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The Hidden Microplastic: A New Insight into Degradation of Plastic in Marine Environment

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ABSTRACT

Plastic is usually used in essential areas like packaging, industries electronic, construction, building, healthcare, transport, etc. gradually pollution is increasing in the world. Plastic makes a high level of pollution that is affecting both the life on earth and the marine organisms. Around the world, many scientists and environmentalists have been developing various technologies to deal with the constant increase of this threat to the environment. Various bio-based solutions are to be kept in the account to mitigate the foreseen problem of micro-plastic pollution. The indigenous microbes (exposed to plastic) form the dense bio-film around the plastic and degrade it with the help of active catalytic enzymes. Therefore, in this review, the authors have discussed the source, the harmful impact of micro-plastic, biodegradation of plastic, and future eco-friendly approaches which might help in the removal of plastic from the marine environment.

Keywords: Micro-plastic (MPs); Enzymatic degradation; Microbes; Biodegradation

1. INTRODUCTION

The most common type of micro-plastic trash was fibers (85%), followed by fragments (15%).[1] Chemical waste is created at a rate of 550.9 tons per day, and it is disposed of under the Bio-medical Waste Management Rules. According to UNEP, around 0.5 kilograms of plastic biomedical waste (mask N95, SYRINGES, PPE kit, body bags, etc.) is released per hospital each day during the COVID-19 crisis contributing to major white pollution through single-use plastic and by 2030 it will be in its peak point. According to estimates, the amount of plastic entering the ocean each year ranges between 4.8 and 12.7 million tons.[2] Biofouling (colonisation) of plastic trash, like any other surface, occurs over time. Figure 1 shows the top 10 cities of India which generate maximum plastic waste annually (Fig 1).

Food and beverage packaging, medicines, cosmetics, detergents, and chemicals all are packed by using plastics as mentioned in Table 1. Nearly 30-50 per cent of plastics are in the packaging companies around the globe. It is favored as it carries mind-blowing chemical composition, such as hydrophobicity, toughness, and lightness, which are reasonable explanations for its appeal.[3] Aside from these beneficial characteristics, plastics are extremely strong and long-lasting.

Plastic materials are categorised majorly into toughness and strength: thermosetting and thermoplastic.[10]

Thermosetting: Heat-hardened thermoset polymers have a permanent design. When exposed to severe temperatures, thermosets will burn rather than melt once set. The following are examples of thermoset polymers that are often used: Polyurethane, Epoxy, Phenolic, Certain polyesters, and Phenolic. Thermosets are utilised in a range of applications due to their durability and temperature resistance, including household appliances, lighting components, electronic insulators, other components, energy equipment, motor parts, heat shields, and covers.[11]

Thermoplastic: The essential molecular makeup of thermoplastics does not change when they are warmed and molded. When subjected to high temperatures, they melt, making them perfect for forming and molding production operations. Thermoplastics include a diverse spectrum of materials, such as Acrylonitrile Butadiene Styrene (ABS), acetals, Polystyrene (PS), Polyethylene (PE), and thermoplastic olefins, polypropylene, Polyvinyl Chloride (PVC), nylon, polyester.[4]

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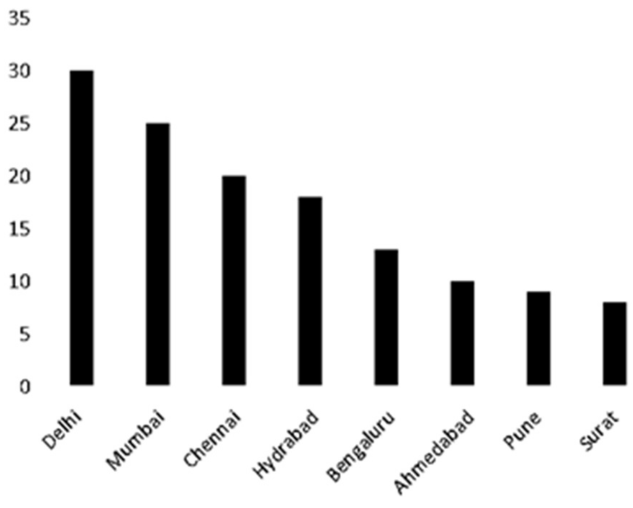

Figure 1. Top 10 Indian cities for waste generation annually (in lakh tons).

Conventional treatment processes such as incineration, landfill, and chemical treatment (using N-TiO_2) are used for the degradation of polymers, but these methods have certain drawbacks such as emission of toxic chemicals, sometimes do not degrade properly and might have produced certain toxic by-products also. In addition, micro-plastic also shows harmful effects on the life present on earth.[5] Upon exposure, it shows effects on the immune system, sensory organs, liver, and kidney, impacts-neuro, reproductive, developmental toxicity, neurological damages, and cancer.

Therefore, there is a need for a biological method for the effective and economical degradation of micro-plastic. Biodegradation is one such effective method that uses microbes and their enzymes for the degradation of plastic material. Hence, this review paper aims to address briefly the source of marine plastic waste and its impact on marine organisms. Additionally, this paper also covers the biological methods which help in the degradation of plastics especially plastic degrading microbes and their enzymes.

2. SOURCE OF PLASTIC IN THE MARINE ENVIRONMENT

Land-based sources (nearly 80 %) are the main reason for plastic pollution in the marine environment. Many hazardous components from coastal landfill operations and inaccurate disposal of plastic dirt and sewage enter the water bodies.[12] Also, litters formed from boats by recreational activities, fishing net, etc. are the remaining 20 per cent source of micro-plastic generation in the marine environment. Nearly, 5.25 trillion MPs contaminate the earth's sea and due to this reason, the ocean servesas a base for MPs. Plasticizers, chemicals, and stabilizers are also present in the plastic to suit their requirement.[13] Micro-plastic (MPs) of dimensions less than 5 mm are released into the ocean after initial and final division by UV photodegradation, biological degradation, hydrolysis, and mechanical action.[14] Pollutants are polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), persistent organic pollutants (POPs), etc., are normally absorbed by micro-plastic because they have the high surface area and hydrophobic properties.[15]

3. PERFORMANCE OF MICRO-PLASTIC ON THE ECOLOGICAL FUNCTIONALITY OF MARINE SPECIES

Plastic components are stable in the aquatic system and have a dangerous impact on the microbiota.[16] Marine lives are get attracted to plastics as they have their color, and odor, and also most algae grow on the plastics floating around. It is abovementioned that Plastic debris has 5mm in diameter, these are termed as MPs that's the reason it is a biological barrierand can penetrate the tissue and the cells.[10] Hence, these also get into the various food chains, of the bioavailability to planktons, mollusks, corals, etc.[17] MPs spread many toxic chemicals and by this aquatic life face problems in facilitating molecular modulations, mortality, and physical damage elaborated in Table 2. Toxic effect of micro-plastic on marine organisms

Hydrophobicity, polymer nature, Pollutant dose, surface chemistry, size, etc. are common functions of MPs that add toxicity to marine life depends on. If the concentration of the MPs increases proportionally alteration of the food web of the ocean body also increases.[18]

The discovery of unusually high amounts of micro-plastic in oceanic convergence zones sparked an investigation on the presence of micro-plastic in marine bodies. It is been found in the waters across the world, including in far-flung locations like Antarctica and the deep sea[19]. Micro-plastic is distributed in the waters in a highly diverse way. Micro-plastic concentrations under the surface layer of the sea are lower compared to the surface**.** Some research suggests the amount of MPs in the water is approximately from 0.015 to 13.5 items/m^3 [20]. Recent research in the north-eastern Pacific, along the coast of Brazil, found significantly greater amounts. substances that cause weight gain by interfering with normal hormone action.[21] Other substances that adhere to plastics might cause cancer or birth abnormalities, and flame retardants may interfere with brain development in fetuses and children.[22] The dosage creates the poison, according to a basic theory of toxicology, yet several of these chemicals-for example, BPA (Bisphenol A) and similar compounds-appear to impair lab analytic performance.[23]

4. BIODEGRADATION OF PLASTICS

As it is ecofriendly and affordable mechanismhas become a widely approved category of degradation. This process combines the many environmental factors for the degradation of recalcitrant plastic on ocean/marine bodies.[24] Figure 2 represents the systematic representation of the degradation of MPs into monomers, dimers, and oligomers and degradation into microbial biomass, water, and carbon dioxide. The most common steps in microbial breakage of plastics are:

Table 1. Use of plastic material in commercial and industrial sector

Sectors	Plastic materials	Applicability	References
Aircraft	PA, PC, PPO, PVC, PPS, PI, PE & PTFE	Windows, interior wall panels, pipes and tubing, bushing, bearings, landing gear components, and luggage compartments.	[4]
Alternative enthalpy	PC, PPO, PA, PEEK, PAI, PB, PET, PE, PP & PU	Insulators, films, housings, bearings & bushings, braces, pipes, valves, and fitting.	[5]
Chemical Material	HDPE, PA, PE, PVC, PTEF, PVDF & PPS	Pump & valve components, fume hoods, and ducting, laboratory equipment, chemical containers	[6]
Environmental Material	PA, PS, PVC, LDPE, CPVC, HDPE, PBT, PC, PP, PET	Vent pipes, water treatment plant components, incineration and storage components, energy cell panels & containers	[6]
Food and Beverages	HDPE, PEEK, PE, PET, PEI, PC, PP, PAI, PVC & PTFE	Packing materials, pistons, rollers, safety guards, seals, strips	[7]
Life sciences	PEEK, PP, PMP, PE, PSU, PPSU, PC, PEI, PET & PVC	Pharmaceutical tablet, optics, laboratory equipment, Production and syringe, surgical trays, catheters, packing, and lab machine.	[7]
Marine	HDPE, PU, PBT, PC, PA, PET, PVC	Fuel lines, pump bearings, boat and dock bumpers, fairings, swim platforms, and sheaves	[8]
Agriculture	HDPE, PA, PC, PVC & PTFE	Pipe, nozzle, valve, bearings, feeders, and tank	[8]
Construction	CPVC, PE, PFA PVC, PP, PET, PC, PS, PTFE, PA	Shutters, mirrors, lighting lenses & tubes	[9]
Transportation	HDPE, PEI, PC, PEEK, PE, PET, PE, PTFE, Silicones & PVC	Bearings, lighting covers. windows, luggage compartments, brake guides, board panels	[9]

Abbreviations: LDPE – Low-Density Polyethylene; PI – Polyimide; PC – Polycarbonate; PPO – Polyphenylene oxide; PSU – Polysulfone; PU – Polyurethane; PTFE – Polytetraflfluoroethylene; HDPE – High-Density Polyethylene; PVC – Polyvinyl chloride; PE – Polyethylene; PET – Polyethylene terephthalate; PB – Polybutylene; PPS – Polyphenylene sulfide; PAI – Polyamideimide; PEEK – Polyetheretherketone; PBT – Polybutylene terephthalate; PP – Polypropylene; PVDF – Polyvinylidene fluoride; PEI – Polyester imide; PS – Polystyrene; CPVC – Chlorinated polyvinyl chloride; PMP – Polymethyl pentene; PPSU – Polyphenyl sulfone; PA – Polyamide.

Microbes biofilm: In this step, the microbe attaches to the surface of the plastic and forms a microbial biofilm known as plastisphere which hosts distinct microbial communities.[27] In addition, it also harbors potential plastic degrading microbes. In the marine environment, polymer degradation starts as soon as the microbial biofilm develops which decreases the plastic buoyancy and hydrophobicity.

Bio-deterioration: It affects the plastic's mechanical, physical, and chemical characteristics. A catalyst for bio-deterioration is the microbial bio-film which is on the surface and inside the plastics.[25] The content and structure of the plastic, as well as the ambient circumstances, influence the growth of the bio-film. During the bio-film synthesis, extracellular polymeric substances are released, which helps the bio-film to stay together and stick to the surface of the plastics.[26] EPS gets into the pores, bacteria start to grow within by expanding the size and causing fractures, also the microbe's colonies are much more diverse. Acidic compounds are released such as nitrous acid and H_2SO_4, also the pore pH starts degrading.[24]

Bio-fragmentation: Plastics are fragments into oligomers and monomers can occur for a variety of reasons. Polymers are heavy molecular weight components that cannot pass through the cell wall. Extracellular enzymes are secreted by microorganisms and can catalyze processes on the plastic's surface. Further enzymes can carry out a variety of chemical processes, but lysis occurs in the presence of electric charge imbalance because it creates an overall charge on the object, all charges present is not add up to 0, ions have a charge

Table 2. Toxic effect of micro-plastic on marine organisms

Source of toxic substance	Organisms that are affected	Symptoms	Reference
Micro-plastic leachates	*Sea urchin (Paracentrotuslividus)*	The freshwater species Daphnia Magna causes acute poisoning.	[18]
	Intertidal gastropod (Littorina littorea)		[19]
Micro-plastic shares, fragments, and fibers micro polyvinyl chloride (mPVC)	*Grass shrimp (Palaemonetes pugio)*	Oxidative stress, inflammatory lesions, and enhanced absorption or translocation can all lead to toxicity.	[20]
	Dinoflagellate (Kareniamikimotoi)		[20]
	Marine microalgae (Skeletonemacostatum)		[21]
Nanosized microbeads	*Marine rotifer (Brachionuskoreanus)*	Composition, toxin adsorption capabilities, and propensity to move up the marine food chain	
Polystyrene nano and microbeads	*Marine copepod (Paracyclopina nana)*		[21]
Polystyrene nanoplastics	*Planktonic organisms (Daphnia Magna)*	Styrene and benzene are probable human carcinogens and neurotoxins.	[22]
Polystyrene nanoparticles	*Planktonic organisms (Daphnia Magna)*	Inflammation of the lungs and cardiac issues may be present in the body.	[23]
	Marine planktonic species (DunaliellatertiolectaandArtemia franciscana)		[23]
Polyethylene microbeads	*European sea bass larvae (Dicentrarchuslabrax)*	Composition, toxin adsorption capabilities, and propensity to move up the marine food chain	[24]
Polyethylene micro-plastic	*Blue mussels (Mytilus edulis),*	In the freshwater species Daphnia magna causes acute poisoning.	[25]
	Antarctic krill (Euphausiasuperba)		[25]
Micro-plastic	*Marine polychaete worm (Sternaspisscutata, Magelonacincta) and Marine bivale molluscs (Tellina sp.)*		[26]
	Blue mussel (Mytilus edulis)		[26]
Plastic litter	*Sea birds (Pelecanoidesgarnotii, Pelecanoidesurinatrix,Phalacroxoraxbougainvillii,S.humboldti)*	Cause cancer, congenital defects, immune system disorders, and developmental disorders in children.	[26]

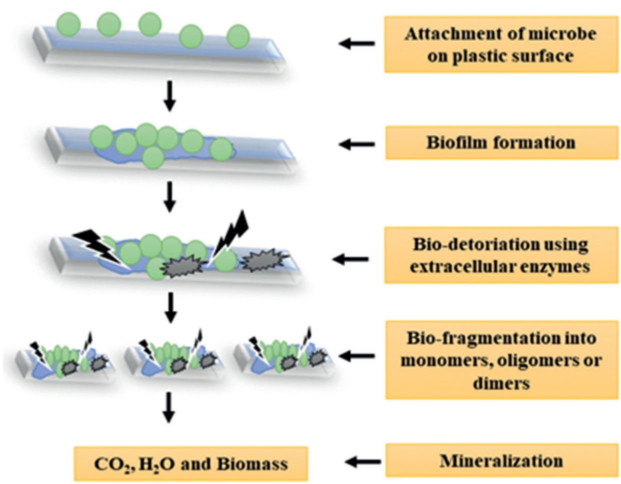

Figure 2. General representation of plastic degradation by microbes.

imbalance, in other terms can be called as Static electric. *Bacillus brevis* can only degrade polycaprolactone, but *Streptomyces* can degrade PHB, poly(3-hydroxybutyrate-co-3-Hydroxyvalerate), as well as starch and polyester. The majority of PHB (polyhydroxybutyrate)-degrading bacteria belong to diverse taxa, including Gram-positive and Gram-negative bacteria, including *Streptococcus.*[29]

Assimilation and mineralisation: The production of monomers does not guarantee that microbes will assimilate them. Some monomers may remain in the microbial cell's environment without being absorbed. Monomers are oxidised into the cells by catabolic processes to form energy, new biomass, and cell structure (in the form of a microbial cell).Secondary metabolites released utilised by any other cell for another breakdown. The mineralisation mechanism refers to the complete breakage of primary and secondary metabolites, resulting in the release of purely oxidised metabolites (H_2O, N_2, CH_4, CO_2).[30] (Fig 2)

It is important to understand the biochemical mechanism, relationship, and interaction involved between both plastic and microorganism to overcome the environmental challenges associated with its biodegradation.[31] Environmental factors and polymer characteristics are the important factors that have an impact on the degradation process.

Polymer characteristics: Due to the recalcitrant nature of plastic, elevated molecular weight, and 3-dimensional structures, the factors driving the degradation and hydrophobic natureare complicated and all of them restrict its availability to microorganisms.[32] The weathering of micro-plastic is the major reason for micro-plastic production. The rate of degradation of plastic is increased if it gets exposed to waves in the ocean. Plasticizers, high molar mass and crystallinity, chain configuration, and tacticity, molecular orientation, and mobility, and type of functional groups are the dynamic factors that help in the maintenance of the degradation process.

Environmental conditions: Both the abiotic and biotic factors catalyze the metabolic reaction for healthy ecology function andalso structure in the aquatic world. Temperature, pH, UV, and salinity are the abiotic factors that all affect the rate of hydrolysis.Less molecular weight polymer fragments are generated from the photooxidation of MPs present in the ocean and the degradation rate will be spontaneous if it is vulnerable to mechanical forces such as waves and wind. In the marine system, both photo- and temperature incorporate slower degradation of plastic polymers.TheRange of polymer degradation is increased with the increased pH. Extracellular enzymes and hydrophobicity of plastics also affect the degradation rate.

4.1 Microbial Degradation of Plastic in the Marine Environment

These days plastics and polymers are seen as a big threat because they cause huge environmental damage. It has been proved that microorganisms have a major role in plastic degradation. Different types of microbes (bacteria, fungi, actinomycetes, etc.) have been isolated that can degrade different types of plastic materials with the help of their enzymes. They use polymers as their source of nutrition. Table 3 shows the microbes and their associated enzymes which help in plastic degradation.

Degradation can take place by different mechanisms such as cracking, erosion, discoloration, and phase transition. Figure 3 represents the microbes and the enzyme responsible for plastic degradation**.**

4.1.1 Bacteria

Different bacterial species such as *Pseudomonas* sp., *Micrococcus* sp., *Streptococcus* sp., *Bacillus* sp., *Staphylococcus* sp., *Moraxella* sp., and *Diplococcus* sp. are found to have plastic degrading properties. Among these, *Pseudomonas* and *Moraxella* are the most active species. Some bio-plastic degrading bacteria are, *Bacillus megaterium, Alcaligenes aquatilis,* and *Shewanellahaliotis.* Also, *Bacillus brevis, Acidovoraxdelafieldii, Paenibacillusamyloticus, Bacillus pumilus, Bordetella petri, Pseudomonas aeruginosa* are seen to degrade bio-plastic.[33]

The bacterium *Ideonellasakaiensis*has was seen to be very effective in Polyethylene terephthalate (PET) degradation. This bacterium, isolated from a sediment sample, uses PET as its sole carbon and energy source during the process. Some polyethylene degrading bacteria that have been isolated in recent years, are *Acinetobacter baumannii, Arthrobacter viscosus, Arthrobacter sp., Viscosus sp., Bacillus amyloliquefaciens, Thuringiensis, Mycoides, Cereus, pumilus, Staphylococcus cohnii, Xylosusspp, Pseudomonas fluorescens,* etc. The bacterial species of *Streptococcus, Bacillus, Staphylococcus, Micrococcus, Pseudomonas,* and *Moraxella* have been isolated from polythene bags and are observed to be effectively involved with degradations.[34]

4.1.2 Fungi

Fungi can degrade plastic materials at a considerably high rate. The fungal species of *Penicillium oxalicum, Penicillium chrysogenum, Myceliophthora sp., Phanerochaetechrysosporium,*

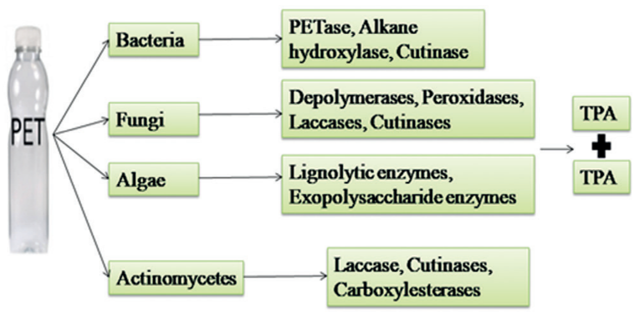

Figure 3. Plastic degrading Microbes and the produced enzymes degrading plastic.

and *Trametes Versicolor* have been detected for their ability to degrade polyethylene. *Aspergillus tubingensis,* a typical soil fungus, is detected for its plastic degrading abilities. The white rot, *Pleurotusostreatus* PL06, is capable to degrade oxo-biodegradable plastics and green polyethylene. Most fungal genera like *Eupenicillium, Acremonium, Cladosporium, Debaryomyces, Emericellopsis, Fusarium, Mucor, Rhodosporidium, Penicillium, Pullularia,* etc can degrade PHB and polyesters.[35] PCL is degraded by the fungi belonging to the genus of *Aspergillus, Aureobasidium, Chaetomium, Cryptococcus, Fusarium, Rhizopus, Penicillium, Thermoascus,* etc.[36] Only two fungi that can degrade polylactic acid (PLA), are, *Penicillium roqueforti* and *Tritirachium album*. It has been reported that *Aspergillus niger* van Tieghem F-1119 can degrade PVC plastic effectively.[37]

Many research works have been done on bioplastic degradation using fungi, which involved *Paecilomyceslilacinus D218, Fusarium moniliformeFmm, Aspergillus flavus ATCC9643, Thermoascusaurantiacus IFO31910, Tritirachium album ATCC22563, Paecilomycesverrucosum*and *Aspergillus sp. XH0501-a*. The enzyme lipase from *Rhizopus arrhizus*>, *Rhizopus Delmar, Achromobacter*sp., and *Candidacylindracea*, have been seen to be very important in degrading activities.

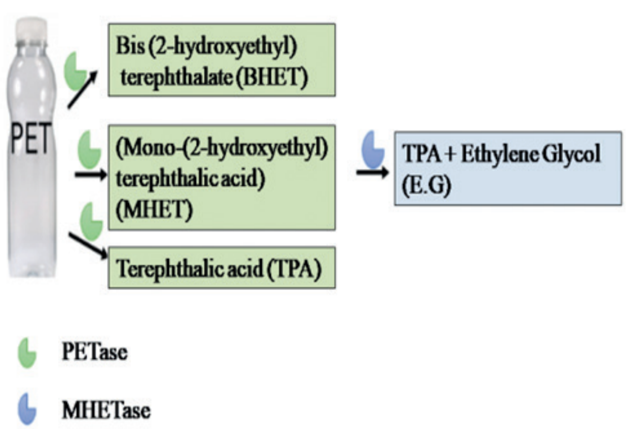

Figure 4. Schematic representation of the mechanism of PU degradation.

4.1.3 Actinomycete

Actinomycetes are found to play an important role in PLA degradation. Microbes belonging to the genera *Actinomadura, Micromonospora, Amycolatopsis, Kibdelosporangium, Nonomuraea, Pseudonocardia, Saccharothrix, Streptoalloteichus, Streptomyces, Thermomonospora,* are involved. Actinomycetes involved in Bioplastic degradation are, *Amycolatopsis* sp. 3118, *Amycolatopsis*sp. HT-6, *Saccharothrix*JMC9114, *Kibdelosporangiumaridum* JMC7912, *Actinomadurakeratinilytica* T16-1, *Amycolatopsisthailandensis*PLA07, *Streptomyces Bangladeshis* 77T4, *Streptomyces thermoviolaceus* subsp. *Thermoviolaceus*76T-2 etc. Polyester degrading actinomycete species are *Streptomyces* sp. and *Micromonospora*sp.

4.2 Enzymatic Degradation of Plastic in the Marine Environment

Several enzymes have been identified from microorganisms that can degrade different types of polymers. These enzymes can be classified into two sections, (1) extracellular and (2) intracellular enzymes. The group of extracellular enzymes helps to play a wide range of reactivity. They depolymerize the long carbon chains of the polymers into a mixture that consists of oligomers, dimers, and monomers also. Most of these enzymes belong to the classes of laccases, hydrolases, lipases, peroxidases, hydroxylases, esterases, etc. They act on various polymer substrates i.e., polyethylene, polyurethane, polystyrene,polyethylene, nylon, terephthalate, etc.

Laccase enzymes found from *Rhodococcusruber* C208 and *Trametes Versicolor* can act on membranes. *Bacillus cereus* was seen to be able to act on UV irradiated PE with the help of the enzyme's laccase and manganese peroxidase. In a study, a gene from *Pseudomonas* sp[38]. E4 was copied to *Escherichia coli* BL21. This recombinant strain showed considerable activity on low molecular weight PE. Some strains of Streptomyces and RhodococcusRuber (actinomyces) and Aspergillus flavus and Pleurotusostreatus (fungi) also can degrade PE. The possible mode of action was the oxidation of the PE hydrocarbon.

Different enzymes from several microorganisms have been seen to act on polyurethane (PU), which include cutinases, lipases,esterases, laccases,proteases, peroxidases, and ureases.[39] The discovery of serine and cysteine hydrolase from *Pestalotiopsis*microspor, which degrades PU, was a turning point. In a reaction medium involving a consortium of different microbes, PU was degraded efficiently with the help of different decarboxylases, transferases, ligases, dehydrogenases, hydrolases & isomerases.

Figure 4 shows the schematic representation of the mechanism of PU degradation. The activity of PETase on PET has been highlighted, which is secreted by *Chlamydomonas reinhardtii, Ideonellasakaiensis* 201-F6, *Phaeodactylumtricornutum,* and *Streptomyces scabies*. It

Table 3. List of plastic degrading microbes and their associated enzymes

S. No.	Microorganisms	Plastic degraded	Enzymes involved	Ref.
1	*Rhodococcusruber* C208	PE films	Laccase	
2	*Trametes versicolor*	PE membranes	Laccase	
3	*Phanerochaetechrysosporium* ME-446	High molecular weight PE membrane	Manganese peroxidase	
4	*Bacillus cereus*	PE (UV-irradiated)	Laccase and manganese peroxidase	
5	*Pseudomonas pseudoalcaligenes*	Polyesters	Cutinase	
6	*Pseudomonas pelagia*	Polyesters	Lipase	
7	Streptomyces sp.	PE fraction of a heat-treated plastic blend	lignin peroxidases	
8	*Phanerochaetechrysosporium* MTCC-787	High molecular weight PE	lignin peroxidases and manganese peroxidase	
9	*Azotobacterbeijerinckii* HM121	PS	hydroquinone peroxidase	[33]
10	*Nocardia farcinica*and *Alcaligenes faecalis*	solid polyester PUR	Polyamidase and *Nocardia farcinica,* respectively	
11	*Delftiaacidovorans*	PUR	A membrane-bound esterase	
12	*Bacillus licheniformis* *Bacillus subtilis* *Thermobifidafusca*	PET fibres and PET oligomers	Carboxylesterases	
13	*Thermomycesinsolens*	PET	cutinaseHiC	
14	*Thermobifidafusca* KW3	Amorphous PET films	variants of the polyester hydrolase TfCut2	
15	*Fusarium solani* and *Thermobifidafusca*	PET	polyester hydrolase	
16	*Candida Antarctica*	MHET	hydrolase HiC and the lipase CalB	
17	*Chlamydomonas reinhardtii*	PET	PETase	
18	*Pseudomonas aestusnigri* VGXO14	PET	PE-H	
19	*Ideonellasakaiensis* 201-F6	PET	PETase	
20	*Phaeodactylumtricornutum*	PET	PETase	
21	*Pseudomonas chlororaphis*	PUR	PueB lipase	
22	*Pseudomonas protegens* strain Pf-5	PUR	*pueE* and *pueB*	
23	*Comamonasacidovorans* TB-35	PUR	PudA	
24	*Pseudomonas* sp. AKS2	LDPE	Hydrolase	
25	*Pseudomonas aeruginosa* MZA-85	Polyester	Esterase	

26	*Pseudomonas putida*	Vinyl chloride	Alkenemonooxygenase
27	*Pseudomonas protegens* BC2-12	Polyester	Lipase
28	*Pseudomonas fluorescens A506* and Pf0-1	Polyester	Lipase
29	*Pseudomonas stutzeri*	PEG	PEG dehydrogenase
30	*Pseudomonas vesicularis* PD	PVA	Esterase
31	*Pestalotiopsismicrospora*	PUR	A metallo-hydrolase
32	*Flavobacterium* and *Pseudomonas* sp.	Nylon	Hydrolase
33	*Cryptococcus* sp. MTCC 5455	PBS, PBSA	Lipase
34	*Pseudomonas chlororaphis*	PU	Polyurethanases (PUase)
35	*Cryptococcus* sp. Strain S-2	PLA	Cutinase like enzyme
36	*Candida rugose*	poly (butylene succinate-co-hexamethylene succinate) copolymer	Lipase
37	*Aspergillus fumigatus*	PHB, PBS, PES	Polyhydroxybutyrate depolymerase
38	*Pichia pastoris*	PBS	Cutinase

is the most studied enzyme in this group. A recent study showed the activity of the PE-H enzyme of *Pseudomonas aestusnigri* VGXO14 on PET.[40]

Thermobifidafusca KW3 secretes variants of the polyester hydrolase TfCut2 which is very effective on amorphous PE films. *Thermobifidafusca*isseen to secrete two different enzymes (Carboxylesterase and hydrolase) that can act on PET fibers. Figure 5 shows how PETase and MHETase degrade PET into monomeric TPA and ethylene glycol.

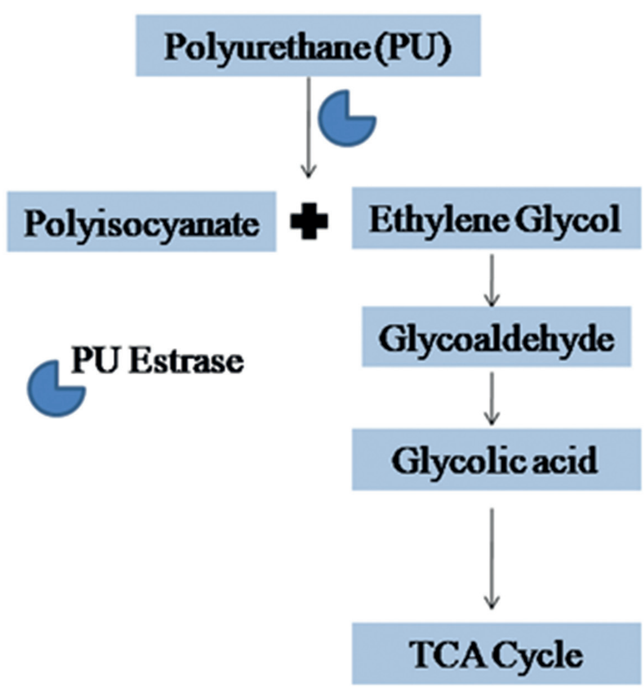

Figure 5. Mechanism of PET degradation.

The microbial degradation of polystyrene is done with the help of major bacterial and fungal enzymes that can do the initial depolymerisation of the polymers have not been identified yet,also a recent study says the presence of an extracellular esterase, secreted by *Lentinustigrinus*that can break PS. *Azotobacterbeijerinckii* HM121can act into PS by the enzyme hydroquinone peroxidase. Polymerases from *Pseudomonas* and*Bacillus* species were identified for their role in PS degradation[41] (Fig. 5).

5. FUTURE SCOPE

For plastic degradation, it is very important to form an important biotechnological solution as the plastic materials harm the water bodies and the marine lives. The rate of recycling has also reduced which has raised considerable concern. Plastic pollution can be resolved to keep the following points in mind:

- Enhancing microbial enzyme activity using protein engineering.
- Use of mixed culture to enhance the degradability of plastics.
- Computational-based approaches to study the plastic degrading enzymes and their connection with the genome, transcriptome, and metabolome data.
- Metagenomic approach for the identification

and diversity of novel enzymes and microbial communities that are un-culturable.[42]

- Both the physicochemical and biological treatments have combined approaches that could be effective for plastic degradation.[43]

6. CONCLUSION

Now a day's plastic pollution is one of the major concerns. Many current technologies are present that help in the degradation of plastic but due to some drawbacks, it is very difficult to implement them fully. Therefore, this review paper highlights the polymer type, its source, and its impact on the marine environment. Synthetic plastic gives rise to various environmental concerns associated with ingestion, suffocation, and being highly resistant to biodegradation, it also exerts long-term toxic effects. Substantial search is being done in the process of biodegradation but due to the slow degradation rate of synthetic polymer to date biodegradation has not been applied commercially. The toxic implications of plastic on the marine environment can be reduced if the suitable biodegradable plastic material is developed. Many enzymes have also been studied by the researcher which degrades the plastic. In addition, this field required wide investigation and research and paradigm shift to allow the application of enzymes, protein engineering approach, etc. for the pollution-free marine environment. Most importantly, the standardisation of the isolation process of microbial species that contains the plastic degrading enzyme should be done. This will reduce the screening process and also increase the number of pure breeding colonies.

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