Mycoremediation: Role of Mushroom in the bioremediation of heavymetals

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ABSTRACT: The removal and recovery of heavy metals from the polluted environment are now possible because of the new and promising method known as bioremediation. Macrofungi can accumulate and break down a wide variety of hazardous metals and the same is a highly effective way to restore a damaged environment. In general,mushrooms recover contaminated or polluted soils using three efficient strategies: biodegradation, bioconversion, andbiosorption. The process of mycoremediation employs a variety of wild and domesticated mushroom species which may break down significant amounts of organic and inorganic contaminants and eventually produce marketable goodsor chemicals. White rot fungi have been widely employed in the conversion of pesticides, breakdown of petroleum hydrocarbons, and treatment of lignocellulosic waste in the pulp and paper sector. Several mushrooms, including *Phanerochaete chrysosporium*, *Agaricus bisporus*, *Trametes versicolor*, and *Pleurotus ostreatus*, among others, have been documented for their involvement in the remediation of contaminated locations..

Keywords: Bioremediation, Mycoremediation, Mushroom, mycelium, heavy metal, ecology

INTRODUCTION: Bioremediation, in its broadest sense, refers to any method in which a living or dead biological system (usually bacteria, microalgae, fungus, and plants) is used to remove environmental contaminants from air, water, soil, flue gases, industrial effluents, and so on**.** Bioremediation is frequently used to remove/convert harmful contaminants such as heavy metals into less harmful substances; and/or remove toxic elements from contaminated environments; or degrade organic substances to carbon dioxide, water, nitrogen gas, and so on. Mushrooms play a crucial role in the field of geomycology as they have the ability to alter organic and inorganic substances, facilitate the cycling of elements, interact with metals, and even contribute to the formation of mycogenic minerals (Falandysz & Borovička, 2013; Geoffrey M Gadd, 2007; Geoffrey MichaelGadd, Rhee, Stephenson, & Wei, 2012). Within the colonization zone, the mycelia of mushrooms (specifically saprophytes) generate a diverse range of chemically active compounds, such as enzymes and organic acids. These substances play a crucial role in the biotransformation, solubilization, and mobilization of various nutrients. These nutrients include amino acids, peptides, proteins, amino sugars, chitin, nucleic acids, as well as organic nitrogen and phosphorus (Baldrian, 2008; Van Schöll, Hoffland, & Van Breemen, 2006). Just like other plants, mushrooms have the ability to dissolve various metals and minerals. These solubilized substances can contribute to the formation of mycogenic minerals through precipitation. The specific types and quantities of extracellular enzymes and other bioactive substances released by mushrooms vary significantly depending on the mushroom species. However, the intricate chemical processes involved in mineralization within soils are also associated with phenomena such as the absorption, transportation, and storage of different metals within the fruit bodies of mushrooms (Chatterjee et al., 2017). A typical mushroom picture illustrating the pathways for metal uptake inside organelles is represented in Fig. 1 (Chatterjee et al., 2017).

MUSHROOMS AND BIOREMEDIATION: Mushrooms reclaim and improve polluted fields using three successful methods: biodegradation, bioconversion, and biosorption.

Biodegradation: Certain mushroom species can degrade polycyclic aromatic hydrocarbons using the lignin-modifying enzymes laccase, manganese-dependent peroxidase (MnP), and lignin peroxidase (LiP). *Pleurotus ostreatus*, *Lentinula edodes*, *Pleurotus pulmonarius*, and *Polyporus* sp. are some of the mushrooms that have been identified with the potential efficiency of degrading complex pollutants like waste plastic, 2,4-dichlorophenol, radio-contaminants, Malachite green, respectively, and/or converting them into their simpler non- or less-toxic constituents (Jindal & Thakur, 2019).

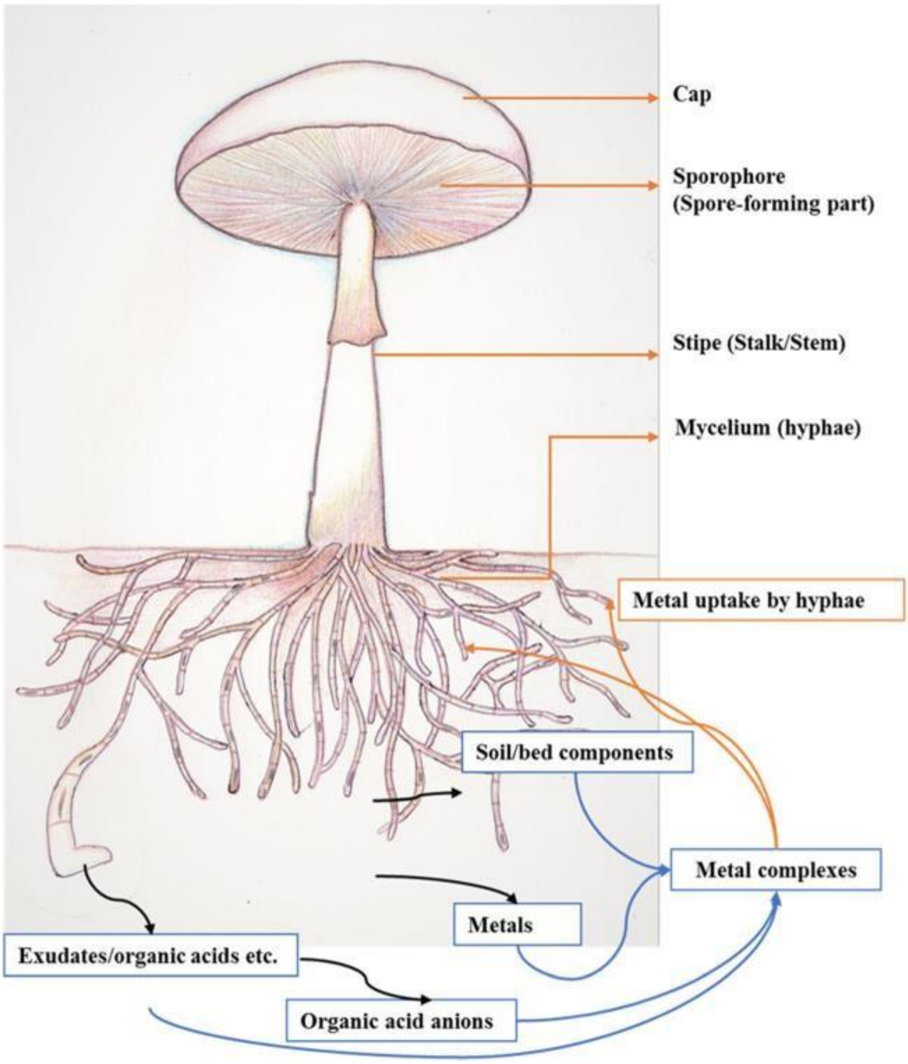

Fig. 1 Mushroom exhibiting routes of heavy metal uptake (Chatterjee et al., 2017)

Bioconversion: In this process, industrial wastes are used as the substrate to cultivate different mushroom species. During cultivation, the mushrooms usually degrade or convert the waste products into simpler components. *Volvariella volvacea*, *Lentinus conatus*, *V. volvacea*, *Pleurotus ostreatus*, *Lentinula tigrinus*are a few among many that are efficiently cultivated on agricultural wastes (Akinyele, Olaniyi, & Arotupin, 2011; Belewu & Belewu, 2005; Jindal & Thakur, 2019; Lechner & Papinutti, 2006).

Biosorption: Biosorption refers to the absorption of metallic ions, pollutants, or xenobiotic compounds from wastewater by mushrooms that exhibit significant tolerance to high metal concentrations and other unfavorable environmental conditions. Various chemical processes, such as adsorption, ion exchange, and covalent binding, can be involved in biosorption. The polar groups found in proteins, amino acids, lipids, and structural polysaccharides (such as chitin, chitosan, and glucans) are also engaged in the biosorption process. Table 1 provides examples of different mushrooms and their role in removing heavy metals from the environment.

Table 1 Removal of heavy metals by mushroom through biosorption process

Mushroom species	Pollutants and Role	References
Agaricus bisporus, Lactarius piperatus	Species exhibited greater efficacy in the removal of Cd(II) ions.	(Nagy et al., 2014)
Fomes fasciatus	Mushrooms demonstrate effectiveness in the biosorption of Cu (II) ions	(Sutherland & Venkobachar, 2013)
Pleurotus platypus, *Agaricus bisporus, Calocybe indica*	Eliminate heavy metals such as copper, zinc, iron, cadmium, lead, and nickel from liquid waste.	(Prasad & Sachin, 2013)
Flammulina velutipes	The fruiting body is employed as a biosorbent to extract copper ions from liquid wastes.	(Luo, Xie, Tan, & Li, 2013)
Pleurotus tuber-regium	Pollutants, specifically heavy metals, are bioabsorbed from soils that have been intentionally contaminated with certain heavy metals.	(Oyetayo, Adebayo, & Ibileye, 2012)
Pleurotus ostreatus	Cadmium ions are taken up from the substrate through absorption.	(Tay et al., 2011)
Pleurotus sajor-caju	Take up heavy metals through absorption.	(Jibran)

Širić and coworkers (2017) studied the bioremediation efficiency of different mushrooms considering different heavy metals as sole pollutants [Table 2]. After conducting statistical analysis, it was discovered that every mushroom species examined exhibited lower lead levels compared to the soil they were cultivated in. *M. procera* and *C. nebularis* demonstrated the highest lead concentrations, while among ectomycorrhizal species, the highest concentrations were observed in two species belonging to the *Boletus* genus (Širić, Kasap, Bedeković, & Falandysz, 2017).

Table 2 Heavy metal concentrations in the analyzed species of mushrooms (mg kg^{-1} dry matter); mean ± SD (n=20), quotient (Qc/s) of cap to stem (Širić et al., 2017)

Species	***Location***	***Pb***	***Cd***	***Hg***
A. campestris	Cap,	1.51±0.03	3.23 ± 0.28	1.68 ± 0.12
	Stipe,	1.12 ± 0.02	2.42 ± 0.22	1.27 ± 0.12
	Qc/s	1.35	1.33	1.32
A. mellea	Cap,	0.71 ± 0.04	1.34 ± 0.03	0.27 ± 0.05
	Stipe,	0.48 ± 0.04	1.01 ± 0.05	0.14 ± 0.02
	Qc/s	1.48	1.33	2.07
C. inversa	Cap,	1.53 ± 0.03	1.62 ± 0.02	1.15 ± 0.08
	Stipe,	1.11 ± 0.07	1.34 ± 0.13	0.66 ± 0.04
	Qc/s	1.38	1.21	1.74

C. nebularis	Cap,	1.82 ± 0.23	1.44 ± 0.04	1.47 ± 0.03
	Stipe,	1.36 ± 0.14	1.16 ± 0.02	1.02 ± 0.04
	Qc/s	1.34	1.24	1.44
M. procera	Cap,	1.91 ± 0.19	2.74 ± 0.24	1.55 ± 0.05
	Stipe,	1.60 ± 0.13	2.20 ± 0.06	1.17 ± 0.04
	Qc/s	1.19	1.25	1.32
B. aestivalis	Cap,	1.46 ± 0.04	1.87 ± 0.03	2.55 ± 0.07
	Stipe,	1.06 ± 0.04	1.68 ± 0.02	2.11 ± 0.07
	Qc/s	1.38	1.11	1.21
B. edulis	Cap,	1.42 ± 0.10	1.93 ± 0.08	2.56 ± 0.05
	Stipe,	0.99 ± 0.03	1.73 ± 0.02	2.35 ± 0.03
	Qc/s	1.43	1.12	1.10
L. deterrimus	Cap,	1.03 ± 0.03	0.83 ± 0.16	0.99 ± 0.08
	Stipe,	0.79 ± 0.03	0.62 ± 0.08	0.61 ± 0.04
	Qc/s	1.30	1.34	1.62
T. portentosum	Cap,	1.14 ± 0.08	1.20 ± 0.04	1.17 ± 0.06
	Stipe,	0.51 ± 0.04	1.05 ± 0.07	0.82 ± 0.08
	Qc/s	2.24	1.14	1.43
T. terreum	Cap,	0.95 ± 0.12	0.97 ± 0.13	0.49 ± 0.02
	Stipe,	0.88 ± 0.09	0.63 ± 0.08	0.22 ± 0.03
	Qc/s	1.08	1.54	2.23

POTENTIAL OF MUSHROOMS IN BIOREMEDIATION AND RESPECTIVE DEGRADATION SYSTEM:

Adenipekun et al., 2012 tried to bioremediate cutting fluid-contaminated soil using *P. tuber-regium* and showed an improvement in soil nutrient quality and enzyme activity (C. O. Adenipekun, Ejoh, & Ogunjobi, 2012). Additionally,biodegradation of the cutting fluids is associated with bioaccumulation of heavy metals, and degradation of TPH and lignin which eventually increase the activity of polyphenol oxidase and peroxidase and ultimately improve the nutrientcontents of the soil. Emuh (2010) states that mushroom hyphae and mycelia play a role in breaking down and absorbing heavy metals and crude oil found in polluted soil. This is achieved through the production of enzymes, which ultimately result in the generation of carbon dioxide and water. White rot fungi such as P. pulmonarius, L. squarrosulus, and P. tuber-regium are actively involved in the remediation of oil-based pollutants. However, it is worth noting that after mycoremediation, an unexpected increase in lead concentration has been observed in all levels of crude oil. On the other hand, the same process has proven effective in reducing the concentration of other metal contaminants present in oil samples (C. Adenipekun & Lawal, 2012). White rot fungi primarily employ the enzymatic degradation of lignin as the main mechanism for biodegradation. These fungi produce extracellular lignin-modifying enzymes that have low substrate specificity, allowing them to break down a broad range of highly resistant organopollutants that share structural similarities with lignin (Mansur, Arias, Copa-Patiño, Flärdh, & González, 2003; Pointing, 2001). Lignin peroxidase, manganese peroxidase, H_2O_2 producing enzymes and laccase are the main components of the lignin degradation system of white-rot fungi. However, not all ligninolytic fungi exhibit the three types of enzymatic activity (Kirk & Farrell, 1987).

HYPER ACCUMULATION OF ELEMENTS- A PATHWAY FOR BIOREMEDIATION: Certain mushroom species possess the ability to accumulate specific trace elements in their fruiting bodies, reaching concentrations that are at least 100 times higher than those found in other species growing in the same environment. These species are referred to as hyperaccumulators for those particular elements. For example, *Amanita regalis* and *Amanita velatipes* can accumulate several hundred milligrams of vanadium (V) per kilogram of dry mass, whereas other mushrooms typically have concentrations below 1 mg kg^{-1} of dry mass for the same element in the same region. Another notable example is the fungus *Sarcosphaera coronaria*, which demonstrates a hyperaccumulation of arsenic. It has been reported to contain as much as 7090 mg kg^{-1} of dry mass, significantly higher than the commonly observed values of up to 1000 mg kg^{-1} of dry mass. In the fruiting bodies of *Sarcosphaera coronaria*, the main form of arsenic is methylarsonic acid (Borovička, Kubrová, Rohovec, Řanda, & Dunn, 2011; Chatterjee et al., 2017; Garner et al., 2000). *Amanita* species have been identified as having the capability to accumulate a significant quantity of silver within their tissue, reaching levels up to 2000 times higher compared to other species. This accumulation occurs through intracellular sequestration utilizing metallothioneins present in the extraradical mycelium and fruit bodies. The exact purpose of hyperaccumulation in mushrooms remains uncertain; however, some researchers propose that it may function as a defense mechanism against natural adversaries, including bacteria, pathogenic microfungi, insect larvae, and gastropods. Additionally, it is possible that hyperaccumulating fungi lack the metabolic mechanisms necessary to prevent the exclusion or excretion of these substances. (Chatterjee et al., 2017).

CONCLUSION: According to the current review, mushrooms have good metal absorption capability and can degrade many types of waste, which is very promising for future mycoremediation technologies. Because certain mushroomsare extremely selective accumulators of both heavy metals and radionuclides, they may pose a health concern to users.White-rot fungi are believed to be relatively affordable to utilize in bioremediation since they may be grown on a variety of low-cost agricultural or forest wastes such as rice straw, corn cobs, and sawdust. It is necessary to conduct more thorough research on the ecology and bioremediation potentials of edible mushrooms of different species. It's also important to consider and offer solutions for the difficulties encountered in field application, such as contamination by other fungi, particularly *Penicillium* spp. and *Aspergillus* spp.

FUTURE SCOPE: Understanding the process of eliminating pollutants is essential for understanding mycoremediation, regardless of whether the fungal mycelia are native to the site or have just been imported. Complete mycoremediation cannot be predicted in advance because different pollutants and application types require different amounts of time. Because of this, this field of study is still in its exploratory stages. Furthermore, there will be a huge need for much more effort to streamline the procedures in order to use this technology in large-scale projects.

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Author contributions. SB conceived and designed the study; SB & KG collected the data and wrote the paper.

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