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Article

Role of Fungi in Bioremediation and Environmental Pollution: A Review Article

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Abstract: The significance of fungi in all ecosystems as decomposers and symbionts is discussed in the presented paragraph. The most sustainable and safest technique to clean up polluted environments is fungal bioremediation. Fungi may remove a broad range of recalcitrant contaminants and toxins in a number of ways, including by secreting potent enzymes. Through using a variety of biological techniques to convert resistant contaminants into compounds that are safe for the environment, the bioremediation process is both economical and environmentally beneficial. Fungal form and diverse metabolic capabilities make them important bioremediation agents. Microbes need organic matter from pollution in order to properly develop and flourish. Mineralizing pollutants through converting them to water, carbon dioxide, hydrochloric acid, nitrogen gas, etc. is the primary bio-remediation goal. Heavy metals as well as radioactive ions are transformed into less soluble forms, making their decomposition challenging.

Keywords: fungi, bioremediation, environment pollutent

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1. Introduction

The ecologically friendly technique of bioremediation uses a variety of microbes in a sequential or parallel way for detoxifying and weakening dangerous pollutants. Green plants, fungi, bacteria, and other microorganisms could transform toxic pollutants into less toxic forms such as H_2O, CO_2, microbial biomass, inorganic salts, and other products by speeding up the natural metabolic processes which lead to such results [1], [2]. The pursuit of a sustainable method for restoration and purification of polluted habitats has led to a rise in interest in the study of microbial biodegradation of toxins in recent times. Using organisms, like bacteria, fungi, and their enzymes, to clean up polluted water and soil has been considered as an economical, environmentally friendly, and natural approach (when compared to other common treatments) [3].

Microbes are added to bioremediation technologies in order to enhance the elimination or decomposition of hazardous contaminants including both inorganic and organic pollutants. Numerous techniques, including biostimulation, natural attenuation, bioaugmentation, and combinations of such techniques, could be used to accomplish pollutant bioremediation [4]. Fungi are especially well-suited for bioremediation due to their versatile metabolic ability and consistent morphology, which enable them to perform vital functions as symbionts and degraders throughout ecosystem as a whole, such as soil as well as aquatic habitats.

Mycoremediation is a bio-remediation technique that utilizes the fungi to clean up contaminated environments. The main way that arbuscular mycorrhizal fungi (AMFs) work is in the soil, where they establish and modify the microbial balance. AMFs mainly promote growth of soil microbes and inhibit plant pathogen proliferation. AMFs are symbiotic, meaning they require plant roots to supply them with sugar and carbon they require to develop and multiply. As plants and fungi coexist and flourish, eventually they both gain from their relationship. In comparison to non-mycorrhizal plants, mycorrhizal pairings improve plant growth, overall health, and soil tolerance. The review's primary section gives an introduction of bioremediation; it places particular attention on the microbial process because bioremediation relies heavily on the cycling of organic molecules in the environment [5].

2. Materials and Methods

Through treating areas contaminated with hazardous pollutants via microbial processes, bioremediation is specified as a biological degradation mechanism that reduces the toxicity and concentrations of a broad range of contaminants. Pollutants interact physically and chemically with microorganisms, which can cause structural changes or the complete dissolution of the pollutants. Microbes could use a combination of electrons as well as electron acceptors to speed up their metabolism. Throughout bioremediation, microbes consume organic pollutants to accumulate. Additionally, there is a proliferation of minor nutrients like trace elements and sulfur, and other key nutrients like phosphorus and nitrogen [6]. Through stimulating chemical reactions which separate chemicals from contaminants and transfer electrons, microbes can obtain energy. We refer to such kinds of processes as reduction and oxidation reactions. It has frequently been noted that in natural settings, the degradation of molecules as well as other xenobiotics is accompanied by their transformation (Figure 1). Co-oxidation, co-metabolism, gratuitous metabolism, and accidental or free metabolism are examples of occurrences that fall under this mechanism [7]. Without any nutritional benefits, co-metabolism is a form of metabolism where the main carbon and energy source is an organically active substrate.

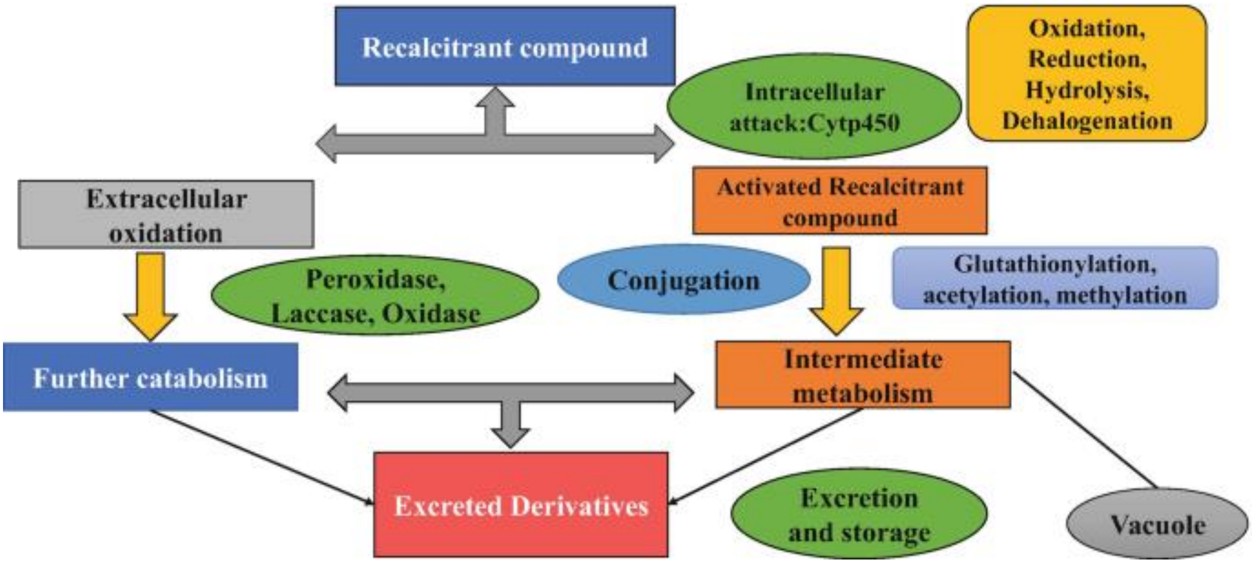

Figure 1. Bioremediation mechanisms

This kind of metabolism occurs frequently in microbes [8]. To facilitate better digestion, the complex organic materials around bacteria are broken down by the metabolic enzymes they release [9]. These enzymes are typically non-specific and could work with various substrates, such as those that are not good for the bacteria in question [10]. For reproduction and growth, microbes need contaminants as carbon sources. They do this by dissolving the contaminants and converting them into more basic compounds. They derive the energy necessary for reproduction and the emergence of new microbial cells from such breakdown of contaminants. The micro-organisms degrade chemical bonds to release electrons that are subsequently utilized in order to create new microbial cells. A chemical compound is said to be oxidized in the case when it loses electrons and decreased when it acquires electrons. This simultaneous occurrence of reduction and oxidation is referred to as a redox reaction. O_2 is an electron acceptor used by the majority of living organisms. Therefore, we can draw the conclusion that, in the presence of oxygen, organisms break down organic compounds into simpler molecules like CO_2 and H_2O. This process is referred to as aerobic respiration. Certain microorganisms have evolved to break down chemical compounds without the need for oxygen [11]. Anaerobic respiration is the process by which contaminants are broken down by sulfate (SO_4^{2-}) and nitrate (NO^{3-}), resulting in hydrogen sulfide (H_2S), nitrogen gas (N_2), and methane (CH_4). Cell synthesis uses the energy released during this process. Microbes use the process of fermentation, which happens in absence of oxygen, to break down contaminants to simpler byproducts like hydrogen, carbon, and ethanol. The contaminants operate as both electron donors and acceptors in this process [12]. The process of some microorganisms converting contaminants to more basic forms that are not needed for any positive purpose is called secondary utilization. Toxic organic materials found in industrial wastes, pesticides, oil spills, and so on. are now broken down into harmless compounds using a variety of bioremediation techniques. The ultimate aim of bioremediation is mineralization, which is their conversion into H_2O, CO_2, hydrochloric acid (HCl), and N_2, etc [13]. Even though they cannot be decomposed, radioactive cations and heavy metals could be physically removed using mycoremediation or phytoremediation, which involves extracting the entire plant or fungus [14]. Pesticide molecules provide nitrogen, carbon, or energy to degrading microorganisms [15]. Therefore, microbial metabolism is the most significant activity in soil for the destruction of pesticides. Fungi are the only organisms on Earth which can break down wood, and it is well recognized that they are essential to the decomposition of leaf litter. Essential components regarding plant fiber include cellulose and lignin, which are broken down into humus by acids secreted from fungal mycelia as well as extracellular enzymes. Adding phosphorus, nitrogen, potassium, and other inorganic elements can speed up the degradation process [16]. Molds like Botrytis and Aspergillus decompose celluloses, starches, hemicelluloses, various sugar polymers, and pectin. They can also decompose chitin, keratin, oils, and lipids.

Those molds could be utilized for biodegradation, where they degrade raw materials for paper and textiles like linen and cotton [17]. Endosulfan can degrade in the environment and in live organisms thanks to fungi including *Cladosporium oxysporum*, *Mucor thermo-hyalospora*, *Trichoderma harzianum*, *Phanerochaete chrysosporium*, and *Aspergillus spp*. Through some processes like hydroxylation, esterification, deoxygenation, and dehydrogenation, fungi could transform pesticides into harmless compounds [18]. The instances listed below are a few. Gallic acid and phenol are produced by further deoxygenation of 3-hydroxy-5-phenoxybenzoic acid, which is hydroxylated from 3-phenoxybenzoic acid [19]. A *Rhizopus oryzae* fungal strain known as CDBB-H1877 could be utilized for pentachlorophenol bio-sorption via dechlorination and methylation. Textile wastewater could be detoxified and decolored by the fungus Zygomycetes and Aspergillus. Non-ligninolytic enzymes made by fungi like *Penicillium chrysogenum*, *Penicillium digitatum*, *Scedosporium apiospermum*, and *Fusarium solani* are how polychlorinated biphenyls (PCBs) are degraded [20]. Because white rot fungus could withstand large concentrations of polluting chemicals, they are favored as durable as well as protective tools in the soil bioremediation [21]. According to reports, white rot fungus digest lignin, leave cellulose intact and give wood a bleached look, whereas brown rot fungi degrade cellulose, leave lignin that are undissolved as brown deposits. Degrading persistent xenobiotic compounds is another ability of some white rot fungi. Among these are *Lentinula edodes*, *Irpex lacteus*, *Bjerkandera adusta*, *Trametes versicolor*, *Agaricus bisporus*, *Pleurotus ostreatus*, *Pleurotus pulmonarius*, and *Pleurotus tuber regium* [22]. Those white rot fungus could also degrade pesticides, chlorophenols, poly-chlorinated biphenyls, phenols, dioxins, dyestuffs, heavy metals, and pulp and paper mill effluent [23]. Additionally, they're capable of degrading pollutants like chlordane, lindane, dichlorodiphenyltrichloroethane (DDT), and CO_2. The production of lactase, manganese peroxidase (MnP), lignin peroxidase (LiP), and other hydrogen peroxide (H_2O_2)$^-$ producing enzymes is the reason for the broad spectrum of activity exhibited by white rot fungus [24]. Their mycelial growth habit that permits quick substrate colonization and hyphal extension, allowing pollutants to be absorbed by soil [25]. Also, produced by *Phanerochaete chrysosporium* are MnP and LiP. Research indicates that *Lentinus subnudus* may degrade atrazine by up to 78% and both heptachlor and metolachlor by up to 94% [26]. It has been reported that *Phanerochaete ostreatus* can degrade heptachlor as well as heptachlor epoxide by as much as 89% and 32%, respectively. The pesticides Dieldrin and Aldrin are degraded by *Phlebia brevispora*, *Phlebia acanthocystis*, and *Phlebia aurea*. Many ascomycetes, hyphomycetes, and basidiomycetes fungus isolated from coastal habitats have been used to degrade wastewater from the textile industry [27].

3. Results and Discussion

3.1. Bioremediation potential of fungi

It was demonstrated that fungi play important roles in bio-remediation of the contaminants, like polycyclic aromatic hydrocarbons (PAHs), pesticides, coal, textile colors, and the effects of tanning on leather and paper [28]. Penicillium, aspergillus, and alkalophilic white-red fungi are among the various groups of fungi that have been reported to be utilized for the decolorization and bioremediation of textile dyes, chemicals utilized in the kraft pulp mills, sugar industry effluent, and leather tanning effluent [29]. This suggests that these fungi have a wide range of substrate preferences. Together with the removal of TOC (i.e., total organic carbon), which can aid in the bioremediation, a significant removal of diesel and petrol contaminants from soil was demonstrated by short-term incubation of *Phanerochaete chrysosporium* and *Aspergillus niger* with the petroleum hydrocarbons (Figure 2) [30].

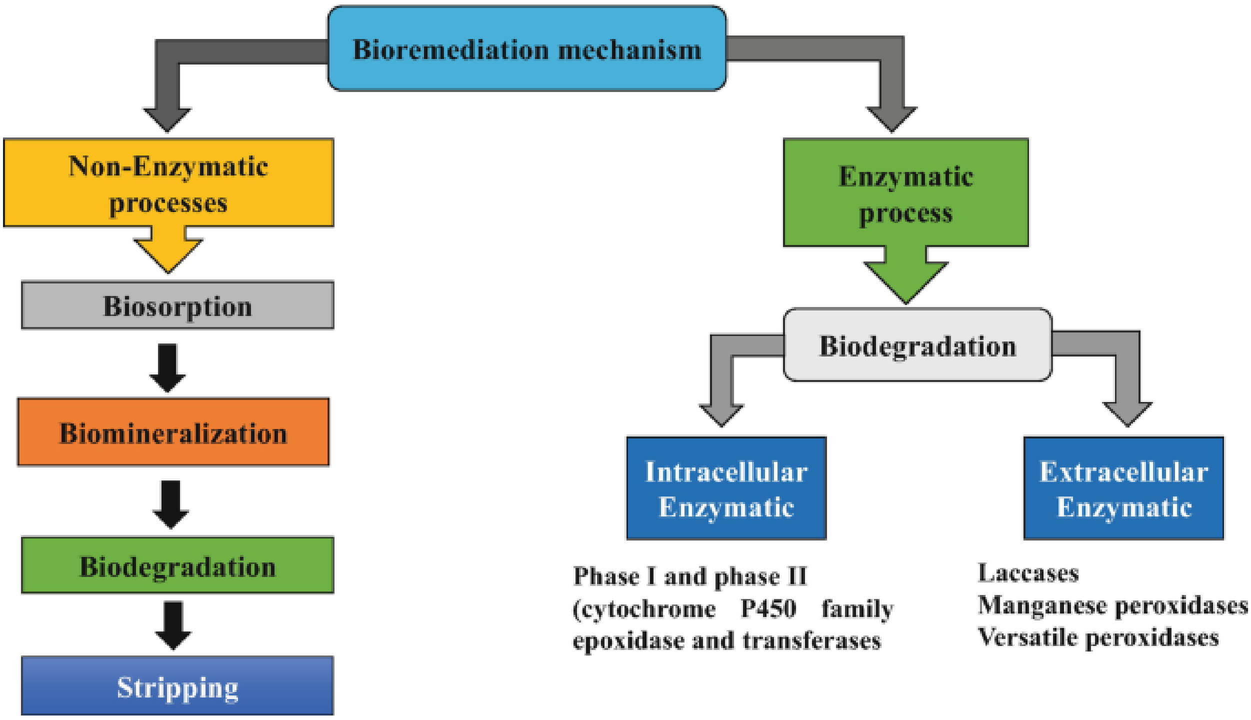

Figure 2. Mechanisms that have been adopted by the fungi for the toxic, recalcitrant compound bioremediation

3.2. Fungal enzyme utilization in the bioremediation

Fungal enzymes with commercial significance, like xylanases, cellulases, proteases, amylases, laccases, lipases, catalases, peroxidases, chitinases, etc., could be utilized in organic waste management techniques, like organic fractionation [31]. White rot fungi can produce one or several different kinds of enzymes, depending upon species and environmental conditions. Their application in bioremediation, which calls for degradation of various xenobiotic substances, which include dyes, isn't restricted to the degradation of naturally occurring substrates of lignocellulose [32]. LiPs and MnPs are two types of lignolytic enzymes released by white rot fungi and are useful for oxidizing lignin in fungal cells. Organic pollutants are known to be degraded by laccases and specific fungal class II peroxidases that are generated by the white rot basidiomycetes [33].

3.3. Mycoremediation using fungi

The enzymes that are secreted by white rot fungi break down the lignin and cellulose, giving the cellulose its white appearance. Fungi are used in approximately 30% of the bioremediation related to the literature [34]. To synthesize certain enzymes which could accomplish the degradation of relevant pollutants, bacteria should be adopted. Different strains of white rot fungus could degrade different chemical molecules, which include the untraceable and persistent components like PAHs, to varying levels [35]. There is a possibility of combining crude oil-polluted soil with lignocellulose substrate, like the sawdust or corn cob, for the purpose of encouraging fungi growth that will decompose crude oil. In addition to that, it was shown that the white rot fungi are capable of efficiently decomposing hazardous substances like the phenols, poly-chlorinated biphenyls, pesticides, and effluent, dyestuffs, chlorophenols, and heavy metals [36].

3.4. Advanced technologies utilized in the fungal bioremediation

Various technological advancements were developed in fungal bioremediation to address the related drawbacks. Using enzymes to shorten the bioremediation process and make it simpler while giving more control over the fungal biomass is one of these advancements. Lately, bioremediation was developed employing immobilized fungus in a variety of bioreactors, including fluidized bed reactors as well as rotating biological contactors [37]. Throughout ligninolysis-based bioremediation regarding benzo[a]pyrene under the nutrient-enhanced conditions, PAH oxidant monooxygenesis is produced. This was subsequently eliminated through a nonligninolytic mechanism [38]. When carried out via a continuous method, bio-remediation of the waste-water sludge from plants of sewage treatment combined with filament inoculum in broad-scale bio-reactor was demonstrated as environmentally benign and sustainable [39]. 90% removal of PAHs was accomplished over the course of 14 days in an additional creative method that involved growing permeable new reactive bio barriers of *Trichoderma longibrachiatum* on the nylon sponges [40].

3.5. Factors affecting bioremediation

The microbial detoxification of contaminants is influenced by the availability of nutrients. Nutrient deficiencies have the direct effect of preventing pollutant-degrading organisms from proliferating and from activating their enzymes. In contaminated environments, microbes need nutrients including nitrogen, potassium, phosphorous, and minerals for cell metabolism and effective multiplication. Site-specific factors which could impede the growth of contaminant-degrading microbes required to propel the bioremediation process include temperature, pH, oxygen content, salinity, and water availability. Under ideal environmental conditions, bacteria could metabolize more contaminants, and pathogens break down and thrive in the contaminated atmosphere [41]. The degree to which a contaminant is free to enter an organism could be identified as a specific organism. Pollutants might interact with their surroundings to alter their bio-availability, which varies from species to organisms. The quantity and catabolic efficacy of the microbes present at a place determine the capacity of the microbial community to eliminate pollutants. Environmental as well as dietary factors could both control the occurrence of soil pathogens [42].

4. Conclusion

The practice of bioremediation is expanding quickly and is a flexible, eco-friendly treatment option. Microbes could be employed for disintegrating and/or detoxifying environmental pollutants into less hazardous forms by using their ability to cope with them [43]. Whole-genome studies can aid in explanation and exploration of bioremediation path-ways, according to recent research aimed at improving our understanding of bioremediation mechanisms and genetic developments. *Arbuscular mycorrhizal* fungi (AMFs) are a viable means of remediating land that is unsuitable for agriculture due to pollution or other issues. Using AMFs increases agricultural productivity and nutritional value as well. AMFs contain powerful degraders of polycyclic aromatic hydrocarbons. AMFs might be utilized to examine the toxicity levels of soil in bioassays due to their sensitivity to a wide range of pollutants.

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