, Aspergillus glaucus*), [40, 25]. Sanchez *et al*., [47] has reported that the PCL-degrading fungi, *Aspergillus* sp is effective in biodegradation as plastics studies.

Many studies on fungal degradation of the bioplastic have also been performed including *Paecilomyces lilacinus* D218 [44]**,** *Fusarium moniliforme Fmm* [45], *Aspergillus flavus* ATCC9643 [46], *Thermoascus aurantiacus* IFO31910 [47], *Tritirachium album* ATCC22563 [48], *Paecilomyces verrucosum* [48] and *Aspergillus sp*.XH0501-a [50]. On the other hand, polylactic acid (PLA) is subjected to degradation by only two genera of fungi (*Penicillium roqueforti* and *Tritirachium album*) [51] reported that *Aspergillus niger* van Tieghem F-1119 had the ability to degrade PVC. PHB and polyesters are degraded by many fungal genera such as *Acremonium, Cladosporium, Debaryomyces, Emericellopsis, Eupenicillium, Fusarium, Mucor, Paecilomyces, Penicillium, Pullularia, Rhodosporidium,* and *Verticillium*. Similarly, PCL is degraded by *Aspergillus, Aureobasidium, Chaetomium, Cryptococcus, Fusarium, Rhizopus, Penicillium, and Thermoascus*. PEA is degraded by *Aspergillus, Aureobasidium, Penicillium, Pullularia*. Fungus like *Alternaria solani, Spicaria sp., Aspergillus terreus, Aspergillus fumigates, Aspergillus flavus* were isolated from soil where plastic have been dumped. These caused significant weight loss in the PS PUR blocks in the shaken cultures, reaching up to 100% in case of the isolate *Fusarium solani* [52].

Actinomycetes

PLA-degrading actinomycete, and *Amycolatopsis* sp. Strain isolated from the sample, reduced 100 mg of PLA film by ~60% after 14 days in liquid culture at 30°C. There are many species of microorganisms which can degrade PLA, PCL and PBS such as actinomycetes. Several actinomycetes including *Amycolatopsis sp*. 3118 [55], *Amycolatopsis sp*. HT-6 [56], *Saccharothrix* JMC9114 [57], *Kibdelosporangium aridum* JMC7912 [58), *Actinomadura keratinilytica* T16-1 (Sukkhum *et al*., 2011) [58], *Amycolatopsis thailandensis* PLA07 [59], *Streptomyces bangladeshensis* 77T-4[60], *Streptomyces thermoviolaceus* subsp. *thermoviolaceus*76T-2 [61] were reported as bioplastic degraders. *Cryptococcus sp.* S-2 [53] and *Pseudozyma antarctica* JCM10317 [54] were reported to be bioplastic-degradings yeasts.

CONCLUSION

Many studies showed the striking effect of plastic waste on the aquatic and marine ecosystem, and thus, it has become one of the major problems for the modern environmentalist. To the get rid of such a menace, people usually put them in landfills or burn it, but both these practices cause very serious threats to the environment and the ecosystem. Some plastics are designed to be biodegradable and can be broken down in a controlled environment such as landfill. Biodegradation of waste plastic is an innovative are of research solving many environmental problems. This review discusses on the literature of microbes used for biodegradation of plastic waste. Most of the plastic wastes are degrade by the microorganisms. Based on these literatures available one could conclude that in order to enhance biodegradation of plastics waste the following approaches could be adopted as the biodegradation studies of plastics in dumped soil.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interests.

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