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Role of Cultivated Mushrooms in Bioremediation: A Review

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ABSTRACT: Environmental pollution with synthetic organic compounds has become a hazardous issue world-wide. Thus, efforts are greatly required for bioremediation of soil pollutants and for the present scenario of excessive use of harmful chemicals. A rapid cost effective and ecologically responsible method of clean-up is "bioremediation" which utilizes micro-organisms to degrade toxic pollutants is an efficient economical approach. It has been exposed newly that the mycelia of edible mushroom will hit a great performance within the reclamation of defective surroundings (myco-restoration) through myco-filtration (using mycelia to filter water or mycelia area unit used as a filter to get rid of cyanogenic materials and microorganisms from water within the soil), myco-forestry, mycoremediation, and myco-pesticides. As we all know that mushroom forming fungi, are amongst nature's most powerful decomposers, secreting strong extra cellular enzymes due to their aggressive growth and biomass production, that's why the present review article basically emphasizes on the use of fungal mycelia in bioremediation (myco-remediation) and studies on the uses of mushrooms for bioremediation.

Keywords: Biodegradation, Bioremediation, Fungi, Mushrooms, Pollutants

INTRODUCTION

The pollution of natural resources such as air, water and soil due to heavy metals has become one of the most important ecological problems on the planet (Kour *et al.* 2018; Ramya and Boominathan, 2018). The natural deterioration of artificial organic compounds has become a number one obstacle across the globe. The term 'xenobiotics' refers to the materials which don't occur naturally within the environments and most of them do not degrade by the autochthonal microflora and fauna (Sullia, 2004). The poor management of the waste and effluents from households, industries, and agricultural fields is further deteriorating the already crippling ecosystem (Akhtar and Amin-ul Mannan, 2020). To get eliminate such ample ranges of pollutants and cyanogenic wastes from the part with very little surroundings impact are, thus an entire demand to develop a property and healthy improvement of our society. Because of the lack of an economic decision and the consequences of this obstacle, a productive and commercial methodology of clean-up is greatly enforced (Hamman, 2004).

Bioremediation is the process of onsite advancement of alive soil creatures like bacteria, fungi, and immature plants to disintegrate the hydro-carbon and biological contamination (Atlas and Bartha, 1992; Geethanjali and Jayashankar, 2018). Bioremediation demands the adoption of organisms and nutrients to the unclean ground to set up biodegradation. Utilization of fungi as well as their consortia is an efficient, cost-effective and economical strategy as compare to other conventional methods for contaminated soil remediation (Khatoon *et al.* 2021). Micro-creatures applied in bioremediation should are tested and tried to be an outstanding in-lab investigation. The deterioration of definitive soil pollutants like chlorinated hydrocarbons takes place by the role of microorganism but it could also be engaged to barrage by bioremediation techniques. Among the most dominant decomposers of nature's Fungi is one of them, as they secrete potential stimulants. According to (Ashoka *et al.,* 2002), the blessing capability of fungi in bioremediation is that they underneath of their combative growth, superior biomass construction, and comprehensive hyphae ability within the enveloping. As a source of energy, Fungi required substrates like alternative carbon supply (straw, corn cobs) and polysaccharide to upgrade deterioration rates by these creatures at the unclean ground. Also, the separate attenuated (filiform) style of plant life growth permits a lot of economical organization and exploration of contaminated soil (Hamman, 2004). There's a quantity of precise bioremediation with references to the potential of assorted fungi and their stimulant to bio-revolutionized defoliant (Raj *et al.* 1992). Various organisms like microorganisms, fungi, algae, and plants are used for the decomposition of pollutants and clean up our surroundings (Leung, 2004). However, fungi area unit the foremost outstanding biological decomposer and; then i.e., they play an important role in changing these wastes into a valuable product. They exist during a style of habitats because of their versatile physiological nature so found in acidic hydrogen ion concentration, temperature, chemical element concentrations, salinity, and significant metal concentrations (Chang and Miles, 1992). Mushrooms are shown to degrade various forms of wastes; organic and inorganic pollutants because of extracellular stimulants they possess thereby changing the waste and pollutants into foods of a prime quality, flavor, and alimental price. Therefore, the mushroom could also be promising fungi for environmental bioremediation. Mushrooms belong to the family of Basidiomycetes normally referred to as saprophytic fungi. The plant organ of mushrooms consists of steam (Stipe) with and an impression cap (Pileus) spore-forming half (sporophore). Mushroom uptake nutrients from the substrate/soil via specious plant structure. The age and size of the plant organ verify the uptake of nutrients from the substrate or the soil (Das, 2005). The lifetime of the plant organ is just 10-14 days; hence the time taken consumed for the uptake of those nutrients from the substrate is restricted (Sharma *et al.* 2010) had recommended in their studies on nutrient contents in mushrooms that the uptake rate of nutrients is correlative with the contact time. Nutrient concentrations within the mature bodies area unit stricken by age of plant structure and the interval between fructification (formation of mature (Sharma *et al.* 2010). It has been exposed newly that the mycelia of edible mushroom will hit a great performance within the reclamation of defective surroundings (myco-restoration) through myco-filtration (using mycelia to filter water or mycelia area unit used as a filter to get rid of cyanogenic materials and microorganisms from water within the soil), myco-forestry, mycoremediation, and myco-pesticides. These keys perform the possible to generate a clean and clear system, wherever no harm is going to be left when plant life implementation (Stamets, 2005). Besides their ability to degrade and convert lignocellulosic materials into human food, they will conjointly act as an efficient bio-sorbent of cyanogenic metals (Costa and Leite, 1991).

Most of the alternative fungi and cultivated mushrooms acquired protein appliances for the deterioration of environmental contaminants and so is enforced for an enormous kind of contaminants (Purnomo *et al.* 2013; Kulshreshtha *et al.* 2013). Nonetheless, cultivated mushrooms have become a lot of standards today for correction functions as a consequence of it's not completely a bioremediation appliance anyhow they simultaneously provide plant arrangement or sophisticated frame as a quantity of supermolecule. The efficiency of mushroom species in construction of cooking magnificent particle within the diversity of biomass or mature bodies from exactly various contaminants deception in their capacity to deteriorate pollutants through excretion of dissemination of hydrolyzing and oxidizing stimulants (Kuforiji and Fasidi 2008; Zhu *et al.* 2013). This has fascinated investigation consideration within the territory of mushroom farming and contaminants improvement. Many descriptions are printed to stress the act of cultivated mushrooms within the bioremediation by the technique of bioconversion, biosorption, and biodegradation (Akinyele *et al.* 2012, Kulshreshtha *et al.* 2013; Kumhomkul and Panich-pat 2013; Lamrood and Ralegankar 2013). Several scientists have an investigation on the role of distinct enzymes within the deterioration technique; deterioration product shaped by it and situation pathetic to the deterioration technique (Novotný *et al.* 2004; Akinyele *et al.* 2011; Zhu *et al.* 2013). However, safety aspects of the process and products have not been reported so far. There is scarcity of reports indicating the pros and cons of mushroom cultivation on wastes and their further utilization as food. Moreover, mushroom as a product is meagerly reported (Kulshreshtha *et al.* 2014). Cultivated mushroom isn't purely a mycoremediation technique however working together as a product (Kulshreshtha *et al.* 2014). Mushroom mature bodies bring about industrial and agro-industrial contaminants are a reflection of as a product. Among Nature's most dynamic promoter, fungi aspects for the deterioration of contaminants elements and are the beloved unit of the soil food network (Rhodes, 2012), contributing nutrition to the many alternative biotas that remain in the soil. Mushrooms can degrade and recycle wastes and pollutants to their mineral constituents and convert wastes, sludge, and pollutants into useful forms. In addition, they can uptake heavy metals from substrates via biosorption, which is a very effective method to reclaim polluted lands (Uddin *et al.* 2020). Keeping this in thought, during this review we contribute to deliberate the business trade of cultivated mushrooms as an organic mechanism for clean up the surroundings.

A. Mushrooms along with Bioremediation

The deterioration processes of White-rot fungi consequences in the lightening of wood substrates (Kirk *et al.,* 1992). As they absorb lignin from wood by the excretion of stimulant providing wood as achromatize display. The white-rot fungi technology is quite distinct from other techniques of bioremediation. The distinct is primarily due to the unpredictable tools that nature has shared with them with clear improvement for contaminants deterioration (Asamudo *et al.,* 2005). One categorical favor of these fungi over bacterial mechanisms is that they do not prescribe any requirements to the specific contaminants. Bacteria frequently pre-exposed to contaminants to grant the stimulant that deteriorates the contaminants to be activated. To inauguration of enzyme synthesis, the contaminants must be in a powerful concentration. Thus, there is a precise match to which bacteria can reduced contaminants. (Asamudo *et al.,* 2005).

According to Barr and Aust (1994), various strains of white-rot fungi that help in the deterioration process of aromatic compounds.

Lang *et al.* (1995) reported that to disciple recalcitrant pollutants like polycyclic aromatic hydrocarbons, lignin decomposition white-rot fungi display outstanding strength. The remarkable capabilities of white-rot fungi may be used for the purification of oil-contaminated soils although lignocellulosic substrates must be equipped for the survival of fungal species in the soil. Heavy metals are necessary for the growth and metabolism of living organisms at low concentrations, but several of them are poisonous at higher concentrations (Menaga *et al.* 2021). For the stimulation of heavy metals and the bioremediation of contaminated soils, white-rot fungi have been used. They have also been boosted to be associate with biodegradation, bio-deterioration, transformation, co-metabolism, and mineralization (Bennet *et al.,* 2002). Recent advances are necessary for treating the heavy metal-contaminated water by efficient and low-cost technology (Tajuddin *et al.* 2020). White-rot fungi are progressively being investigated and used in bioremediation because of their stability and durability to deteriorate a remarkably distinct dimension of very toxic surroundings contaminants Isikhuemhen *et al.* (2003).

B. White-rot Fungi Deterioration System

The lignin deterioration mechanism of stimulants usually employed by the company of fungi, which is one of the popular systems of biodeterioration. To solidify the plentiful dimension of profoundly recalcitrant organo-contaminants which are structurally equal to lignin, Extra-cellular lignin modifying stimulants have very limited substrates-precision (Mansur *et al.,* 2003; Pointing, 2001). Although not all ligninolytic fungi display three kinds of enzymatic action, the main factors of the lignin degradation technique consist of peroxidase generating stimulants, manganese peroxidase, lignin-peroxidase, and laccase (Kirk and Farrell, 1987). It has been proven that a frequently appearing polymer known as lignin which can be reduced by the plenty of species associated with the company of white-rot fungi (Hattaka, 1994). This capability is considered to the consequence of the action of extracellular laccases and oxidases (Glenn and Gold, 1983).

These substrates can oxidize a plentiful length of xenobiotics which are usually non-specific (Barr and Aust, 1994; Martens *et al.,* 1996). For the biodeterioration of contaminated sites that consists of arduous mixtures like crude oil, creosote, and so on White-rot fungi have been recommended (Loske *et al.* 1990). A solid-state fermentation experiment has been conducted with *Lentinus squarrosulus* using strain MBFBL 201 on cornstalks to know the lignocellulolytic substates action (Isikhuemhen *et al.* 2011). The results displayed that after 30 days *L. squarrosulus* was able to deteriorate cornstalks successfully. On day 6 of the cultivation technique, a high rate of lignocellulolytic stimulants action was accelerated and are a useful manufacturer of exopolysaccharides. For the biodelignification of lignocellulosic biomass and industrial pretreatment, *L. squarrosulus* is an admirable candidate for utilization as it displays an energetic acceptance supply.

C. Heavy Metal Content in Sporocarp of Different Tolerant Mushrooms

Table 1: Heavy Metal Content in Sporocarp of Different Tolerant Mushrooms.

Mushroom Species	Metal Pollutants (Accumulated metals in sporocarp, mg/kg of dry weight)	References
Agaricus bisporus	Cu (107), Pb (21), Zn (57.2), Hg (0.03), Pb (0.28), Cd (0.78) Fe (31.3)	Demirbas, 2001; Isildak *et al.* (2003)
Boletus edulis	Pb (0.96), Cd (1.03), Hg (0.13), Fe (31.1)Cu (4.7), Mn (2.9), Zn (26.2)	Kalac *et al.* 1996; Tuzen *et al.* 1998
Lepiota rhacodes	Hg (8), Pb (66), Cd (3.7)	Kalac *et al.* 1996
Paxillus involutus	Pb (1.6.0), Cu (57.0)	Kalac *et al.* 1991
Pleurotus sp.	Pb (3.24), Cd (1.18), Hg (0.42), Cu (13.6), Mn (6.27), Zn (29.8), Fe (86.1)	Damodaran *et al.* 2011
Tricholoma terreum	Pb (2.4), Cd (1.6), Hg (0.06), Cu (35.8),Mn (24.8), Zn (48.0), Fe (169.0)	Demirbas, 2001
Volverilia volvacea	Hg &Pb (5-5.23), Cu 500	Damodaran *et al.* 2011
Volvariella murinella	Pb (2.4), Cd (1.6), Hg (0.06), Cu (35.8)	Damodaran *et al.* (2011)
Havlvellaleucomelaena	Pb (3.1), Cd (1.1), Hg (0.26), Cu (13.6);	Tuzen *et al.,* (2003)
Paxillus rubicondulus	Pb (0.69), Cd (0.78), Hg (0.21), Fe (37.0), Cu (51.0), Mn (10.8), Zn (16.8)	Damodaran *et al.* (2011)
Source: Das (2005).		

Table 2: Edible mushrooms involved in the disintegration of distinct agricultural wastes Chakravarty, (2011).

Mushroom species	Growth substrates	Potential substrates	Yield
Pleurotus flabellatus	Mango, Jack fruit, Coconut, Jam, Kadom, Mahogony, Siris sawdust	Mango sawdust	150 gm
Pleurotus ostreatus	*Ficus carica, Albizia saman, Swietenia mahagony, Leucaenaleucocephala, Eucalyptus globulus,* and a mixture of all above mentioned sawdust	*Albizia saman*	373.4gm
Volvariella volvacea	banana leaves	Banana leaves	2.5 kg

D. The System Associated in the Deterioration of Agrochemicals and Alternative Contaminants by Mushroom

Industrially produced heavy metal ions are considered as a major source of environmental contamination that led to worsening of natural ecosystems and social health (Zakaria *et al.* 2017). The iron is a priority heavy metal which poses a significant problem in groundwater due to its toxic nature (Menaga *et al.* 2021). The bioconversion, biosorption, and enzymatic deterioration techniques include mushroom situated deterioration of agrochemicals contaminants, polyhydroxy aromatic hydrocarbons, heavy metals, and other alternative contaminants. A large number of articles on mushroom situated biodeterioration of agronomic contaminants have been broadcasted by many researchers (Hussain, 2009; Gupta *et al.* 2018).

E. Enzymatic degeneration of agricultural wastes

Mycologists and environmental researchers are offering consideration to the mushroom-based enzymatic degeneration of agricultural contaminants. Yet in pesticide degeneration, the appropriate performance of stimulants is still in confusion. Although few signals are promoting that the lignin degeneration stimulants are responsible for the deterioration of pesticides. Mushrooms never release deterioration of pesticides stimulants in an exact process; *i.e.*, they distinct from chemical and physical factors, kinds of situation, and species to species (Kulshreshtha 2014; Gupta 2018).

The chemical amalgamation that is observed in the surroundings but they do not occur naturally in the surroundings is called Xenobiotics. However, a commonly occurring factor when they are extremely accessible in the surroundings is also called xenobiotics. They do not get quickly degeneration in nature and are profoundly available in the environment. Microbes play a very important role within the territory of biodegradation. The degeneration methods of mushroom fungi include the deterioration action of agrochemicals contaminants and alternative pollutants by releasing distinct stimulants like laccases and peroxidases. These stimulants can reduce the risky amalgamation by the breakdown of amide, ester, and aromatic ring too (Chaudhary, 2018; Gupta, 2018; Trejo-Hernandez *et al.* 2001). The precise amount of uncertain amalgamation, sensible location, and reaction situation is also liable for the degeneration of such amalgamation. For the proper growth and improvement of mushrooms, they handled xenobiotic compounds as their source of C, N, and energy (Chaudhary *et al.* 2018). Mushrooms can reduce polycyclic aromatic hydrocarbon into mineral mode by releasing the ligninolytic stimulants. Phthalic acid and CO_2 can be released by the further deterioration of anthraquinone (Agrawal *et al.* 2018). Mushrooms that can reduce agrochemical contaminants by releasing stimulants are mentioned in Table 3. The degeneration of 2,4,6-Trinitrotoluene in the absence of ligninolytic stimulants by *P. Chrysosporium* has been announced by Jackson *et al.* (Jackson *et al.* 1999). According to Bending *et al.* 2002, in an aqueous situation, the atrazine and terbuthylazine can be degenerated by white-rot fungi without being the presence of ligninolytic stimulants.

F. Bioconversion of Agricultural Contaminants

Agricultural transforming trades like vegetable and fruit transforming trades, brewery company, and grain milling company releases agro-industrial contaminants as their by-products which are great sources of distinct bioactive compounds and nutrients. These contaminants can be taken into consideration for the bioconversion into some major alternative helpful factors (Kulshreshtha *et al.* 2014). The cultivation of mushrooms can be done on agro-industrial contaminants which is one of the top classical examples of bioconversion where fruiting bodies of mushroom can be consumed as useful products (Alborés *et al.* 2006). The choices can be made upon agro-industrial substrates only if there is a huge presence of the substrates (Kulshreshtha *et al.* 2014).

Table 3: Role of mushrooms in the deterioration of contaminants by releasing stimulants.

S. No.	Contaminant's name	Stimulants released	Involved Mushroom	References
1.	2,4-Dichlorophenol	Ligninolytic stimulants-develop vanillin	*Lentinula edodes*	(Tsujiyama *et al.* 2013).
2.	Crude oil	Peroxidase	*Pleurotus pulmonarius*	(Olusola *et al.* 2010).
3.	Polycyclic aromatic hydrocarbons	Lignin peroxidase, laccase, and manganese-dependent peroxidase.	*Coriolus versicolor*	(Jang *et al.* 2009).
4.	Crude oil	Ligninolytic stimulants	*Pleurotus tuber-regium*	(Isikhuemhen *et al.* 2003).
5.	Plastics	Lignocellulolytic stimulants	*Pleurotus ostreatus*	(da Luz *et al.* 2015).
6.	Contaminants based on Radioactive cellulosic	Ligninolytic stimulants	*Pleurotus pulmonarius*	(Eskander *et al.* 2012).
7.	Malachite green	Enzymatic degeneration and biosorption	*Schizophyllum commune*, *Polyporus* sp., *Auricularia* sp.	(Yogita *et al.* 2011).
8.	Anthracene	Laccase, manganese peroxidase, and Lignin peroxidase	*P. ostreatus*	(Zebulun *et al.* 2011).
9.	Crude oil	Ligninolytic stimulants	*Lentinus squarrosulus*, *Pleurotus tuber- regium*, *Pleurotus palmonarius*.	(Adedok *et al.* 2014).
10.	Green polyethylene	Laccase	*Pleurotus ostreatus*	(da Luz *et al.* 2015).

Table 4: Mushroom performance on bioconversion of agro-industrial contaminants.

S. No.	Agro-industrial contaminants	Consequences	Mushroom involved	References
1.	Straw of Wheat	The fusion of lignocellulosic stimulants can be done by the bioconversion of wheat straw and yield can be improved.	*Lentinula edodes*	(Lechner and Papinutti, 2006).
2.	The straw of rice and cotton contaminants	The action of stimulants like peroxidase, Lipase, carboxymethylcellulose, and cellulase can be increased.	*Pleurotus tuber-regium*	(Kuforiji and Fasidi, 2008).
3.	Leaves of banana	The continual fodder for ruminant animals can be made by upgrading yield.	*V. volvacea*	(Belewu and Beluwa, 2005).
4.	The stalk of sorghum, straw of rice, and stem of banana	Degeneration of lignin was recognized and increased in yield	*Pleurotus eous, Lentinus connatus*	(Rani *et al.* 2008).
5.	Stover of corn, a stalk of banana bagasse of sugarcane, and cobs of corn	Ligninolytic and cellulolytic stimulants can be generated through the mechanism of bioconversion.	*Pleurotus sapidus*	(Bilal and Asgher, 2016).

Mushroom-involved mycoremediation on agro-industrial contaminants contributes to the growth of protein-rich fruiting bodies by degeneration of those industrial contaminants as these contaminants are top sources of nutrients (Alborés *et al.* 2006). Mushroom grown on agro-industrial contaminants are listed in Table 4.

G. Performance of cultivated mushroom as a necessary product

Myco-remediation tools involved different kinds of cultivated mushrooms because they are involved in distinct kinds of remediation of contaminants and hence mushrooms are also called myco-remediation tools.

Table 5: Performance of cultivated mushroom as a necessary product.

S. No.	As a necessary product	Mushroom involved	References
1.	To fight against cancer, they possess antigenotoxic or antimutagenic power.	*Agaricus* and *Pleurotus*	Gameiro *et al.* (2013); Kang *et al.* (2012)
2.	To upgrade the immune power, they have been used as medicine. They also respond against the cancer	*Ganoderma Schizophyllan commune, Pleurotus, and Agaricus Ganoderma lucidum, Grifolafrondosa and Coriolus versicolor*	Kodama *et al.* (2002); Gao *et al.* (2003) Maehara *et al.* (2012)
3.	They have been used as an antitumor and antioxidant agent	*Phellinus rimosus, Ganoderma lucidum, Pleurotus florida and Pleurotus pulmonaris.*	Ajith and Janardhanan (2007)

Table 6. Performance of mushroom in the deterioration of contaminants.

S. No.	List of contaminants	Mushroom involved	References	Remarks
1.	Contaminants based on Radioactive cellulosic.	*Pleurotus pulmonarius*	Eskander *et al.* (2012)	Contaminants that consist of mushroom mycelium gets stiffen with portland cement which acts as the barricade against the clemency of radio-contaminants.
2.	Crude oil	*Pleurotus pulmonarius*	Olusola and Anslem (2010)	The degeneration of crude oil takes place.
3.	Oxo-Biodegradable plastic	*Pleurotus ostreatus*	da Luz *et al.* (2013)	The plastic gets degenerated by mushrooms and survives on it.
4.	2,4-dichlorophenol	*Lentinula edodes*	Tsujiyama *et al.* (2013)	Activator like vanillin helps to deteriorate 2,4-dichlorophenol by mushrooms
5.	Malachite green	*Jelly sp., Schizophyllum commune, and Polyporous sp.*	Rajput *et al.* (2011)	In 10 days, almost 68.5% *Polyporous* sp., 97.5% *Schizophyllum commune*, 99.75% Jelly sp.dye has degenerated

The myco-remediation process is based upon the efficient stimulants released by the distinct kinds of cultivated mushrooms, for the degeneration of different kinds of substrates. Because of the presence of a huge amount of protein and the sweet flavor of mushrooms, they have been used as a product for consumption for a long time.

CONCLUSION

As we all know due to the powerful enzymatic activities as well as high adaptability under physically harsh conditions, microbial bioremediation and biodegradation is one of the most focused research areas for sustainable developments.

So, as per the above contexts, it is concluded that mushroom cultivation got much more attention in the field of biodegradation and bioremediation research. The use of mushrooms with beneficial bacterial strain could help to degrade pollutants at faster rates. For future prospects, identification of such genes that are responsible for biodegradation of pollutants and the introduction of such genes to the indigenous strain could solve the availability of capable strain under field conditions. For future research, there is critical need to make connection among the researchers of interdisciplinary research fields like biotechnology, microbiology, chemistry, and genetic engineering could help to develop a successful technique for bioremediations.

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REFERENCES

Adedok, O.M. and Ataga, A.E. (2014). Oil spills remediation using native mushroom—A viable option. *Research Journal of Environmental Sciences*, **8**(1): 57.

Agrawal, N., Verma, P. and Shahi, S.K. (2018). Degradation of polycyclic aromatic hydrocarbons (phenanthrene and pyrene) by the ligninolytic fungi *Ganoderma lucidum* isolated from the hardwood stump. *Bioresources and Bioprocessing*, **5**(1):11.

Ajith, T.A. and Janardhanan, K.K. (2007). Indian Medicinal Mushrooms as a Source of Antioxidant and Antitumor Agents. *J Clin. Biochem. Nutr*, **40**:157–162.

Akhtar, N. and Amin-ul Mannan, M. (2020). Mycoremediation: Expunging environmental pollutant. *Biotechnology Reports*, **26**: e00452.

Akinyele, J.B., Fakoya, S. and Adetuyi, C.F. (2012). Anti-growth factors associated with *Pleurotusostreatus* in submerged liquid fermentation. *Malaysian J. Microbiol.*, **8**: 135–140.

Akinyele, B.J., Olaniyi, O.O. and Arotupin, D.J. (2011). Bioconversion of selected agricultural wastes and associated enzymes by *Volvariellavolvacea*: An edible mushroom. *Res J Microbiol.*, **6**: 63–70.

Alborés, S., Pianzzola, M.J., Soubes, M. and Cerdeiras, M.P. (2006). Biodegradation of agroindustrial wastes by *Pleurotus* spp. for its use as ruminant feed. *Electronic Journal of Biotechnology*, **9**(3): 215-220.

Asamudo, N.U., Dada, A.S. and Ezeronye, O.U. (2005). Bioremediation of textile effluent using *Phanerochaete chrysosporium*. *Afr. J. Biotechnol*, **4**(13):1548-1553.

Ashoka, G., Geetha, M.S. and Sullia, S.B. (2002). Bioleaching of composite textile dye effluent using bacterial consortia. *Asian J. Microb. Biotechnol. Environ. Sci*., **4**: 65-68.

Atlas, R.M. and Bartha, R. (1992). Hydrocarbon biodegradation and oil spill bioremediation. *Adv. Microbiol. Ecol*., **12**: 287-338.

Barr, B.P. and Aust, D. (1994). Mechanisms of white-rot fungi use to degrade pollutants. *Environ. Sci. Technol*., **28**: 78-87.

Belewu, M.A. and Belewu, K.Y. (2005). Cultivation of mushroom (*Volvariella volvacea*) on banana leaves. *African Journal of Biotechnology*, **4**(12): 1401-1403.

Bending, G.D., Friloux, M. and Walker, A. (2002). Degradation of contrasting pesticides by white-rot fungi and its relationship with ligninolytic potential. *FEMS Microbiology Letters*, **212**(1): 59-63.

Bennet, J.W., Wunch, K.G. and Faison, B.D. (2002). Use of fungi in biodegradation: of fungi in bioremediation pg. 960-971 In Manual of Environmental Microbiology Washington D.C.: ASM Press.

Bilal, M. and Asgher, M. (2016). Biodegradation of agro-wastes by the lignocellulolytic activity of an oyster mushroom, *Pleurotus Sapidus*. *Journal of the National Science Foundation of Sri Lanka*. **44**(4): 399-407.

Chakravarty, B. (2011). Review on Trends in Mushroom cultivation and breeding. *Australian Journal of Agricultural Engineering*, **2**(4): 102-109.

Chang, S.T. and Miles, P.G. (1992). Mushroom biology—a new discipline. *The Mycologist*, **6**: 64-65.

Chaudhary, K., Agarwal, S. and Khan, S. (2018). Role of phytochelatins (PCs), metallothioneins (MTs), and heavy metal ATPase (HMA) genes in heavy metal tolerance. *In*: Mycoremediation and Environmental Sustainability. Cham: Springer, pp 39-60.

Costa, A.C.A. and Leite, S.G.C. (1991). Metal Biosorption by Sodium Alginate Immobilized Chlorella Hemisphere. *Biotechnology*, **13**: 559-562.

da Luz, J.M.R., Paes, S.A., Nunes, M.D., da Silva, M.C.S. and Kasuya, M.C.M. (2013). Degradation of Oxo-Biodegradable Plastic by *Pleurotusostreatus*. *PLoS ONE*, **8**(8): 69386.

da Luz, J.M.R., Paes, S.A., Ribeiro, K.V.G., Mendes, I.R. and Kasuya, M.C.M. (2015). Degradation of green polyethylene by *Pleurotus ostreatus*. *PLoS One*, **10**(6): e0126047.

Damodaran, D., Mohan, B. and Shetty, V.B.M. (2011).Mushrooms in the remediation of heavy metals from soil. *International Journal of Environmental Pollution Control & Management*, **3**(1): 89-101.

Das, N. (2005). Review on heavy metal biosorption by mushrooms. Indian Institute of Technology; *Natural Product Radiance*, **4**(6): 454-459.

Demirbas, A. (2001). Heavy Metal Bioaccumulation by Mushrooms from Artificially Fortified Soil. *Food Chem.*, **74**: 293-301.

Eskander, S.B., Abd El-Aziz, S.M., El-Sayaad, H. and Saleh, H.M. (2012) Cementation of bioproducts generated from biodegradation of radioactive cellulosic-based waste simulates by mushroom. ISRN Chemical Engineering, **2012**: 329676.

Gameiro, P.H., Nascimento, J.S., Rocha, B.H., Piana, C.F., Santos, R.A. and Takahashi, C.S. (2013). Antimutagenic effect of aqueous extract from *Agaricus brasiliensis* on a culture of human lymphocytes. *J Med Food*, **16**: 180–183.

Gao, Y., Dai, X., Chen, G., Ye, J. and Zhou, S. (2003). A randomized, placebo-controlled, multicenter study of *Ganoderma lucidum* (W. Curt.:Fr.) Lloyd (Aphylloromycetidae) polysaccharides (Ganopoly R) in patients with advanced lung cancer. *Int J Med Mushrooms*, **5**: 369–381.

Geethanjali, P.A. and Jayashankar, M. (2018). Efficiency of paddy residues as substrates for fungal laccase production. *International Journal of Theoretical & Applied Sciences*, **10**(1): 190-193.

Glenn, J.K. and Gold, M.H. (1983). Decolorization of several polymeric dyes by the lignin-degrading basidiomycetes *Phanerochaete chrysosporium*. *Appl. Environ. Microbiol*., **45**: 1741-1747.

Gupta, S., Annepu, S.K., Summuna, B., Gupta, M. and Nair, S.A. (2018). Role of mushroom fungi in decolorization of industrial dyes and degradation of agrochemicals. *In*: Biology of Macrofungi. Cham: Springer, pp 177-190.

Hamman, S. (2004). Bioremediation capabilities of white-rot fungi. *Biodegradation*, **52**: 1-5.

Hattaka, A. (1994). Lignin-modifying enzymes for selected white-rot fungi production and mode in lignin degradation. *Microbiol. Rev*., **13**: 125-135.

Hussain, S., Siddique, T., Arshad, M. and Saleem, M. (2009). Bioremediation and phytoremediation of pesticides: Recent advances. *Critical Reviews in Environmental Science and Technology*,**39**(10):843-907.

Isikhuemhen, O.S., Anoliefo, G. and Oghale, O. (2003). Bioremediation of crude oil polluted soil by the white-rot fungus, *Pleurotus tuber-regium* (Fr) Sing. *Environ. Sci. Pollut. Res*., **10**: 108-112.

Isikhuemhen, O.S., Mikiashvilii, N.A., Adenipekun, C.O., Ohimain, E.I. and Shahbazi, G. (2011). The tropical white-rot fungus, *Lentinus squarrosulus* Mont: lignocellulolytic enzymes activities and sugar release from cornstalks under solid-state fermentation. *World J. Microbiol. Biotechnol*., **28**(5): 1961-1966.

Isildak (2003). Analysis of Heavy Metals in Some Wild-grown Edible Mushrooms from the Middle Black Sea Region. *Turkey Food Chemistry*, **86**: 547-552.

Jackson, M.M., Hou, L., Banerjee, H.N., Sridhar, R. and Dutta, S.K. (1999). The Disappearance of 2,4-dinitrotoluene and 2-amino,4,6-dinitrotoluene by *Phanerochaete chrysosporium* under non-ligninolytic conditions. *Bulletin of Environmental Contamination and Toxicology*, **62**(4):390-396.

Jang, K.Y., Cho, S.M., Seok, S.J., Kong, W.S., Kim, G.H. and Sung, J.M. (2009). Screening of biodegradable function of indigenous ligno-degrading mushroom using dyes. *Mycobiology*, **37**(1): 53-61.

Kalac, P., Burda, J. and Staskova, I. (1991). Concentration of Lead, Cadmium, Mercury, and Copper in Mushrooms in the Vicinity of a Lead Smelter. *Science and the Total Environment*, **105**: 109-119.

Kalac, P., Niznanska M. and Bevilaqua, D. (1996). Concentrations of Mercury, Copper, Cadmium, and Lead in Fruiting Bodies of Edible Mushrooms in the Vicinity of a Mercury Smelter and a Copper Smelter [J]. *Science of the Total Environment*, **177**: 251-258.

Kang, M.Y., Rico, C.W. and Lee, S.C. (2012).*In vitro* antioxidative and antimutagenic activities of oak mushroom (*Lentinus edodes*) and king Oyster mushroom (*Pleurotus eryngii*) byproducts. *Food Sci Biotechnol*, **21**: 167–173.

Khatoon, H., Rai, J.P.N. and Jillani, A. (2021). Chapter 7 - Role of fungi in bioremediation of contaminated soil. *In*: Fungi Bio-Prospects in Sustainable Agriculture, Environment and Nano-technology, Editor(s): Vijay Kumar Sharma, Maulin P. Shah, Shobhika Parmar, Ajay Kumar, Academic Press, pp 121-156.

Kirk, T.K. and Farrell, R.L. (1987). Enzymatic combination – microbial degradation of lignin. *Annu. Rev. Microbiol*., **41**: 465-505.

Kirk, T.K., Lamar, R.T. and Glaser, J.A. (1992). The potential of white-rot fungi in bioremediation. *Biotechnol. Environ. Sci. Mol. Appl*., pp 131-138.

Kodama, N., Komuta, K. and Nanba, H. (2002). Can maitake MD-fraction aid cancer patients? *Altern Med Rev*, **7**: 236–239.

Kour, J., Chauhan, P.K. and Dulta, K. (2018). Isolation, characterization and identification of microorganisms from distillery effluent contaminated soil and *ex-situ* bioremediation of contaminated soil. *Biological Forum – An International Journal*, **10**(1): 101-110.

Kuforiji, O.O. and Fasidi, I.O. (2008). Enzyme activities of *Pleurotus tuber-regium* (Fries) Singer, cultivated on selected agricultural wastes. *Bioresource Technol*, **99**: 4275–4278.

Kulshreshtha, S., Mathur, N. and Bhatnagar, P. (2013).Mycoremediation of paper, pulp and cardboard industrial wastes and pollutants. *In*: Fungi as Bioremediators: Soil Biology. Edited by: Goltapeh EM, Danesh YR, Varma A. Springer Berlin, Heidelberg, pp 77–116.

Kulshreshtha, S., Mathur, N. and Bhatnagar, P. (2014). Mushroom as a product and their role in mycoremediation. *AMB Expr.*, **4**: 29.

Kumhomkul, T. and Panich-pat, T. (2013). Lead accumulation in the straw mushroom, *Volvariella* *volvacea*, from lead-contaminated rice straw and stubble. *Bull Environ Contam Toxicol*, **91**(2): 231-234.

Lamrood, P.Y. and Ralegankar, S.D. (2013). Biosorption of Cu, Zn, Fe, Cd, Pb, and Ni by non-treated biomass of some edible mushrooms. *Asian. J. Exp. Biol. Sci.*, **4**: 190–195.

Lang, E., Eller, I., Kleeberg, R., Martens, R. And Zadrazil, F. (1995). Interaction of white-rot fungi and micro-organisms leading to biodegradation of soil pollutants. *In*: Proceedings of the 5th International FZK/ TNO Conference on Contaminated Soil. 30th Oct- 5Nov 1995, Maustrient. The Netherlands by Van de Brink WJ, Bosman R and Arend F., **95**: 1277-1278.

Lechner, B.E. and Papinutti, V.L. (2006). Production of lignocellulosic enzymes during growth and fruiting of the edible fungus *Lentinus tigrinus* on wheat straw. *Process Biochemistry*, **41**(3):594-598.

Leung, M. (2004). Bioremediation: techniques for cleaning up a mess. *Journal of Biotechnology*, **2**: 18–22.

Loske, D., Huttermann, A., Majcherczyk, A., Zadrazil, F., Lorsen, H. and Waldinger, P. (1990). Use of white rot fungi for the clean-up of contaminated sites. *Advances in biological treatment of lignocellulosic materials. Elsevier, London*, pp 311-321.

Maehara, Y., Tsujitani, S., Saeki, H., Oki, E., Yoshinaga, K., Emi, Y., Morita, M., Kohnoe, S., Kakeji, Y., Yano, T. and Baba, H. (2012). Biological mechanism and clinical effect of protein-bound polysaccharide K (KRESTIN®): review of development and future perspectives. *Surgery Today*, **42**(1): 8-28.

Mansur, M., Arias, M.E., Copa-Patiño, J.L., Flärdh, M. and González, A.E. (2003). The white-rot fungus *Pleurotus ostreatus* secretes laccase isozymes with different substrate specificities. *Mycologia*, **95**(6): 1013-1020.

Martens, R., Wetzstein, H. G., Zadrazil, F., Capelari, M., Hoffmann, P. and Schmeer, N. (1996). Degradation of the fluoroquinolone enrofloxacin by wood-rotting fungi. *Applied and Environmental Microbiology*, **62**(11): 4206-4209.

Menaga, D., Rajakumar, S. and Ayyasamy, P.M. (2021). Spent mushroom substrate: a crucial biosorbent for the removal of ferrous iron from groundwater. *SN Appl. Sci*., **3**: 32.

Olusola SA, Anslem EE (2010) Bioremediation of a crude oil-polluted soil with *Pleurotus pulmonarius* and *Glomus mosseae* using *Amaranthus hybridus* as a test plant. J Bioremed Biodegrad **1**: 111, doi:10.4172/2155-6199.1000113

Novotný, Č., Svobodová, K., Erbanová, P., Cajthaml, T., Kasinath, A., Lang, E. and Šašek, V. (2004). Ligninolytic fungi in bioremediation: extracellular enzyme production and degradation rate. *Soil Biology and Biochemistry*, **36**(10): 1545-1551.

Olusola, S.A. and Anslem, E.E. (2010). Bioremediation of a crude oil polluted soil with *Pleurotus pulmonarius* and *Glomus mosseae* using *Amaranthus hybridus* as a test plant. *J Bioremed Biodegr*, **1**: 113.

Pointing, S.B. (2001). Feasibility of Bioremediation by White-rot fungi. *Appl. Microbiol. Biotechnol*, **51**: 20-33.

Purnomo, A.S., Mori, T., Putra, S.R. and Kondo, R. (2013). Biotransformation of heptachlor and heptachlor epoxide by white-rot fungus *Pleurotus ostreatus*. *International Biodeterioration & Biodegradation*, **82**: 40-44.

Raj, H.G., Saxena, M., Allameh, A. and Mukerji, K. G. (1992). Metabolism of foreign compounds by fungi. *Handbook of Applied Mycology*, **4**: 881-904.

Rajput, Y., Shit, S., Shukla, A. and Shukla, K. (2011). Biodegradation of malachite green by the wild mushroom of Chhattisgarh. *J Exp Sci.*, **2**: 69–72.

Ramya, R. and Boominathan, M. (2018). Bioremediation of heavy metal using growing cells in industrial effluent. *International Journal of Theoretical & Applied Sciences*, **10**(1): 100-105.

Rani, P., Kalyani, N. and Prathiba, K. (2008). Evaluation of lignocellulosic wastes for production of edible mushrooms. *Applied Biochemistry and Biotechnology*, **151**(2): 151-159.

Rhodes, C.J. (2012). Feeding and healing the world: through regenerative agriculture and permaculture. *Sci. Prog*, **95**(4): 345-446.

Sharma, R., Rakesh, K. and Akhilesh, K.P. (2010). Dynamics of Acid Phosphatase Production of the Ectomycorrhizal Mushroom *Cantharellus tropicalis*. *African Journal of Microbiology Research*, **4**(20): 2072-2078.

Stamets, P. (2005). Mycelium Running: How Mushroom Can Help Save the World. Ten Speed Press, Berkeley, and Toronto, 574pp.

Sullia, S.B. (2004). Environmental applications of biotechnology. *Asian J. Microbiol. Biotechnol. Environ. Sci.*, **4**: 65-68.

Tajuddin, M.F., Al-Gheethi, A., Mohamed, R., Noman, E., Talip, B.A. and Bakar, A. (2020). Optimizing of heavy metals removal from car wash wastewater by chitosan–ceramic beads using response surface methodology. Mater Today Proc.

Trejo-Hernandez, M.R., Lopez-Munguia, A. and Quintero, R.R. (2001). Residual compost of *Agaricus bisporus* as a source of crude laccase for enzymic oxidation of phenolic compounds. *Process Biochemistry*, **36**(7): 635-639.

Tsujiyama, S., Muraoka, T. and Takada, N. (2013). Biodegradation of 2,4-dichlorophenol by shiitake mushroom (*Lentinula edodes*) using vanillin as an activator. *Biotechnology Letters*, **35**(7): 1079-1083.

Tuzen, M. (2003). Determination of Heavy Metals in Soil, Mushroom and Plant Samples by Atomic Absorption Spectrometry. *Micro - Chemical Journal*, **74**(3): 289-297.

Tuzen, M., Ozdemir, M. and Demirbas, A. (1998). Study of Heavy Metals in Some Cultivated and Uncultivated Mushrooms of Turkish Origin. *Food Chemistry*, **63**: 247-251.

Uddin, M., Zhang, D., Proshad, R. and Haque, M.K. (2020). Role of mushrooms in soil mycoremediation: a review. *Chinese Journal of Applied and Environmental Biology*, **26**(2): 460-468.

Yogita, R., Simanta, S., Aparna, S. and Kamlesh, S. (2011). Biodegradation of malachite green by wild mushroom of Chhattisgarh. *Journal of Experimental Sciences*, **2**(10): 69-72.

Zakaria, A.Q., Mohd, A.Y. and Mohammad, A.S. (2017). On the performance of bioadsorption processes for heavy metal ions removal by low-cost agricultural and natural by-products bioadsorbent: a review. *Desalin Water Treat*, **85**: 339–357.

Zebulun, H.O., Isikhuemhen, O.S. and Inyang, H. (2011). Decontamination of anthracene-polluted soil through white-rot fungus-induced biodegradation. *Environmentalist*, **31**: 11-19.

Zhu, M. J., Du, F., Zhang, G. Q., Wang, H. X. and Ng, T. B. (2013). Purification a laccase exhibiting dye decolorizing ability from an edible mushroom *Russula virescens*. *International Biodeterioration & Biodegradation*, **82**: 33-39.

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