Review on plastic degradation by fungi

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ABSTRACT

Our goal in this review is to investigate the possibility of fungal breakdown of plastic. The deterioration of plastic pollution has become a major global concern, and finding sustainable solutions is crucial. One promising avenue of research is the use of fungi to degrade plastics.. Investigations are required to identify and isolate specific fungal species with potential to degrade different types of plastics. This knowledge will be crucial in developing techniques and strategies to harness the full potential of fungal plastic degradation.

***Keywords**: Plastic biodegradation, Bioremediation, Marine fungi, Phylogenetic analysis*

1. INTRODUCTION

Plastics were created as a robust, lightweight, and long-lasting material that can be used for a variety of products, some of which have commercial, medicinal, pharmaceutical, and agricultural uses. Many natural materials, including metals, forests, and gravel, have been substituted by plastics[1].Synthetic polymers known as plastics are extremely resistant to microbial deterioration and are added to the environment at a pace of 25 million tons annually [2]. It is estimated that 12,000 Mt (million metric tons) of plastic garbage would be present in landfills and the environment by the year 2050 [3].The plastic used in horticulture, primarily non-degradable PE (Polyethylene) or PVC (Polyvinyl chloride) significantly contribute to plastic waste pollution [4]., it is predicted that plastic last in landfills for greater than 300 years before being completely degraded.

Plastic waste is very harmful for environment and for the living organism also,Plastics can negatively affect the soil ecosystem by releasing toxic substances and inhibiting soil dwelling microbes and other organisms. Furthermore, plastic-associated toxic compounds can potentially enter the food chain and affect human health leading to the microplastic toxication in human body which affects various vital organs [5].The adverse effects of plastic contamination on seed germination, root penetration, nutrient and water flow, and root uptake of water and nutrients from soil which leads to stunted growth of plants and early senescence. [5]. Micro plastic has become a concerning global environmental problem. It is toxic to aquatic organisms and can spread through the food chain and pose a threat to humans [6]. In the environment, the size of microplastic is similar to that of the food of many aquatic organisms; microplastic is often eaten by mistake [7].More studies have focused on the effects of microplastic on marine organisms, and some reports showing that microplastic can enter the terrestrial food chain [8].

Some species of fungi have been found to degrade different types of plastic like petroleum-based polymers and thin microplastics as demonstrated by the following examples: an isolate of *Aspergillus flavus* can degrade polyester PU (PS-PU) isolated from different Jordanian habitats. *Streptomyces* and *Aspergillus flavus* shows biodegradation of disposable polyethylene[9].*G. panoramas*has been reported to degrade PUA[10].*C. cladosporioides* has been demonstratedto degrade PU from plastic debris[11].Fungi*Trichoderma viride* and *Aspergillus nomius* can degrade LDPE (Low density polyethylene)[12].

*A. fructus*degrade PE by forming biofilmthe involvement of various enzymes secreted by different fungi help to make the plastic polymer structure fragile and easy to degrade [13]. The mechanism behind their degradation process is reviewed and thephylogenetic analysis of various fungi degrading plastic is been discussed.

This review proposes a critical cross-assessment of knowledge from different researcheswhich can be applied to plastic degradation by fungi and aid in bioremediation strategies development for removal of plastic from environment.

2.Plastics and their biodegradability

There are various classifications of plastics, and for this review, their level of biodegradability is considered an important role (Table 1). Depending on the plastic type, plastic can be produced aseither a resin or a fiber or a mixture of both. There are several major chemical bonds found in plastics, such as C-C bonds [*e.g.,* in the back bone of PE, PVC and PP (Polypropylene)], amide NH-CO bonds (*e.g.,* in nylon), and ester bonds [*e.g.,* in PET(polyethylene terephthalate)].Research on the biodegradability of plastics indicates that the presence of hydrolysable ester bonds in plastics such as polyesters contributes to the degradation [14].

The terms "plastic types" and "production types" were derived from reviewShah et al. (2008) [15]. A biodegradable plastic product is indicated by a +, and a non-biodegradable plastic product by a −. The review focuses on how insights gained from fungal degradation can enhance the breakdown of both degradable and non-degradable plastics,listed in Table 1.

Table.1. Types of plastics based on their production type (resin or fibre) along with their ability to get degraded

Sr No.	Abbreviations	Name	Production type	Biodegradability
1	PU(R)	Polyurethane	Resin	-
2	PET	Polyethylene terephthalate	Resin & fibre	-
3	PVC	Polyvinyl Chloride	Resin	-

4	PVP	Polyvinyl polypropylene	Resin	-
5	LDPE	Low density polyethylene	Resin	-
6	HDPE	High density polyethylene	Resin	-
7	PS	Polystyrene	Resin	-
8	PP	Polypropylene	Resin	-
9	PA	Polyamides (nylon)	Fibre	-
10	PGA	Polyglycolic acid	Resin	+
11	PLA	Polylactic acid	Resin	+
12	PCL	Polycaprolactone	Resin	+
13	PHB	Polyhydroxybutyrate	Resin	+
14	PHV	Polyhydroxyvalerate	Resin	+
15	PVOH	Polyvinyl alcohol	Resin	+
16	PVAc	Polyvinyl acetate	Resin	+
17	PBS	Polybutylene succinate	Resin	+
18	PBSA	Polybutylene succinate adipate	Resin	+

A biodegradable plastic product is indicated by a +, and a non-biodegradable plastic product by a −. The terms "plastic types" and "production types" were derived from review Shah et al. (2008) [15]. A biodegradable plastic product is indicated by a +, and a non-biodegradable plastic product by a −.

3. Potential of fungi degrading the natural materials in environment

Fungi candegrade complex compounds present in nature by secreting various enzymes and one of the toughest natural materials is the lignin which is composedof cellulose, hemicellulose and pectin.There are various types of lignocellulosic wastes which can be degraded by fungi such as wheat or rice straw, pulp, wood chippings or wood sawdust [16].Biomass degrading fungi mainly rely on complex degradative machineries that generally catalyzes two types of processes:first is the direct enzymatic depolymerization, for example, by cellobiohydrolases and second is the generation of oxidative species (e.g., radicals) that then act on the biomass [17].Only two groups of basidiomycetes fungi have evolved the ability to degrade wood from dead plants they are called as “white-rot” and “brown-rot” fungi, which can degrade it fullyor partially [18].The mechanism of the degradation is followed by attack on lignocellulose can be primarily oxidative where the white-rot fungi attack the lignin by peroxidases or laccases to render the cellulose and hemicellulose accessible for further degradation. In contrastto this mechanism brown-rot fungi use non-enzymatic Fenton’s chemistry to directly attack the cellulose [19]. Some ascomycete fungi can also degrade wood cell walls by forming chains of diamond-shaped cavities that generally follow the orientation of the S2 elementary fibrils, causing soft rot [20].Soft rot fungi are known to produce a full complement of cellulolytic enzymes which can act on any wood cell but its activity on lignin degradation is unreported(17). Lignocellulosemonomers are linked together by glycosidic bonds and therefore it is cleavable by hydrolysis, lignin is a complex aromatic biopolymer [21] displaying methyl ester and C-C bonds. The same bonds occur in many plastics types although the surrounding bonds can differ.

Research on the disintegration of low- or non-biodegradable polymers, like polyolefins (like PE or PP), are becoming more and more extensive. The mechanisms underlying the breakdown of these polymers are still not well understood, though. Examples of bacterial systems and enzymes are discussed in this section since the molecular and biochemical insights are more advanced for these systems and enzymes than for their fungal counterparts.As an illustration, consider monoxygenases, an alkane hydroxylase that can break down PE. An example of this would be the alkane hydroxylase from *Pseudomonas aeruginosa*.Low molecular weight PE is degraded by AlkB [22].It is known that alkane hydroxylases work in this manner, hence terminal hydroxylation is the mechanism of this degradation [23].The absence of reports of C-C bond cleavage in the PE backbone owing to biodegradation or the emergence of long carbon chain hydrolysis products, which would indicate C-C bond cleavage in the PE backbone, was highlighted by [24].

According to a distinct study, PE degradation required a novel combination of analytical methods based on NMR spectrometry and liquid chromatography-mass spectroscopy [25]. The bacteria *Rhodococcus rhodochrous* degrades oligomers isolated following an oxidative pretreatment of HDPE films for up to 240 days [25]. Although the β-oxidation of C-C bonds within cells is regarded as a significant mechanism for chain cleavage, external mechanisms also seem to have a significant role in causing chain cleavages [25].The ability of bacterial system PETases causes PET degradation. The crystal structure of a PETase from the *Ideonellasakaiensis* bacterium has beenelucidated[26].

4. Plastic degradation by fungi

4.1 Landfill isolates and plastic degradation

Plastics are mainly dumped in the landfill; all over the world landfills are saturate with plastic waste. In a recent research fungal candidates were isolated from local landfill soil from different sites;all isolates were screened for their ability to grow in LDPE containing MSMB (Mineral salt medium broth) medium. The medium was supplemented with 0.5% glucose to initiate the growth of isolates. Results showed that two isolates, Isolates RH03 and RH06 identified as *Trichoderma viride*and *Aspergillus nomius* with 97% and 96% similarities(12) exhibited slow growth, while the others did not until 45 days incubation.These two isolates were considered as potential fungi and used for further study[12].

The LDPE film strength was reduced by average in with 58% and 40% reduction in RH03 culture and RH06 culture respectively. This means that LDPE film treated with these isolates became fragile and analyses in this study confirmed that the tested isolates have an ability to degrade the plastic (LDPE)[12].

Another similar research carried out by using Landfill soil isolates collected from Vellore Institute of Technology (VIT), Tamil Nadu, India. All the fungal isolates collected from landfill soil area were screened for their potency to degrade LDPE after 8–10 days of incubation time at 25–30^{0}C in enrichment medium. Based on this screening, the Phylogenetic and molecular evolutionary analysis, strain*A. clavatus* strain JASK1 was selected for LDPE degradation studies (27)weight reduction test is carried outin that study, 35 % weight loss of LDPE films was observed after 90 days of incubation with *A. clavatus*strain JASK1 whereas in control flask there is no weight loss of LDPE films [27].

CO2 evolution test is carried out toassess degradation of metabolic carbon dioxide evolved during the growth period. In that study, the LDPE was incubated for 4 weeks, along with *A. clavatus* sp. resulting in 2.32 g l-1 production of CO2. Their findings were found to be similar with the work done by [28]. FTIR analysis is done of the degraded LDPE films which gives a close view of N–H stretching of aldehyde group at 3334.92 and 3228.84 cm-1, C–C=C symmetric of aromatic ring at 1639.49 cm-1, C=O stretching of aldehyde group at 1735.93 cm-1, peak at N=O bend which corresponds to 1365.60 cm-1, C–O stretching of ether group at 1217.08 and 1078.21 cm-1 . The most prominent structural changes were observed in the LDPE sample degraded by strain JASK1.Similar pattern was also observed with oxo-biodegradable plastic by *Pleurotusostreatus*when analyzed using FTIR spectrum.

In AFM analysis the micrographs demonstrate localized degradation of the LDPE in the presence of *A. clavatus* strain JASK1 resulting in the formation of grooves, fractures and mild erosion which suggested that the fungus had penetrated into LDPE matrix during the degradation period [27].SEM analysis is used to confirm that the surface of LDPE becomes physically weak after biological treatmentwith*A. clavatus* strain JASK1 showed surface erosion, cracks, folding and fungal colonization, by all these test analysis A. clavatusqualifies as a suitable candidate for LDPE degradation [27].

4.2 Marine isolates degrading plastic

Plastic debris in the environment poses a significant threat because of their resistivity to photo oxidative, thermal, mechanical and biological processes [15].Plastic debris makes their way to water bodies they're through water and wind accumulates on the shoreline on the beaches. Plastic debris wereused to isolatefungi[11]. In total twelve fungus species and one species of Oomycota were tested to degrade PE or PU, after three weeks of inoculation there was no sign of halos in PE degradation but visible halos were observed in PU degradation assay.Four fungal species were identified as potent degradersand molecular characterization was done(*Cladosporium cladosporioides, Xepiculopsisgraminea, Penicilliumgriseofulvum, and Leptosphaeria* sp.).Out of the four fungal species isolated from the plastic debris and able to degrade PU, *Xepiculopsisgraminea*was the only species that was able to degrade TA. The best-known fungi are members of the genera *Aspergillus*, *Penicillium*, and *Trichoderma*. Two ascomycete and two basidiomycete fungi from this study were reported to to degrade PU (11).

In another study where a total of 262 fungal strains were isolated from 47 PET wastes an after screening 146 representative strains of 108 species were used in PCL degradation test, the clear zone lengths of the fungal strains were in the range of 0–13.96 mm. out of 146 strains Five species exhibited strong PCL degradation, 18 species showed moderate PCL degradation, 64 species presented with weak PCL degradation, and 21 species did not degrade PCL at all. After species identification*Phaeophleosporaeucalypticola* had the strongest PCL degradation ability (clear zone length=13.96 mm). Four *Cladosporium* species also showed strong PCL degradation activity in there are *Cladosporium allicinum* had the widest clear zone (13.92 mm) followed by *C. xanthochromaticum* (11.37 mm), *C. rectoides*(10.34 mm), and *C. tenuissimum* (10.21 mm) andSeventeen species of moderate PCL-degrading fungi were classifed into ten genera which include two *Alternar*ia spp., two *Aureobasidium* spp., two *Phaeosphaeria*spp., five*Cladosporium*spp., and each one species of *Cytospora*, *Epicoccum*, *Neodevriesia*, *Nothophoma, Sarocladium, Sphaeropsis*, Weak PCL-degrading fungi included 64 species. They were classified in 30 genera [30].

Thisstudy demonstrated that numerous fungi inhabit PET wastes in the marine environment, some species are potent PCL degraders.This research indicated that various fungal taxa play a vital role in marine plastic waste decomposition.

4.3 Edible fungi a potent degrader of plastic bags

The palatable mushrooms Pleurotusostreatus is utilized in the breakdown of oxo-biodegradable plastic, such as the plastic bags seen in supermarkets.In this investigation, after 45 days of incubation, scanning electron microscopy revealed fungal colonization on the oxo-biodegradable waste's surface, confirming the presence of P. ostreatus fungal biomass on the oxo-biodegradable plastic.When compared to the control, the plastic garbage also developed a halo of discoloration during the incubation period.These halos are a result of the lignocellulolytic enzymes that the fungus secretes.The oxidation of the oxo-biodegradable plastic was illustrated in this investigation,in addition, this study offers a novel solution for handling plastic waste that comes from food packaging, grocery bags, and industrial plastic packaging.

4.4 Phylloplane fungi the mulch film degrader

The most popular and extensively used plastic goods on agricultural farms are agricultural mulch films, which are used to cover cultivated fields to keep the soil temperature constant and to keep weeds from sprouting.Phylloplane refers to the surface found on tree leaves, and the fungus that live there are known as phylloplane fungi. Twelve hundred and twenty-seven phylloplane fungal isolates with different morphologies for the investigation. Of these, fifty-five (4.5%) were chosen because they had broken down PBSA emulsion; of these, forty-three (78.2%) and thirty-seven (67.3%) broke down PBS films.On FMZ agarose plate. Only strain B47-9 showed a high degradation rate for both PBSA film (91.2 ± 1.64 %) and PBS film (90.9 ± 1.17 %) out of them, and it was chosen for additional testing. Of them, four strains degraded over 90% of PBSA film.During the process of the treated films incubation, fungal mycelia with a B47-9 culture isolated on BP mulch film increasingly covered the film's surface. after an incubation of six days. A thorough degradation of the films was carried out according to the weight loss of the recovered remaining film [32].When the deteriorated film was examined under a SEM on sterilized soil, cracks were visible along the lines where fungal growth was seen. When it came to breaking down PBSA and PBS films on agarose, B47-9 was shown to be the most effective isolated strain.According to their research, the degradation of soil-mounted film has been accelerated in direct proportion by the identified and verified strain B47-9. It can be presumed that strain B47-9, which was isolated from a healthy barley leaf, can be used safely to speed up the breakdown of BP mulch film for use in degrading [32].

4.5 Plastic degradation by Gut fungi

Microorganisms are ideal candidates for bioremediation purposes as they have the capacity to
synthesize enzymes and due to their small size, they can get access to contact with the complete surface area of plastic. They use plastic and other environmentally harmful chemicals as a source of nutrients (carbon) and energy (electrons) and the end products of degradation will be water and carbon [74]. Microorganisms can thrive in extreme environmental conditions and bear many properties which will be useful for plastic degradation and as such microbe are the gut fungi which can live in the gut of insects as well as mammals with other microbes.

A recent study demonstrated that fungi *Aspergillus, Paecelomyces, Penicillium, Alternaria*, and *fusarium,trichoderma*most common strains synthesizing urease and protease enzymes which can degrade polyurethane [74]. *Pestalotiopsis* an endophytewhich was isolated from wooden plants synthesize enzyme belonging to serine hydrolase family,which are also present in gut of some wood eating insect *Pestalotiopsis and* can degradepolyurethane[75]. In another study Fungus *Aspergillus niger* and *Penicillium pinophilum* were used in whichthermo-oxidized low-density polyethylene (TO-LDPE) showed high degradation by the fungus when treated with ethanol as co substrate[76].High density polyethylenewas exposed to UV radiation before inoculation of fungi*Aspergillus niger, Aspergillus flavus, Aspergillus oryzae,*which increased the rate of degradation [77]. The gut fungi are potential degrader of various plastic polymers such as polyurethane, LDPE,high density polyethylene and other polymers by synthesizing various lytic enzymes like urease, protease, hydrolases.Research is underway for better degradation and more strains are being screened for rapid plastic degradation.

5. Fungi species involved in plastic degradation

Numerous fungi that are found in nature have been shown to have the potential to break down plastic by secreting different enzymes that damage the material's structure and cause it to become fragile. Tree fungi, soil isolates, landfills, and marine plastic are just a few of the places where these fungi are commonly found. Several fungi have been reported to be involved in plastic degradation. Fungi possess enzymes capable of breaking down complex organic molecules, including those found in plastics. Here are some fungi that have shown potential for plastic degradation. Various species of Aspergillus have been studied for their ability to degrade plastics, including polyurethane and polyester. Aspergillus spp. produce enzymes like esterases and lipases that can break down the ester linkages present in many plastic polymers.Penicillium fungi have been investigated for their potential to degrade plastics such as polyethylene and polyurethane. These fungi produce a range of extracellular enzymes, including lipases, esterases, and peroxidases, which can facilitate plastic degradation.Trichoderma species are known for their ability to produce cellulases and hemicellulases, which enable them to degrade cellulose-containing materials. Some studies have suggested that certain Trichoderma strains may also have the capability to degrade plastics like polyethylene.Rhizopus fungi have been found to degrade various plastics, including polyethylene and polyurethane. They produce enzymes like lipases and esterases that can hydrolyze the ester bonds present in many plastic polymers.This fungus gained attention for its ability to degrade polyurethane plastics. It produces enzymes capable of breaking down polyurethane into simpler compounds that can be utilized as carbon sources.Some species of Fusarium have demonstrated the ability to degrade plastics, including polyethylene and polypropylene. Fusarium fungi produce enzymes such as cutinases and esterases, which can hydrolyze ester bonds present in plastic polymers.While primarily known for its ability to degrade lignin in wood, this white-rot fungus has also shown some capability to degrade certain plastics, including polystyrene. Its lignin-degrading enzymes may play a role in plastic degradation as well.

These fungi offer promising avenues for research into bioremediation strategies for plastic pollution. However, it's essential to note that further research is needed to optimize these processes and to develop practical applications for large-scale plastic degradation using fungi.They are also strong degraders. The degrading plastic type and the habitat from which the fungus is separated for study are listed in the Table. 2 below for different genus of fungi.

Table. 2. The degrading plastic type and the habitat from which the different genus of fungi are isolated for study.

Sr no.	Fungi	Plastic type	Environment	References
1.	*Acremonium* sp.	PHB, Poly[3 HB-co-(10 mol%) 3HV]	Soils	44

2.	*Alternaria alternata*	PE, LDPE	Dumpsites, Mangrove stands	45 51
3.	*Aspergillus flavus*	PE, HDPE, LDPE, PVC, PCL, PS-PUR, PEA, PPA, PBA	Soils	51
4.	*Aspergillus fumigatus*	PHB, Poly[3HB-co-(10 mol%) 3HV], HDPE, LDPE, PS-PUR, Sky-Green, Poly[3HB-co-(7–77 mol%) 3HV], PHV,	Soils	47, 48,49, 55
5.	*Aspergillus Niger*	PE, HDPE, LDPE, PVC, Sky-Green, PEA, PPA, PBA	Soils	48, 53,54
6.	*Aspergillus terreus*	LDPE, HDPE, PS-PUR, PE		56,57
7.	*Aspergillus versicolor*	HDPE, LDPE, PVC, PEA, PPA, PBA	Soils, Degraded polyimides, Marine water	58
8.	*Aureobasidium pullulans*	PCL, PEA, PPA, PBA	-	60
9.	*Chaetomium globosum*	HDPE, LDPE, PVC, PCL, PEA, PPA, PBA	Soils	48
10.	*Chrysonilia setophila*	HDPE, LDPE, PVC	Soils	48
11.	*Emericellopsis minima*	PHB, Poly[3HB-co-(30 mol%) 3HV]	-	61

12.	*Fusarium oxysporium*	Poly[3HB-co-(12 mol%) 3HV], HDPE, LDPE, PVC, PET	Soils	62 ,63
13.	*Fusarium solani*	LDPE, HDPE, PVC, PCL, PS-PUR, PHB, PET	Soils	64
14.	*Paecilomyces farinosus*	Poly[3HB-co-(12 mol%) 3HV], PHB, Sky-Green	Soils	61
15.	*Phanerochaete chrysosporium*	PCL, polyalkylene dicarboxylic acids	Soils	66,67
16.	*Rhizopus arrhizus*	PCL, polyalkylene dicarboxylic acids	Soils	68

PHB: Polyhydroxybutyrate, PUR: Polyurethane, PCL: Polycaprolactone, PPA: Polyphthalamide, PBA: Polybutanamide, PHV: Poly (3-hydroxybutyrate-co-3-hydroxyvalerate), PES: Polyethersulfone, PEA: Polyesteracetals, PBS: Polybutylene succinate, PBSA: Poly (butylene succinate-co-butylene adipate), PET: Polyethylene terephthalate, HDPE: High-density polyethylene, PVC: Polyvinyl chloride, LDPE: Low-density polyethylene, PS-PUR:
Polyester-polyurethane, PP:Polypropylene, PS: Polystyrene, PE: Polyethylene, PU:Polyurethane. These keywords are use in the table.

6.0 Phylogenetic analyses of fungi

Phylogenetic analyses are most important process in study of any organism and it reveals the characteristics and genotypic information of the organism. In this review the various methods involved in phylogenetic analyses of plastic degrading fungi has been reported. In one study the 18S rRNA nucleotide sequence of JASK1strain was put in the NCBI and Gene bank and the accession number KT148627 was obtained. The sequences with the highest 18S rRNA partial sequence similarity were selected and compared by CLUSTAL W. Phylogenetic and molecular evolutionary analyses were obtained by using MEGA 4.0 software with the Kimura 2-parameter model and the neighbor-joining algorithm. The alignment of these sequence with other sequence found in the data base showed a 99 % similarity with the sequence of *A. clavatushence the* JASK1strain is considered as *A. clavatus*in that study through analyses [27].

In another studya data matrix containing 395 taxa, including four out-group taxa (*Basidiobolusranarum*AFTOL-ID 301, *Basidiobolusranarum*ARSEF 260, *Basidiobolusranarum*ATCC 14449, and *Olpidiumbrassicae*AFTOL-ID 633) were generated in that study using ITS, LSU, SSU, TEF, RPB1, and RPB2 sequence data a gene bank. They use Multiple sequence alignments for each gene (ITS, LSU, SSU, TEF, RPB1, and RPB2) which were generated with MAFFT version 7 [69]. The Long alignment gaps were removed using trimAl tool [70]these alignment were made available at Phylemon2 web server and manually adjusted and checked in BioEdit v. 7.0.4[71]. Maximum likelihood phylogenetic analyses were performed by using CIPRES web portal using RAxML-HPC2 on XSEDE (8.2.12) tool [72]and by using these software's and technique the compressed overview of the phylogram resulting from the phylogenetic analysis is formed where classes including plastic-degradingfungi are found [27]. These analyses help us to identify and screen the various fungi easily by assessing the analyze comparing the isolates with their similarity leads to easy identification process in any research.

Phylogenetic analyses of fungi involved in plastic degradation have been conducted to understand the evolutionary relationships among these organisms and to identify common traits or genetic factors associated with their ability to break down plastics.

7. Enzymes involved in fungal degradation

The majority of the enzymes released during the plastic biodegradation process fall into the hydrolase and oxidoreductase classes (Table 3). Because these enzymes are involved in both industrial and natural processes, they have been investigated in great detail.
The table contains the enzymes released by various fungal species on different types of plastic that have been examined by various researchers and mentioned in the references. These fungal species are powerful degraders of plastic.

Table.3. Fungal Enzymes involved in plastic degradation

Sr no.	Enzyme	Enzyme Commission (EC) Number	Activity	Plastic type degradation	References
1.	Lipases	1.10.3.2	Oxidoreductases	Polyethylene, PVC	33 34
2.	Cutinases	3.1.1.3	Hydrolases	(ES-PU) film	35
3.	Peroxidase	3.1.1.74	Hydrolases	PET film	36

4.	Proteases	1.11.1.2	Oxioreductases	polyethylene	16, 37
5.	Esterases	3.4.21	Hydrolases	polylactic acid	38
6.	Laccases	3.1.1.13	Hydrolases	polyurethane	39

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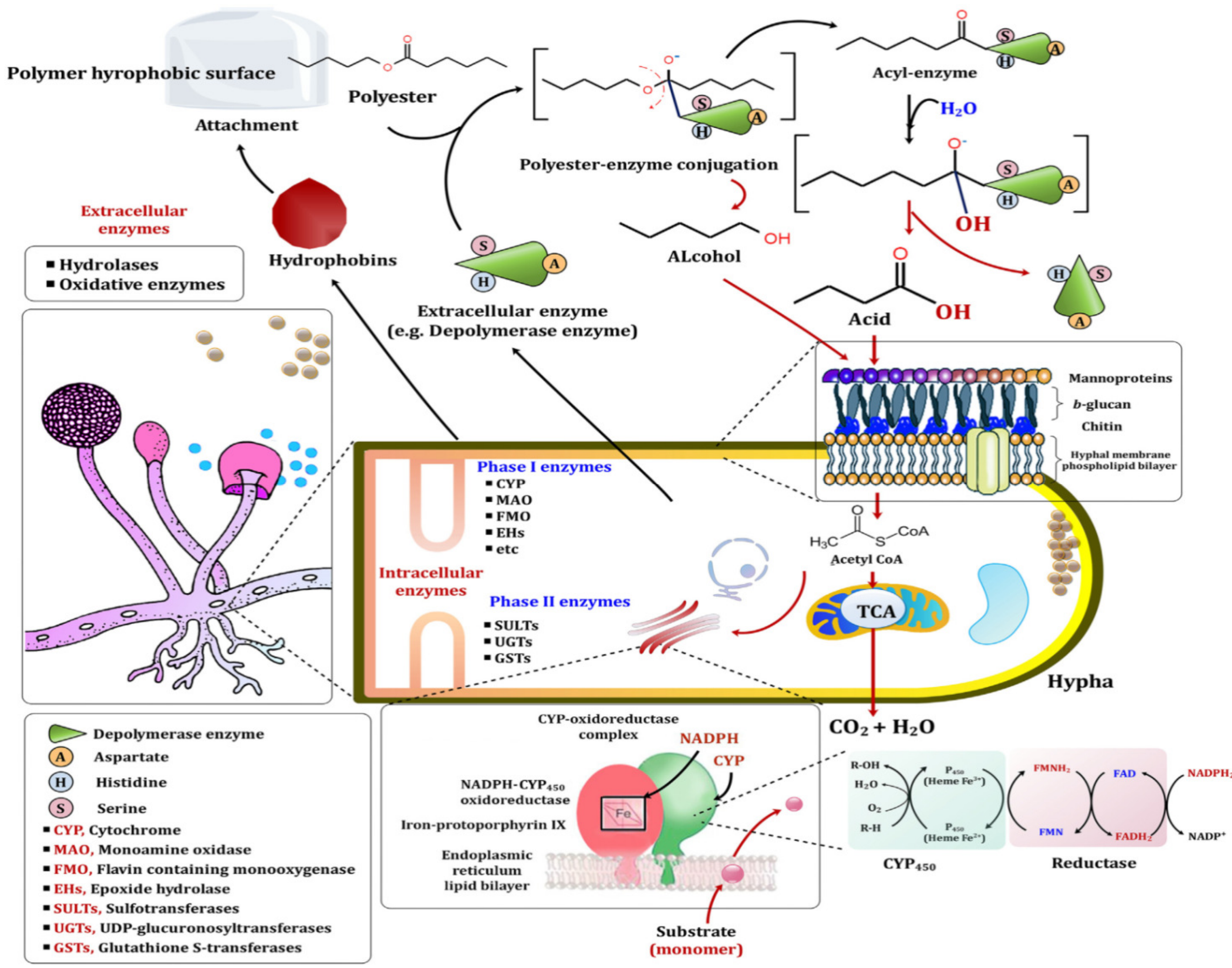

Fig 1. Mechanism of polyester degradation by fungal enzymes (78)

8. Bio-prospecting and plastic degradation

Bioprospecting is a process of converting plastics to any useful products,fungal and microbial biodegradation of plastics would be more effective if it is replaced by the concept of bioconversion of plastics to valuable products as the degradation intermediates of plastics can be directed to form useful by-products [41]. In plastic degradation fungi do not mineralize the plastics, they only weaker the bonds or convert them to another weaker form of plastic which can get deterioted easily therefore by using bioprospecting in this process of degradation we can utilize the converted forms of plastic polymers.

The various enzymesand microbes can be use in bioprospecting converting the plastic into a useful product, Bioprospecting of enzymes which are involved in plastic degradation can be done.Bioprospecting of cutinases can be done which having plastic degrading activity.Cutinase enzymes have been extensively studied for phytopathogenicity but also for plastic degradation [41].Another example of cutinasefrom *A. oryzae*that degrades the biodegradable plastics PBS and PBSA [42].The presence of cutinaseenzymes in phytopathogenic fungiand structural similarity between two cutin monomer units and the PCL trimer is responsible for the biodegradation of plastic polycaprolactone [43]. Various enzymes from phytopathogenic fungi can be extracted and characterize to use their plastic degrading ability.

9.Regulatory hurdles and biosafety

Biosafety is most important in any research and working with organisms, involve extra precaution use of fungi for plastic degradation from this perspective of plastic degradation, *e.g.* if a strain is modified for improved plastic degradation, whether there could be emergent virulence needs to be assessed (by how the engineered fungus also degrades plant cell walls). The avoidance of unintentionally producing microbes with increased pathogenicity [40].The use of genetically modified organisms (GMOs) presents a regulatory hurdle to overcome, particularly in the European Union. Some genetic technologiesused in many of the implementations of CRISPR-Cas9 could overcome some of these regulatory hurdles in jurisdictions that do not consider a CRISPR-Cas9 edited fungus as a GMO [40].However, performing this biosafety risk assessment is worthy of the potential from improved plastic-degrading fungi for emergent virulence towards plants or interference with the natural process.

10. CONCLUSION

Based on the literature survey, it can be concluded that increase in plastic pollution greatly affects living organisms; biodegradation of plastics by fungi can help to decrease the problem. Biodegradation of plastic polymers has been one of the current focused areas of research on solving plastic pollution. The review provides eminent information on various fungi which are involved in degrading different types of plastic polymers, and various enzymes produced by various fungi which are involved in the biodegradation mechanism.The screening of different soil samples, isolating fungi from marine environment and plastic waste dump site could lead to new explored strains, with superior performance, even some edible fungi are also potent degrader. Many studies identified the degrading ability of fungi but very few are effective in biodegrading the plastic polymers. Fungal enzymes show high potential in biodegradation of plastics an also increases the ability of fungal species to degrade it more easily. Currently, most studies are still performed in vitro under laboratory conditions. Further research is required to improve the understanding of the mechanism of action of these enzyme and genomics behind it.These investigations could lead to optimized fungal species with high degradation efficiency and vast industrial applications to help reduce plastic waste pollution and make a plastic free environment.

11. CONFLICTS OF INTEREST

The authors declare there is no conflict of interest

12. REFERENCES:

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Legends to Figures and Tables.

Fig.1. Mechanism of polyester degradation by fungal enzymes
Table. 1.Types of plastics based on their production type (resin or fibre) along with their ability to get degraded.
Table. 2. The degrading plastic type and the habitat from which the different genus of fungi areisolated for study.

Table -3Fungal Enzymes involved in plastic degradation.