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Bioremediation Of Contaminated Environments Through Mycology: A Review Of Current Advancements And Future Prospects A Short Review

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Article History	*Abstract*
Received: 30/09/2023 *Revised: 15/10/2023* *Accepted:30/10/2023* 	Mycological bioremediation is a novel strategy that takes advantage of the special skills of mushrooms, has become a viable method to reduce environmental pollution brought on by numerous toxins. This paper looks at the promise of mycological bioremediation as a long-term, environmental friendly technique for cleaning up the polluted regions while also giving an overview of recent breakthroughs in the field. It has become clear that using living creatures to remove or neutralize environmental pollutants is a potential strategy for dealing with a variety of environmental toxins. Mycology, the study of mushrooms, has become increasingly popular among the many bioremediation techniques due to its extraordinary potential for cleaning up polluted habitats. Fungi are significant agents in bioremediation efforts due to their distinctive characteristics, which include quick development, a wide range of metabolic skills, and an affinity for different contaminants.

Introduction:

Emerging contaminants are mostly caused by the manufacturing, use, and application of pesticides, medications, personal care products (PCPs), plastic polymers, and heavy metals. These substances are made to meet the growing demand for better living conditions, improved health, and food supply. However, there is significant waste generation associated with their production and utilization. Due to the excessive use of antibiotics and improper antibiotic disposal, antimicrobial resistance genes have developed as a result of the widespread use of microbial bioremediation to reduce the impacts and rising levels of these toxins. The enormous natural diversity of bacteria, which have a variety of routes for metabolizing or co-metabolizing a variety of substances, is advantageous for microbial biological degradation operations. Microorganisms can adapt to novel substances at a relatively quick rate, with bacteria's short generation time being coupled by strong rates of evolutionary adaptation.

Even harmful compounds may be used by microorganisms as cellular building blocks or a source of energy. Microbial metabolisms can be improved or designed to target certain contaminants using genetic modification, and microbial communities can be built to tackle specific pollution circumstances using synthetic biology technologies. Bioremediation procedures can be either in-situ, treating pollution where it occurs, or ex-situ, where the polluted matrix is removed and treatment is performed elsewhere. Fungi, which are common chemoheterotrophic organisms, offer a wide range of potential uses in bioremediation because of their capacity for biodegradation, which is mediated by a variety of oxidases and peroxidases.

Fungi as bioremediating agents

Fungi, a diverse eukaryotic kingdom, are increasingly attracting interest due to their potential applications in bioremediation. Fungi are ubiquitous chemoheterotrophic organisms found throughout terrestrial and aquatic environments but have received less attention in aquatic and marine habitats. As a result of their endo and extracellular enzymatic systems and ability to release acids, they are renowned for their power to target and metabolize a wide range of chemical types, including inorganic and organic pollutants.

Fungi have the ability to degrade materials through oxidative enzymatic reactions, which are mediated by various oxidases and peroxidases. Fungi have both intra- and extra-cellular processes for producing enzymes, with laccases and peroxidases being the most extensively studied extracellular enzymes. Quinone cycling is the source of hydroxyl radicals.

Alkanes, aromatics, and substances containing nitrogen, sulfur, and oxygen are among the petroleum-based hydrocarbons that fungi may break down. This highlights their potential in bioremediation procedures, combating environmental pollution of hazardous metals, and being suitable candidates for industrial bioremediation efforts and biotechnological applications. Recently, attention has been drawn to fungi as potential agents for wastewater treatment.

Degradation of pesticides

Pesticides are widely used to eradicate undesirable plants, insects, and rodents, but over 90% of these chemicals diffuse in the environment. White rot fungi (WRF) have been studied for their ability to break down various pesticides and organic pollutants. Thanks to enzymes like lignin peroxidase (LiP), manganese peroxidase (MnP), versatile peroxidase (VP), and laccase (Lac), WRF may perform extracellular and oxidative ligninolysis. Transverse ramets, a research candidate for pesticide bioremediation, have been used to accelerate the deterioration of hydrophobic pesticides at 25°C. The breakdown of pesticides involves fungi like cytochrome P450 in addition to extracellular ligninolytic enzymes. T. versicolor also degrades Fipronil, a phenylpyrazole-class pesticide with low water solubility, and highly polar pesticides acetamiprid and imidacloprid. P. chrysosporium, with 150 P450 monooxygenase genes, uses both external and intracellular processes to break down pesticides.

Extracellular transformations

Case Reference Example for Enzyme Reaction

Phenol and chlorinated phenol, PAH, phenolic azo dyes, and laccase-oxidized PAH are some of the excreted metabolites from TNT (Majcherczyk et al., 1998; Chivukula and Renganathan, 1995; Ehlers and Rose, 2005; Nyanhongo et al., 2006). Peroxidase of manganese Oxidations of PAH, different hues, and excreted TNT metabolites (Van Aken et al., 1999; Baborová et al., 2006; Qin et al., 2014)) Hydrogen atom Oxidation and hydroxyl radical damage Hydroxylation occurs with chlorinated hydrocarbons (Köller et al., 2000; Marco-Urrea et al., 2009c). Through hydroquinonequinone peroxidase reactions, the Fenton reagent 2-fluorophenol is created (Jensen et al., 2001; Kramer et al., 2004).

cellular transformations

Enzyme Reaction Case Study Reference

In certain fungi, there are over 100 genes that encode P450 oxidases. Dioxins, medicines, herbicides, hydroxylation PAH, and epoxidations.*P. chrysosporium* (Hiratsuka et al., 2001; Marco-Urrea et al., 2009b; Hata et al., 2010) encodes for 150 cytochrome P450. Kasai et al. (2010) and Yadav et al. (2006)

Transferases

Conjugate excretion involves the removal of hydroxyl groups to produce conjugates, which are then reduced to hydroxylamine- and dinitrotoluene. Nitro groups in various compounds, such as dioxins, medicines, herbicides, and PAH, are reduced to hydroxylamine- and dinitrotoluene. Fungi, including *P. chrysosporium*, have been shown to break down various fungicides, including pyrazole-carboxamides, DDT, Atrazine, Dieldrin, and Aldrin. These fungi possess a variety of ligninolytic enzymes, including lignin peroxidase (LiP), manganese peroxidase (MnP), versatile peroxidase (VP), and laccase (Lac), making them potential candidates for pesticide bioremediation purposes. Trametes versicolor, a filamentous fungus, has demonstrated the ability to eliminate herbicides like Diuron and Bentazon from agricultural effluent. In addition, cytochrome P450 is crucial in the breakdown of pesticides, providing fungus access to water-insoluble pollutants. *P. chrysosporium*, with 150 P450 monooxygenase genes, uses two different external and intracellular processes. Overall, the degradation of various fungi and their ligninolytic enzymes has shown promising potential for reducing pesticides and promoting their bioremediation.

Extracellular transformations

Fungi play a crucial role in the breakdown of various pesticides, including phenol, chlorinated phenol, phenolic azo colors, PAH, and phenolic azo dyes. They have been shown to effectively remove these chemicals through enzyme reactions, such as oxidation of TNT-excreted metabolites, hydroxyl radicals, nitrogen oxidation, and hydroxyl attack. In marine science, fungi have been shown to be more effective in breaking down specific pesticides than individual strains.

A group of several fungi, such as *Phanerochaete chrysosporium*, can be more effective in breaking down specific pesticides than individual strains. For example, a group of five fungal isolates was better able to break down Diazinon and methomyl pesticides than any of the individual isolates tested. Furthermore, it has been demonstrated that using the WRF *P. chrysosporium* and the mineral tourmaline together is more efficient at eliminating pesticides than applying the fungus or minerals alone. The potential for pesticide breakdown by marine fungus is steadily garnering attention. *Aspergillus sydowii* CBMAI 935, for instance, was the best strain for getting rid of all MP in marine conditions. Fungi can also be used for wastewater degradation, as demonstrated by *Bjerkandera spp*. The primary degrading mechanisms of the Lac enzyme for acetaminophen and bisphenol. A were oxidative coupling and radical polymerization. On multispecies consortia, including *G. applanatum* and the edible fungus *Laetiporus sulphureus,* the degradation of medicines has been studied.

In conclusion, fungi play a vital role in the breakdown of various pesticides, including phenol, chlorinated phenol, PAH, and phenolic azo dyes. By utilizing fungi and specific minerals, these processes can effectively remove pesticides from soil and water sources.

Drug and personal care product breakdown by fungi

Pharmaceuticals and personal care products (PPCPs) are becoming more prevalent as modern cultures place a greater emphasis on personal hygiene, health, and care. A sizeable part of PPCPs are discharged into the environment, for instance through sewage streams and wastewater treatment plants. Many PPCPs lack rules governing their use and disposal, which poses issues, especially when it comes to possible harm to ecosystems and human health if medications are used. Pharmaceuticals are a broad category of chemicals and compounds that are primarily employed in human and animal biological systems to enhance the biochemical or physiological functioning of such systems. Many of the pharmaceuticals' chemical makeup is unaffected by consumption, and their removal efficiency is as low as 10% for many commonly used medications.

Pharmaceuticals can be found in personal care goods like face creams and detergents, and some drugs may be included in personal care products. Microplastics adsorb to sludge, which poses dangers when disposed of, and their removal efficiency in municipal wastewater varies. Even cosmetics advertised as "natural" or "plant-based" may contain potentially dangerous ingredients, making them not environmentally friendly.

Several fungal strains have been studied to get rid of PPCPs, such as T. versicolor, which can break down a range of medicines. T. versicolor's monoculture was more productive than mixed cultures with additional fungus, possibly connected to growth inhibition and competition. T. versicolor may be a useful fungus for detoxifying hospital effluent, as it has been found to eliminate 46 of the 51 drugs and endocrine disruptors found in hospital wastewater.

Conventional plastic polymer degradation by fungi

Plastic waste, primarily produced in industries like packaging, textile, electronics, and consumer goods, poses a significant threat to the environment. According to estimates, 1.8 to 4.1% of plastic produced worldwide makes its way into the ocean through air deposition, riverine input, or coastal deposition. The "missing plastic paradox" has been explained by shear stress and weathering, which cause larger plastic objects to break down into ever-tinier fragments that evade current sampling methods.

Both bacteria and solar radiation degradation (UV-weathering) are likely factors in the disappearance of plastic, but the latter process is particularly poorly understood. Marine plastic may be a challenging substrate for microbiological enzyme metabolism because it provides a novel habitat for eukaryotic and prokaryotic species. Studies have identified potential plastic-degrading microorganisms, such as *Aspergillus, Penicillium, and Trichoderma,* which have been studied for their ability to break down plastics.

Fungi that colonize plastic in freshwater systems or potential degraders have been found, with Cladosporium fungi strains *Xepiculopsis graminea, Cladosporioides, and Penicillium griseofulvum and Leptosphaeria spp.* being the most studied for their ability to break down plastics. The natural fungus population that has grown on plastic surfaces, such as polyethylene terephthalate (PET) drinking bottles exposed to the North Sea, has also been the subject of marine study.

In conclusion, the production of plastic polymers poses a significant threat to the environment and the marine ecosystem. Further research is needed to understand the potential impact of plastic on marine life and the potential for microbial degradation.

Mycoremediation of heavy metals

Heavy metals are dense metals in groups 3 to 16, distributed unevenly throughout Earth's crust. They are a significant threat to human health and ecosystems due to their presence in various materials, including ductile materials like silicon, titanium, and aluminum. These metals can accumulate in plants and animals, causing damage to DNA, denature proteins, decrease enzyme activities, prevent cell division, and disrupt cellular membranes.

Fungi, including filamentous fungi, have both extracellular and intracellular biochemical and molecular mechanisms that prevent metal toxicity. Extracellular defenses include binding or biosorption, regulation of toxicant influx transporters, and release of suppressor enzymes or pollutant chelating agents. Intracellular mechanisms, such as active efflux, biochemical conversion, and antioxidant cellular processes, have the potential to reduce metal concentration, toxicity, or accumulation. Due to their capacity to move molecules and chemicals, including hazardous metals, between various regions of their mycelium as well as between their fungus and plant symbionts, these fungi are particularly intriguing for bioremediation applications.

Application potential of mycoremediation

Mycoremediation is a potential bioremediation technique for contaminated soil, sediment, and aquatic settings. Techniques include in-situ mycoremediation, which involves excavating or transferring contaminated soil, sediment, or water matrix to another area, and ex-situ mycoremediation, which involves excavating or transferring the contaminated material to another area. Popular in-situ techniques include bioaugmentation, bioventing, biosparging, and natural attenuation. Ex-situ bioremediation techniques vary depending on the matrix, with solid matrixes using biopiling, composting, and land farming, while liquid media like slurries and water can be treated using bioreactors and water treatment facilities.

In-situ mycoremediation

In-situ mycoremediation is a complex multi-factor system that involves assessing and characterizing the polluted site before applying fungi-based bioremediation technology. The presence of filamentous fungi in the soil can cause less disturbance to the polluted area than other methods, such as soil excavation. These fungi are useful under low concentration and high dispersion conditions, dismantling physical barriers at air-soil interfaces where water flow is constrained. However, due to biological, practical, and financial difficulties, in-situ large-scale bioremediation applications in soils are not frequently carried out. Other techniques used include bioventing and biosparging, biostimulation, bioaugmentation, bioreactors, composting, regular tilling, and biopiling, which combine irrigation, aeration, and leachate collecting to manage moisture, oxygen, pH, and nutrients in biopiles.

Ex-situ mycoremediation

Ex-situ mycoremediation is a potential solution for addressing pollution in wastewater treatment facilities, such as designated landfills, collection tanks, and bioreactors. This method improves process control by monitoring environmental factors, fungus development, and performance. However, it faces challenges due to high oxygen requirements and financial difficulties. Integrated biological treatment approaches using fungi and bacteria have been researched for aqueous media. Bioremediation of plastic polymers in wastewater treatment facilities has potential as a mitigating strategy, but further research is needed to determine their relevance and potential as plastic degraders. Genetically modified organisms (GMOs) targeting specific pollutants may also be advantageous for ex-situ mycoremediation, but only closed systems with neutralized matrices are suitable for this method.

Using enzyme expression and immobilization, mycoremediation techniques

Ascomycete fungi have the potential for genetic modification and enzyme development, with laccases and tyrosinases being potential enzymes. Peroxidases from basidiomycetes have improved peroxide resistance and a larger redox spectrum for degradation. Recent research has focused on understanding and expressing laccase-mediator systems (LMS) to remove various pesticides from aqueous samples. The laccase-vanillin system was the most effective, removing 77% of pesticides. T. versicolor-derived laccase and 1-Hydroxybenzotriazole (HBT) were used to study the biodegradation of isoproturon, a common herbicide known to produce potentially cancer-causing intermediates. On brand-new support materials, laccases may now be immobilized for efficient pesticide breakdown. For instance, Coriollopsis gallica immobilized laccase on mesoporous nanostructured silicon foam efficiently oxidized dichlorophen pesticide and decreased its apoptotic and genotoxic effects.

Conclusion and Future Perspective

The significance of fungus in bioremediating toxic compounds in aquatic settings is thoroughly discussed in this article. Fungi can act as natural bioremediating agents by degrading or demobilizing contaminants through their intra- and extracellular enzymatic machinery. The whole range of aquatic fungus species that are acceptable and effective bioremediation agents should be identified and studied in future study, as well as their metabolic processes. Future bioremediation techniques could utilize symbiotic relationships between fungi and bacteria, plants, or both, increase enzyme production through genetic engineering, and extract substances like heavy metals after mycoremediation, advancing the use of natural resources that are exhaustible in nature or by humans.

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