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REVIEW OPEN ACCESS

Role of Fungi in Microplastic Degradation: Brief Mechanism, Applications and Future Prospects

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Abstract

Microplastics (MPs), persistent pollutants with particle sizes smaller than 5 mm, have emerged as a serious ecological and health hazard across terrestrial and aquatic ecosystems. Biological degradation, particularly by fungi, has gained attention as an environmentally friendly and sustainable approach for microplastic remediation. This review briefly explores the role of fungi in microplastic degradation, focusing on mechanisms, types of fungi involved, degradation products, factors influencing degradation, analytical methods, and future applications. The article also addresses knowledge gaps, biotechnological advancements, and future research directions to enhance fungal degradation efficiency. More research should be conducted on biotic microplastic degradation in order to find underlying mechanisms in depth, to get rid of microplastics, persistent in the environment.

Keywords: Microplastics; Degradation; Fungi; Environment; Fungal degradation

Introduction

Microplastics, defined as plastic fragments smaller than 5 mm, originate from both primary sources such as cosmetics and industrial abrasives, and secondary sources such as the degradation of larger plastics (Singh, 2022; Ahmed, 2022; Tayal et al., 2023; Singh and Singh, 2024; Kaur et al., 2023; Gupta et al., 2022). They accumulate in soil, freshwater, marine systems, and even the atmosphere (de Souza Machado et al., 2018). Traditional methods like incineration or chemical degradation are energy-intensive and can generate toxic by-products. Fungi, known for their potent enzymatic systems, represent a promising biological agent for microplastic biodegradation (Othman et al., 2021).

Several fungal genera have demonstrated the capacity to degrade synthetic polymers such as polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyurethane (PU) (Table 1). Among the most effective degraders are members of the phylum Ascomycota, including species of *Aspergillus*, *Penicillium*, and *Trichoderma* (Zhang et al., 2020). Basidiomycota fungi such as *Phanerochaete chrysosporium* and *Pleurotus ostreatus* also show significant plastic-degrading abilities. Some Zygomycota like *Rhizopus* species have also been implicated in this role. In marine environments, fungi isolated from plastisphere biofilms—such as *Cladosporium* and *Alternaria* sp. have shown remarkable degradation activity (Oliveira et al., 2020).

Mechanisms of fungal microplastic degradation

The degradation of microplastics by fungi generally begins with colonization and biofilm formation. Fungal hyphae attach to plastic surfaces via hydrophobic interactions, forming dense biofilms that alter the surface characteristics of the plastic and initiate degradation. Once colonized, fungi produce extracellular enzymes capable of cleaving complex plastic polymers. These include laccases, various peroxidases such as manganese peroxidase and lignin peroxidase, as well as cutinases, hydrolases, and esterases (Solanki et al., 2022). These enzymes catalyze either oxidative or hydrolytic cleavage of carbon-carbon (C–C) or carbon-oxygen (C–O) bonds within the polymers.

The initial oxidation introduces functional groups like hydroxyl and carbonyl moieties, increasing the hydrophilicity of the plastic and making it more amenable to enzymatic attack. Eventually, smaller fragments are assimilated intracellularly and mineralized into carbon dioxide (CO_2), water (H_2O), methane (CH_4), and fungal biomass (Golmohammadi et al., 2023).

Table 1. Various studies involving the use of fungal agent for plastic degradation

Study	Fungal Agent	Main Findings	Citation
Marine fungi degrade plastic and can be conditioned to do it faster	Marine fungi (e.g. *Aspergillus*, *Penicillium* spp.)	Over 60% marine fungi near Hawai could degrade polyurethane; conditioning accelerated degradation by 15% in 3 months	de la Rosa et al. (2025)
Microplastic removal and biodegradation by *Alternaria alternata*	Native Mediterranean *A. alternata*	Effectively degraded polyethylene and polystyrene microplastics in aquatic systems	Marino et al. (2025)
Fungal-mediated biodegradation of synthetic plastic	Multiple fungal genera including *Trichoderma*, *Phanerochaete*, *Fusarium*	Review of fungal enzymatic mechanisms, highlighting oxidative and hydrolytic degradation	Patel et al. (2025)
Advances in mycoremediation strategies for emerging contaminants	White rot and soil fungi	Framework of myco-deterioration, fragmentation, assimilation, mineralization; scalable bioremediation potential	Saini et al. (2025)
Ecological and genomic perspectives on fungal plastic biodegradation	Comparative fungal genomics	Showed a strong link between enzyme gene clusters and degradation ability across fungal phyla	Qureshi et al. (2025)

Types of microplastics degraded by fungi

Polyethylene (PE), commonly used in packaging and plastic bags, has been degraded by fungi such as *Aspergillus niger* and *Penicillium simplicissimum*. Polypropylene (PP), used in containers and textiles, has shown susceptibility to degradation by *Fusarium solani* and *Cladosporium cladosporioides*. Polystyrene (PS), found in Styrofoam and insulation materials, can be degraded by *Phanerochaete chrysosporium* and *Trametes versicolor*. Polyurethane (PU), used in foams and adhesives, has been successfully degraded by fungi like *Aspergillus tubingensis* and *Curvularia* sp. (Dey et al., 2023).

Factors influencing fungal degradation

The efficiency of fungal degradation depends on several factors. The physical and chemical properties of plastics—such as crystallinity, molecular weight, and presence of additives—can significantly affect biodegradability. Environmental conditions including pH, temperature, oxygen availability, and moisture levels also play a crucial role. The fungal species' intrinsic factors, such as its enzymatic profile, growth rate, and metabolic adaptability, further influence degradation outcomes (Othman et al., 2021). Pre-treatment methods like UV exposure, mechanical shredding, and chemical oxidation can enhance degradation by increasing the surface roughness and hydrophilicity of the plastic (Solanki et al., 2022).

Analytical techniques for assessing degradation

Various techniques are employed to evaluate the extent and nature of fungal degradation of microplastics. Weight loss analysis helps quantify mass reduction of the plastic sample. Scanning Electron Microscopy (SEM) is used to assess surface morphology changes. Fourier Transform Infrared Spectroscopy (FTIR) detects alterations in functional groups, while Gel Permeation Chromatography (GPC) monitors changes in molecular weight distribution. Thermogravimetric Analysis (TGA) helps understand thermal stability and degradation patterns. CO_2 evolution tests are conducted to measure mineralization of degraded plastic fragments (Solanki et al., 2022).

Biotechnological and environmental applications

Fungi can be utilized in bioaugmentation strategies by introducing potent degraders into plastic-contaminated environments to accelerate degradation. Mycoremediation, the use of native fungal strains, offers eco-friendly solutions in both terrestrial and aquatic ecosystems (Oliveira et al., 2020). The immobilization of fungal enzymes on solid supports has been found to enhance their activity and reusability, while advances in genetic engineering allow for the development of more stable and substrate-specific enzymes. There is significant potential for integrating fungal degradation systems in industrial waste treatment plants and composting facilities to manage microplastic pollution more sustainably (Dey et al., 2023).

Challenges

Despite promising results, several challenges remain. There is a scarcity of field data demonstrating the effectiveness of fungal degradation under natural environmental conditions. Standardized protocols for evaluating and comparing fungal degradation efficacy are lacking. Some degradation processes may generate harmful by-products, raising ecological and health concerns. A deeper molecular understanding of the degradation pathways is needed to optimize fungal systems (Golmohammadi et al., 2023). Moreover, marine and extremophilic fungi remain understudied and underutilized (Lehmann et al., 2022).

Future Directions

Future research should focus on genomic and transcriptomic profiling of fungi to discover novel genes involved in plastic degradation. The application of CRISPR and synthetic biology tools could enhance enzymatic activity and stability. The formation of fungal consortia may result in synergistic degradation effects, enhancing efficiency. Field-scale studies are essential to evaluate the ecological feasibility of fungal degradation systems. Additionally, developing bioreactors optimized for fungal activity could pave the way for controlled, large-scale microplastic remediation (Dey et al., 2023).

Conclusion

Fungi possess unique ecological and biochemical capabilities for the degradation of microplastics. Their diverse enzymatic arsenal, adaptability to extreme environments, and compatibility with biotechnological tools make them highly promising agents for sustainable plastic waste management. By integrating fungal biodegradation with modern ecological and industrial waste management strategies, society can move closer to addressing the global microplastic crisis while fostering a circular bioeconomy.

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