International Journal of Environmental Pollution Control & Management
Vol. 3, No. 1, July-December 2011; pp. 89-101

MUSHROOMS IN THE REMEDIATION OF HEAVY METALS FROM SOIL

Dilna Damodaran Raj[1], Mohan B.[1] & Vidya Shetty B. M.[1]
[1]*Departument of Chemical Engineering, National Institute of Karnataka, Srinivasnagar-575 025.*

Abstract: Macro fungi (Mushrooms) are useful agents in the field of bioremediation. Macro fungi are indicators of heavy metal concentrations in habitat. In general mushrooms both edible and non edible have higher capacity to uptake heavy metals. Mushrooms reflect the level of contamination of the soil through different morphological and metabolic characteristics. Edible mushrooms that contain heavy metals beyond certain concentration pose serious threat to human health as they enter in the food chain. Exposure to these heavy metal results in chronic physical, muscular, and neurological degenerative disorders. Mushrooms being a popular delicacy of modern world researchers are giving more importance to check their heavy metals content from 19th Century. Literature reveals that the mushrooms have the potential to accumulate heavy metals from soil and there is an immediate need of research in the area of heavy metal remediation using wild non edible mushrooms. Mushrooms have several advantages over other bioremediation agents; they have shorter life span, higher accumulation capacity and ease of removal of biomass. Species like *Boletus sp, Agaricus sp, Pleurotus sp., Armillaria sp., Polyporus sp., Russula sp., Termitomyces sp* etc. are few of the commonly reported mushrooms species discussed by the researchers due to their higher potentiality in heavy metal uptake. The present review deals with the bioaccumulation, factors affecting the uptake, its mechanism and the site of accumulation in mushroom bodies, so that effective bioremediation protocols can be designed for bioremediation of heavy metals from polluted soils.

Keywords: Heavy metals, soil pollution, mushrooms, bioremediation.

1. INTRODUCTION

In recent years, heavy metal pollution has gained increasing attention due to its possible toxic effects. Several engineering applications, industrial discharges, agricultural wastes, road runoffs, sewage disposals have lead to the addition of significant quantities of toxic heavy metals in soil, silt and waste water. Prominent sources that lead to contamination of soil are geogenic, mining and smelting, disposals of municipal industrial wastes (Akin *et al*., 2009) use of fertilizers and pesticides, and automobiles. About 90% road runoff and vehicle exhaust contains zinc(Zn), copper (Cu), lead (Pb) and traces of nickel (Ni) and cadmium (Cd). Motor oil also tends to accumulate metals as it comes into contact with surrounding parts as the engine runs, so oil leaks become another pathway by which metals enter the environment (Joshi and Luthra, 2000).

Heavy metals are considered as major environmental pollutants as they are cytotoxic, mutagenic, and carcinogenic (Hamman, 2004 and Mahavi, 2005). Many elements, for example arsenic, cadmium, mercury, etc. are toxic to living organisms even at trace levels. Soil and ground water quality data reported by Central Pollution Control Board (CPCB, December 2009) revealed that heavy metals like Cadmium, Lead, Mercury, Chromium, Cobalt, Zinc, Nickel and Manganese are the major pollutants. Hence there is need for immediate mitigation measures to bring down their levels in the environment. Several methods are used to remove metals from wastes. Chemical precipitation, coagulation with alum or iron salts, membrane filtration, reverse osmosis, ion-exchange and adsorption are some of the most commonly used processes (Francis *et al*., 1999; Salt *et al*., 1995; Krebs *et al*., 1999; Chen *et al*., 2000). These processes are suitable from technological perspective, but are not economically promising for soil remediation, as they need the dissolution of metals from the soil into water prior to the treatments such as membrane filtration, reverse osmosis, ion-exchange and adsorption or may lead to formation of large amount of sludge in the case of chemical precipitation and coagulation (Deils *et al*., 1999; Schnoor, 1997).

Biosorption is the process in which microorganisms are used to remove and recover heavy metals from aqueous solutions, have been known for few decades but have emerged as a low cost promising technology in the last decade in removing metals (Deils *et al*., 1999; Cho *et al*., 2000; Korda *et al.,* 1997 and Schnoor, 1997). In this process, the uptake of heavy metals and radioactive compounds occur as a result of physico-chemical interactions of metal ions with the cellular compounds of biological species (Kapoor & Viraraghavan, 1998). Microorganisms like algae, fungi and bacteria can be used to remove heavy metals and radioactive compounds from aqueous solutions (Volesky, 1994). Mushrooms or macro fungi can act as an effective biosorbent of toxic metals. They grow in natural habitat having large biomass, tough texture and other conducive characteristics that are required for their development to act as sorbents, thus obviating the need for immobilization or deployment of specialized reactor configuration as required for other microbial sorbents (Costa and Leite, 1991). Compared to green plants, mushrooms can build up large concentrations of some heavy metals, such as lead, cadmium and mercury in them as reported by Gast *et al*. (1988) in his studies on interaction of heavy metals with soil and mushrooms. This would suggest that fungi possess a very effective mechanism that enables them to take up some trace elements from the substrate (Latiff *et al*., 1988).

2. HEAVY METAL UPTAKE BY MUSHROOMS

Mushrooms belong to the family of *Basidiomycet*es commonly known as macro fungi. They have a characteristic fruiting body consist of a steam (Stipe) bearing a cap (Pilues) that have the potentiality to bioaccumulate most of heavy metals that are up taken. Mushrooms can uptake heavy metals from the substrate (soil) by means of substrate mycelia. Das (2005) as reported that the age and size of fruiting body any mushroom has negligible role in the uptake of heavy metals (Miersch *et al*., 2005). The life span of fruiting body is only 10-14 days; hence time consumed for uptake of these metals from the substrate is limited Gast *et al*. (1988); Sharma *et al*. (2010) had suggested in their studies on heavy metals contents in mushrooms that the uptake rate of heavy metals can be correlated with the contact time. Metal concentrations in the fruiting bodies are affected by age of mycelium and interval between fructification (formation of fruiting body). The metals are distributed unevenly with in a fruiting body (Elekes *et al*., 2010; Demirbas., 2002; Isildak *et al*., 2003; Yilmaz *et al*., 2003; Thomet *et al*., 1999). Study of mechanism of tolerance and uptake are still in their infancy.

Gast *et al.,* (1988) isolated wild grown edible and non edible mushrooms from both polluted and non polluted site and are analyzed for their heavy metal contents mainly Cd, Cu, Pb, Cr and Mn have found that the mushrooms have the potential to accumulate the heavy metals. Studies on metals in mushrooms by Mc Creight & Scroeder (1977) and Bargali *et al.,* (1984) have shown a correlation between fungal metal concentrations and point sources of metal pollution, such as smelters and road sides. Under natural condition, heavy metal concentrations of some species of wild grown edible mushrooms can be high even if the degree of pollution is low (Falandaysz *et al.*, 2003). There are more than 50 species of mushrooms which are studied and are proved to be efficient in absorbing metals like Pb, Cu, Cd, Fe, Zn, Hg and U. These mushrooms uptake metals through their hype and are distributed unevenly in the fruiting bodies (Thomet *et al.*, 1999). The uptake rate varies from species to species. Many other investigators like Gast *et al.*, (1988); Manzi *et al.* (1999); Kalac *et al.*, (2000) have worked on the metal contents in wild and edible mushrooms.

Demirbas (2002) has obtained mushroom varieties such as *Armillaria mellea, Polyporus squamosus, Polyporus suiphureus* from East Black Sea region and they found that these species could accumulate heavy metals like Hg, Pb, Cd and Cu.Among them *Armillaria mellea* shown to accumulate higher concentrations of Hg^{2+} as the concentration of mercury increases in the soil.

Akın *et al.* (2010) studied heavy metals (Cd, Cr, Cu, Pb, and Zn) concentrations in three edible mushroom species like *Lactarius deliciosus, Russula delica,* and *Hizopogon roseolus* collected from five sampling sites of Canakkale province, Turkey and reported the mean values of Cd, Cr, Cu, Pb, and Zn uptakes by these species as 0.72, 0.26, 28.34, 1.53, and 64 mg kg^{-1} respectively. The highest concentrations of Cd, Cu, Pb, and Zn were determined to be in *R. delica,* while higher Cr level was observed in *L. deliciosus.*

Uptake capacities of *Termitomyces microcarpus* for Cu, Pb, Cd, and As have been studied by Zhang dan *et al.* (2008), to be 135.00, 13.28, 65.30, and 1.60 mg kg^{-1} respectively. *Agaricus bisporus s*howed high potential to absorb heavy metals like Cr, Cu, Cd and Zn where as *Pulveroboletus amarellus* showed highest Zn content of 142.00 mg kg^{-1} in their fruiting body as per the studies of Zhang dan *et al.*, 2008. Species of *Agaricus* genera have been found to accumulate Mn,Fe and Ni (Isildac *et al.*, 2004) and also Cu at high concentrations (Andersen *et al.*, 1982; Kalac *et al.* 2004; Sanglimsuwan *et al.,* 1993; Falandaysz *et al.*, 2003) in their fruiting bodies. *Agaricus macrospores* showed a significant concentration of Cd in their biomass and a phosphoglycoprotein (Cd mycophosphatin) was found to be responsible for Cd-binding in these organisms as per the studies by Kalac *et al.* (1996).

Another mushroom, *Boletus edulis* showed higher uptake rate of Cu, Cd, Zn and Mn (Kalac *et al.*, 2006; Tuzen *et al.*, 2008). In the studies of Isildak *et al.* (2007) other species of Boletus Sp like *Boletus badius* showed higher concentration of lead of about 0.448+0.03 mg kg^{-1} of biomass. Pb accumulations by these mushrooms have also been reported in the studies of Kalac *et al.*, (1989); Mıchelot *et al.*, (1998); Kalac and Svoboda (2000); Isiloglu *et al.*, (2001).

Zhan Dan *et al.*, 2008 studied two geneses of *Boletus Sp, Lactarius Sp and Russula Sp*. These edible mushrooms showed different pattern bioaccumulation for different heavy metals.

B. griseus, R. delica and L.hatsudake found to have higher potential to absorb Cu compared to its other genus while *B. bicolor, R. crestosa* and *L. representaneus* showed higher potential to absorb Zn compared to other. Among these three species *R. crustosa* showed higher potential to absorb Cu and *B. griseus* has higher potential for Zn biosorption between species. Similar results have been observed in case of *Lactarius deliciosus* and *Russula delica* for Pb and Cu (Akın *et al*., 2009). Hence we can say the potential for biosorbtion varies with heavy metals and also intra species levels.

Mushrooms belong to *Russula Sp.* are also reported to have metal uptake capacities. In the studies of Akın *et al*., (2010); Zhan Dan *et al*., (2008), the highest concentrations of Cd, Cu, Pb, and Zn were determined in species *Russula delica*. *Russula delica* showed a Cu content of about 1.556+0.21 to 1.702+1.37 mg kg^{-1} in the reports of Isildak *et al*. (2007). In *Russula albida* Ni, Cr, Mn, Zn concentrations in the range of 1-5 mg kg^{-1} were reported by Zhu *et al*. (2010) in his study.

Pleurotus ostreatus showed a maximum uptake of heavy metals like Cd, Hg and Zn but did not seem to uptake lead to a significant level, this clearly explained that metal uptake mechanism is not same for all mushroom species and need to be studied further (Lasota, 1990; Tuzen *et al*., 1998; Ita *et al*., 2006; Dermirdas, 2001). The heavy metal uptake by *Pleurotus saor-caju* has been studied and reported by Mitra (1994). Among the heavy metals (Cu, Cd, Zn and Pb), Zinc was found to be absorbed maximum. *Pleurotus eryngii* showed higher Bioconcentration Factor (BCF) values for lead and *Pleurotus ostreatus* showed higher Cu and Zn accumulation among other heavy metals as per the reports of Zhu *et al*. (2010). The BCF of heavy metals represent metal concentrations in the mushrooms' body correlated with the metallic element in the soil on which the fungus grows.

Among the 14 species of mushrooms used by Zhu *et al.* (2010), *Corpinus comatus* could accumulate higher concentrations of Cd and Cu, while *Lepista sordid* absorbed Cu and Fe (50-80 mg kg^{-1} respectively) and *Voluariella volvaceae* absorbed significantly higher levels of Cu, and Zn (10-20 mg kg^{-1} respectively) among the studied heavy metals (Ni, Cr, Mn, Zn, Pb, Fe, Cu and Cd). Similar results have been obtained in Agrahar-Murugkar & Subbulakshmi (2005).

Bioaccumulation studies of Tuzen *et al*. (1998); Dermirdas (2001); Yilmas *et al*. (2008) found significant BCF values for metals like Pb, Cd, Hg, Cu, Mn and Zn in *Trichiloma terreum.* Zhang *et al*. (2008) studies found 343.00 mg kg^{-1} of Cu in the fruiting bodies of *Lepista nudain* his studies on bioaccumulation of heavy metals in wild mushrooms.

According to the findings of Elekes *et al*. (2010) mushroom species from the forest area of Bucegi showed higher concentration of heavy metals in their fruiting bodies. The concentration of each heavy metal in the biomass varied from species to species. Literature brings out the mean value of 11.94 mg kg^{-1} for Ti, 1.07 mg kg^{-1} for Sr, 1163.86 mg kg^{-1} for Bi and 17.49 mg kg^{-1} for Mn. The highest BCF value was found to be in *Marasmius oreades* species for bismuth and titanium.

Sanglimsuwan *et al.* (1993) studied on 21 mushrooms obtained mainly from Japan in his studies on factors affecting resistance to and uptake of heavy metals in mushrooms. Among them the *Pleurotus* species strains showed higher resistance to the heavy metals like Cu, Cd, Zn, Ni, Co and Hg than the other species. *Pleurotus ostreatus* exhibited the highest resistance to all these heavy metals. He studied the Cu, Zn and Cd accumulation mechanism in*Pleurotus ostreatus* and observed that the uptake of heavy metals into the mycelia of*P. ostreatus* increased proportionally to an increasing concentration of these metals in the medium. From his results it's evident that all mushroom species cannot accumulate heavy metals, it mainly depends on its tolerance nature.

In the case of Isildak *et al.* (2007) studies conducted BCF of heavy metals viz. Cu, Pb, Fe, Zn, Cd, Mn, Ni, Cr and Co on mushrooms, *Lepista nuda, Verpa conica* and *Russula delica* found to have unique in accumulating metals. *Lepsita nuda* found to accumulate Fe and Cr in higher concentrations (3.376+0.247 mg kg^{-1} and 1.515+0.11 mg kg^{-1} respectively) compared to other metals. Similarly *Verpa conica* and *Russula delica* found to accumulate higher concentrations, of Mn and Ni (3.775+0.32 mg kg^{-1} and 1.552+0.05 mg kg^{-1}). Among the 3 mushrooms sp Co and Zn concentration ranged from 0.011 to 0.314+0.03 mg kg^{-1} and 3.417+0.21 and 6.095+0.44 mg kg^{-1} respectively. Similar results have been observed in (Andersen *et al.*, 1982; Kalac *et al.*, 1989; Falandaysz and Bona, 1992; Falandyzs *et al.*, 1994) studies.

Table 1
Heavy Metal Content in Sporocarp of Various Tolerant Mushrooms

Mushroom Species	*Metal content (Accumualeted metals in sporocarp, mg/kg of dry weight)*	*References*
Agaricus bisporous	Cu (107), Pb (21), Zn (57.2)	Isildak *et al*. (2004)
	Pb (2.4), Cd (3.48), Hg (0.6), Cu (5.22)	Kalac *et al*. (2004)
	Hg (0.03), Pb (0.28), Cd (0.78) Fe (31.3)	Demirdas (2001)
Boletus edulis	Pb (0.96), Cd (1.03), Hg (0.13), Fe (31.1)	Tuzen *et al*. (1998)
	Cu (4.7), Mn (2.9), Zn (26.2).	Kalac *et al*. (1996)
	Hg (32.4), Cu (66.4), Cd (6.58), Pb (3.03)	
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 & 2004)
Pleurotus sp.	Pb (3.24), Cd (1.18), Hg (0.42), Cu (13.6), Mn (6.27), Zn (29.8), Fe (86.1).	Zurere *et al*. (1998)
	Pb (0.11), Cd (0.55), Hg (0.31), Fe (48.6),Cu (5.0), Mn (10.3), Zn (19.3)	Mithra *et al*. (1994)
Tricholoma terreum	Cu (25), Zn (179), Mn (19), Fe (744), Co (2.6) Cd (0.56), Ni (5.6), Pb (4.4).	Yimaz *et al*. (2003)
	Pb (2.4), Cd (1.6), Hg (0.06), Cu (35.8), Mn (24.8), Zn (48.0), Fe (169.0).	Dermirbas *et al*. (2001)
Volverilia. volvacea	Hg & Pb (5-5.23), Cu 500	Purkayastha *et al*. (1992)
Volvariella murinella	Pb (2.4), Cd (1.6), Hg (0.06), Cu (35.8)	Purkayastha *et al*. (1992)
Havlvella leucomelaena	Pb (3.1), Cd (1.1), Hg (0.26), Cu (13.6);	Tuzen *et al*. (2003)
	Pb (4.8), Cd (2.0), Hg (0.21), Fe (54.5)	Durken *et al*. (2000)
Paxillus rubicondulus	Pb (0.69), Cd (0.78), Hg (0.21), Fe (37.0), Cu (51.0), Mn (10.8), Zn (16.8)	Durken *et al*. (2000)

3. FACTORS AFFECTING UPTAKE

Bioaccumulation capability of Basidiomycetes depends on the nature of metals, pH of the soil; species of mushrooms and to a small extend the genus and biomass. Hence the factors affecting the growth of mushroom also play a vital role in bioaccumulation mainly temperature and humidity. As per Chen *et al.* (2009) mushrooms grow well at 20-30^{o}C and 90-98% humidity. Elevated concentrations of heavy metal has been observed in those mushrooms species collected from highly polluted areas like road sides, smelters, landfills of sewage sludge etc. (Kalac *et al*., 1991 and 2004; Ita *et al*., 2006; Begum *et al*., 2009). Tyler (1982); Michelot *et al*. (1998); Kalac & Svoboda (2000) reported that the nature of substrate and ecosystem play an important role in uptake of individual metals by mushrooms. Kalac and Svoboda (2000) reported that the age of the fungal fruiting body or its size is of less importance in the accumulation of heavy metals by mushrooms. However, variations in heavy metal accumulation could be ascribed to individual species potential and their ecosystem (Seeger, 1982).

There has been a previous report on the uptakes of Cd, Cu, Pb and Zn in mushrooms and their relationship with soil characteristics (Gast *et al*., 1988; Mıchelot *et al*., 1998; Aruguate *et al*., 1998). We also found fairly low concentration of Ni, Co, Pb, and Cr in mushroom species compared to other studied metals, which is mainly due to mobility characteristic. Alloway, 1990; Kalac *et al.*, 2004 reports clearly shows that Ni, Co, Pb, and Cr have lesser mobility when compared to Cd.

In Akın *et al*. (2010) studies *Russula delica* shows higher and lower Pb content in the fruiting body isolated from two different study areas, this shows that the amount of heavy metal in the substratum play an important role in uptake rate. Similar results are observed in case of *Termitomyces microcarpus* in the study of Cu in Dan *et al*. (2008).

According to Das *et al*., 2005 reports the heavy metal uptake by mushrooms from the substrate mainly depends on the nature of metallic compounds as the availability of cations depends mainly on the anions. Similar results are observed in case of *Suillus granulates, Lactarius delicosus, Tuber melanosporium and Tuber brumale* shows higher rate of copper biosorption with the supply of surplus amounts of potassium and magnesium ions which are essential for the growth (Poitou and Oliver, 1990).

The uptake of heavy metals also depends on the concentrations of other metals in the substratum. Mitra (1994) reported that the interaction of copper and cadmium at low concentrations significantly reduces Cd uptake in *Volvariella volvacea* and *Pleurotus Saju-caju* but enhanced Cu uptake. Cd was also found to inhibit mycelial growth of these mushrooms there by restricting the bio-contact of the heavy metals in the soil. Similar results have been observed by Gadd *et al*. (1996), in their studies. Hockertz *et al*. (1987); Auling (1994) observed that at 100nM concentration of $MgCl_2$ the uptake rate of Mn by *Aspergillas niger* show a drastic reduction upto 57%. These fungi showed a specific high-affinity Mn^{2+} transport system (K, = 3 pM) has been detected at sub micromolar concentrations of Mn^{2+} which functioned independently of the transport of Mg^{2+} and Ca^{2+} but was preferentially inhibited by lower concentrations of Zn^{2+},Cu^{2+} and Cd^{2+}.

4. UPTAKE MECHANISM & SITE OF ACCUMULATION

In the literature, it has been observed that the heavy metal accumulations in mushrooms are species – specific. Elevated concentrations of heavy metals have been reported in the fruiting bodies of mushrooms collected from the sites adjacent to industrial complex that are prone to heavy metal contamination (Isiloglu *et al*., 2001, Kalac *et al*., 1991 and 1996).

The macro fungi are found to have high tolerance against elevated concentrations of heavy metal in their habitat, mainly through various mechanisms as reported by many researchers (Bruins, Kapils and Oehme, 2000; Cobbett and Goldsbrough, 2002). Usually microorganisms were found bind the heavy metals at the cell wall level and try to avoid their cytoplasmic exposure. Other mechanisms include uptake into the cell across the cell wall. (Gomes *et al*., 2002; Vanho, Mcveyward and Kaplan, 2002) the uptake mechanism found to involve the combined effect of accelerated efflux and /or the chelation of toxic ions in cytosol and subsequent transport into vacuoles (Clemens, 2001; Cobbett and Goldsbrough, 2002). The formation of such complexes generally involves thiols. These thiols found to occur as low molecular weight phytochelatins in plants (Clemens, Palmgren and Krämer 2002; Seregin and Ivanov, 2001) and in some fungi (Gadd, 2001; Clemens and Simm, 2003). High molecular weight compounds are cysteine-rich proteins like metallothioneins and they have been found in many animals (Nordberg 1998), a few fungi (Gadd and Sayer, 2000; Clemens and Simm, 2003) and plants (Cobbett and Goldsbrough, 2002) as reported in the literature. Biosynthesis of phytochelatins is closely linked to the glutathione metabolism as reported by Pennincks, 2002 in his studies on glutathione production in yeast owing to metal stress.

Blaudez *et al*. (2000) studied the uptake of Cd through sub cellular compartmentalization. They have found that heavy metals accumulate in mushrooms as organic or inorganic compounds or get associated with proteins and lipids. These complexes over the course of time found to form the integral part of a cell wall or cytoplasm or vacuole based on the type of mechanism involved during the uptake. Passive uptake of charged molecules by a living cell observed to depend on osmolarity. Thus ability of the microorganisms to survive against the exposure of heavy metals, depend on mechanisms to regulate intracellular concentrations (Miersch *et al*., 2005; Hentschel *et al*., 1993).

Hentschel *et al*. (1993) reported on the bioaccumulation of Al by mushrooms that are naturally grown in the areas adjacent to smelters. The uptake of metals to the cell mainly depends on osmotic balance, the results reported by them clearly indicated that mushrooms influx negatively charge ions as the concentration of Al increased in them in order to maintain the osmolarity. Studies for the uptake mechanism of higher concentrations of Cd, Zn, Cu and Hg, as well as cytosolic Cd-binding capacity (CCBC), glutathione (GSH) and free proline (Pro) in fruiting bodies of *Boletus edulis* was reported in the literature (Hansen *et al*., 2003).

Demirdas (2002) reported that mushrooms have the capacity to accumulate heavy metals phosphate or sulfates instantly from soil ($PbSO_4$, $CdSO_{4,}$ etc.). Several researchers have used X-ray Absorption Near Edge Structure (XANES) spectra to analyze the site of accumulation. Smith (2007) used XANES for toxicity studies in mushrooms and identified that fleshy cap of mushrooms can be a potent site for toxic metal accumulation like As.

Metal distribution among cytosolic compounds were investigated by size exclusion chromatography (SEC), followed by metal determinations with atomic absorption chromatography (AAS) and HR-ICP-MS. Cd-binding compounds in SEC eluents were investigated further by high performance liquid chromatography-mass spectrometry (HPLC-MS) and total protein content variation in response to soil heavy metal content was analyzed by SDS-PAGE in the reports of Goldani *et al*. (1994). The enzymes and proteins which play an important role in metal uptake can be studied as per Horie *et al*. (2009). They analyzed the protein profile of *Sparassis crispa* and *Hericium erinaceum* by ESI-LC-MS/MS and the resulted sequence has been blasted in protein database to find out the stress protein related to heavy metal shock. This method has been widely followed many researchers to identify the unknown protein in any samples.

Thus the above literatures reveal that mushrooms naturally accumulate high concentrations of the heavy metals in their tissue by unrestricted absorption and tolerate their toxicity. Metal tolerance and higher uptake have intrinsic strategies and requires some mechanism(s) to detoxify the metals. However more information on the mechanism of the uptake like genes and the signal mechanism involved in these process in mushroom species have to be addressed for a higher and engineered mycoextraction process.

5. CONCLUSIONS

A great deal of evidence indicates that mushrooms have the potential to clean up soil contaminated with toxic metals. Identification of major metal accumulating species has been an impetus for mycoremediation research. Despite of significant research efforts mycoremediation is still an emerging technology. Researchers needs to put their efforts to close the knowledge gaps in metal uptake mechanism, antagonistic and synergetic effects of metals in uptake and the characters of these accumulates in molecular level. The metal uptake potential of mushrooms should be critically analyzed for health risk as mushrooms have become a popular delicacy of modern world.

The advantages of using mushroom as bioremediating agent are as follows:

- Mushrooms in general can accumulate heavy metals in their Pilues at higher quantities and species specific.
- *Pleurotus Sp.*, *Russula Sp.* and *Boletus Sp.* are reported to have higher potentiality in the biouptake of toxic heavy metals from the soil.
- Uptake concentration of heavy metals by the mushrooms found to depend on the type of mechanism and the bioavailability of the metals.
- Heavy metal uptakes in mushrooms were found to be characterized by the production of unusual proteins, like glutathione (GSH) and free proline. The quantities of these proteins were found to vary based on the level of heavy metal stress experienced by the organism.

Due industrialization, tremendous use of pesticides, road runoffs and sewage disposals have lead to the addition of significant quantities of toxic heavy metals in soil, silt and waste water of India many places in India are reported to have heavy metal pollution.

References

Agrahar-Murugkar, D, G. Subbulakshmi (2005), Nutritional Value of Edible Wild Mushrooms Collected from the Khasi Hills of Meghalaya. *Food Chem.*, 89, 599-603.

Akın, C., Munevver, C. and Mahmut, C. (2010), The Heavy Metal Content of Wild Edible Mushroom Samples Collected in Canakkale Province, Turkey. Biology of Trace Elements, 134, 212-219.

Alloway, B. J. (1990), Heavy Metals in Soils; John Wiley: New York.

Andersen, A., Lykke, S. E., Lange, M., and Bech, K. (1982), Trace Elements in Edible Mushrooms. Publ. 68, Stat. Levnedsmiddelinst; Denmark, pp. 29.

Aruguate, D. M., Aldstadt, J. H. and Mueller, G. M. (1998), Accumulation of Several Heavy Metals and Lanthanides in Mushrooms (Agaricales) from the Chicago Region. Sci. Total Environ., 224, 43-56.

Atlas, R. M. (1981), Microbial Degradation of Petroleum Hydrocarbons: An Environmental Perspective. *Microbial Review,* 45, 180-209.

Ita, B. N., Essien, J. P., G. A. Ebong (2006), Heavy Metal Levels in Fruiting Bodies of Edible and Non-Edible Mushrooms from the Niger Delta Region of Nigeria. *Journal of Agriculture &Social Sciences,* 87, 1813-2235.

Bargali, R., Baldi, F. (1984), Mearcury and Methylemercury in Higher Fungi and their Emission with Substrate in Cinnabar Mining Area. *Chemosphere,* 13, 1059-1071.

Begum, A., Ramaiah, M., Irfanulla Khan and Veena, K. (2009), "Analysis of Heavy Metals Concentration in Soil and Litchens from Various Localities of Hosur Road, Bangalore India." *E-Journal of Chemistry,* 6(1), 13-22.

Blaudez, D., Bernard, B. and Michel, C. (2000), Cadmium Uptake and Subcellular Compartumentalization in the Ectomycorrhizal Fungus Paxillus Involutus. *Journal of Microbiology,* 146, 1109-1117.

Bruinsmr, Kapils S. & Oehme F. W. (2000), Microbial Resistance to Metals in the Environment–Ecotoxicology and Environmental Safety, 45, 198-207.

Carmen, C. E. and Gabriela, B. (2010), The Mycoremediation of Metals Polluted Soils Using Wild Growing Species of Mushrooms. Education'10 Proceedings of the 7th WSEAS International Conference on Engineering Education, 256-257.

Chen, H. M., Zheng, C. R., Tu, C. and Shen, Z.G. (2000), Chemical Methods and Phytoremediation of Soil Contaminated with Heavy Metals. *Chemosphere,* 41, 229-234.

Cho, Y. G., Rhee, S. K. and Lee, S. T. (2000), Effects of Soil Bioremediation of Chlorophenol-contaminated Soil. *Biotechnol Letters,* 22(11), 915-919

Clemens, S. (2001), Molecular Mechanisms of Plant Metal Tolerance and Homeostasis-Planta and Lead Toxic Effects on Higher Plants. *Russian Journal of in Yeast Microbiology,* 56, 237-261.

Clemens, S., Palmgren, M.G., Krämer, U. (2002), A Long Way Head: Understanding and Engineering Plant Metal Accumulation. *Trends in Plant Science,* **7**, 309-315.

Clemens, S., Simm, C. (2003), *Schizosaccharomyces pombe* as a Model for Metal Homeostasis in Plant Cells: the Phytochelatin-dependent Pathway is the Main Cadmium Detoxification Mechanism. New Phytologist, 159, 323-330.

Cobbett, C., Goldsbrough, P. (2002), Phytochelatins and Metallothioneins: Roles in Heavy Metal Detoxification and Homeostasis. *Annual Review of Plant Biology,* 53, 159-182.

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

Das, N. (2005), Heavy Metal Biosorption by Mushrooms. *Natural Radiance,* 4(6), 454-459.

Deils, L., De Smet., Hooyberghs, L., Corbisier, P. (1999), Heavy Metal Bioremediation of Soil. *Molecular Biology,* 12, 149-158.

Demirbas, A. (2002), Metal Ion Uptake by Mushrooms from Natural and Artificially Enriched Soils. *Food Chem.,* 78, 89-93.

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

Demirbas, A. (2000), Accumulation of Heavy Metals in Some Edible Mushrooms from Turkey. *Food Chemistry,* 68, 415-419.

Ebbs, S. D., Kochian, L. V. (1998), Phytoextraction of Zinc by Oat (Avina sativa), Barley (Hordeum vulgare) and Indian Mustard (Brassica juncea), *Environmental. Science and Technoogyl,* 32, 802-806.

Ebbs, S. D., Brady, D. J., Kochian L.V. (1998), Role of Uranium Speciation in the Uptake and Translocation by Plants. *Journrl of Expression Botany,* 49, 1183-1190.

Falandaysz, J., Kawano, M., Swieczkowski, A., Brzostowski, A., Dadej, M. (2003), Total Mercury in Wild-Grown Higher Mushrooms and Underlying Soil From Wdzydze Landscape Parc, Northern Poland. *Food Chem.,* 8, 21-26.

Falandysz, J., Bona, H. (1992), Metals Content in wild Growing Mushrooms (Agaricus spp.) in the City and Region of Gdansk. Bromatologia i Chemia Toksykologiczna, 25, 251-256.

Falandyzs, L., Bona, H., Danisievicz, D. (1994), Silver Uptake by Agarigus Bisporus from an Arti.cally Enriched Substrate. Z. Lebensm. Untersuch. Forsch. A, 199, 225-228.

Francis, C. W., Timpson, M. E., Wilson, J. H. (1999), Bench- and Pilot-scale Studies Relating to the Removal of Uranium from Uranium Contaminated Soils Using Carbonate and Citrate Lixiviants. *Journal of Hazardous Matter,* 66, 67-87.

Gadd, G. M. (2001), Metal Transformations. In Gadd GM (ed) Fungi in Bioremediation, pp. 359-382. Cambridge University Press.

Gadd G. M., Sayer G. M. (2000), Fungal Transformations of Metals and Metalloids. In Lovley DR (ed) Environmental Microbe-Metal Interactions, pp. 237-256. *American Society of Microbiology,* Washington.

Gast, G. H., Jansen, E., Bierling, J. and Haanstra, L. (1988), Heavy Metals in Mushrooms and their Relationship with Soil Charecteristics. *Chemosphere,* 60(4), 789-799.

Goldani, L. Z., and Michele, A. M. (1994), Sugar Synthesis of Heat-Shock Proteins in Mycelia and Yeast Forms of Paracoccidioides Brasiliensis. J*ournal of Medical Microbiology,* 40, 124-128.

Gomes D., Fragoso L., Riger C., Panek A., Eleutherio, E. (2002), Regulation of Cadmium Uptake by *Saccharomyces cerevisiae*–Biochimica Biophysica Acta, 1573, 21-25.

Hall, J. L. (2002), Cellular Mechanism for Heavy Metal Detoxification and Tolerance. *Journal of Experimentation Biology,* 53, 1-11.

Hamman, S. (2004), Bioremediation Capabilities of White Rot Fungi. BI570–Review Article. *Journal of Molecular Biology,* 23, 234-238.

Hentschel, E., Douglas, L., Petra, M., Hedda, S. and Georg, J. (1993), The Effect of Padus involutus Fr. on Aluminum Sensitivity of Norway spruce Seedlings. *Tree Physiology,* 12, 379-390.

Isildak, O., Turkekul, I., Elmastas, M., Aboul, E., Hassan Y. (2007), Bioaccumulation of Heavy Metals in Some Wild-Grown Edible Mushrooms, Analytical Letters, 40, 6, 1099-1116.

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

Isildak. Y. E., Ashmawy, A., Badr, S. (2008), Biosorption of Cadmium and Nickel by Nile Water Algae. *Journal of Applied Science,* 4, 391-396.

Isiloglu, M., Merdivan, M. and Yilmaz, F. (2001), Concentration of Trace Elements in Wild Edible Mushrooms. *Food Chem.,* 73, 169-175.

Ita, B. N., Essien, J. P. and Ebong, G. A. (2006), Heavy Metal Levels in Fruiting Bodies of Edible and Non-edible Mushrooms from the Niger Delta Region of Nigeria. *Journal of Agriculture & Social Sciences,* 46, 1813-2235.

Joshi, U. N. and Y. P. Luthra (2000), An Overwiew of Heavy Metals: Impact and Remediation. *Curr. Sci.*, 78, 2-4.

Juan, A., Campos, N. A., Tejera Sanchez, C. J. (2008), Substrate Role in the Accumulation of Heavy Metals in Sporocarps of Wild Fungi. *Biometals,* 22, 835-841.

Kalac, P., Niznanska M., 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.

Kalac, P., Svoboda, L. (1998), Heavy Metals in Edible Mushrooms. *Czech J. Food Sci.,* 16, 110-116.

Kalac, P., Svaboda, L. (2000), A Review of Trace Elements Concentrations in Edible Mushrooms. *Food Chemistry,* 69, 273-281.

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., M. Wittingerova, I. Staskova, M. Simak and J. Bastl (1989), Contents of Mercury, Lead and Cadmium in Mushrooms. *Ceskoslovenska Hygiena,* 34, 568-76

Kalac, P., Niznaska, M., Staskova, I. (1996), Concentration of Mercury, Copper Cadmium and Lead in Fruiting Bodies of Edible Mushrooms in the Vicinity of Mercury and Copper Smelter. *The Science of Total Enviornament,* 177, 251-258.

Kalac, P., Wittningesova, M., Staskova, I. Simak, M., Bastl, J. (1989), Contents of Mercury, Lead and Cadmium in Mushrooms. Ceskoslovenska Hygina, 34, 568-76.

Kapoor, A., Viraraghavan, T. (1998), Biosorption of Heavy Metals on Aspergillus Niger: Effect of Pretreatment, *Biores Technol*, 63, 109.

Korda, A., Santans, P., Tenente, A., Santans, R. (1997), Petroleum Hydrocarbon Bioremediation: Sampling and Analytical Techniques, in-situ Treatments and Commercial Microorganisms Currently Used. *Applied Microbial Biotechnology,* 48(6), 677-686.

Krebs, R., Gupta, S. K., Furrer, G., Schulin, R. (1999), Gravel Sludge as an Immobilizing Agent in Soils Contaminated by Heavy Metals – A Field Study. *Journal of Water, Air Soil Pollution,* 115, 465-479.

Lasota,W., Florezak & Karmanska, A. (1990), “Effects of Toxic Metal on Protein Content of Mushrooms.” *Bromatol, Chem Toksykol,* 22(3), 95-99.

Latiff, L. A., Daran, A. B. M., Mohamed, A. B. (1996), Relative Distribution of Metals in the Pileus and Stalk of Some Selected Edible Mushrooms. *Food Chemistry,* 56, 115-121.

Lepsova, A. and Kral, R. (1988), Lead and Cadmium in Fruiting Bodies of Macrofungi in the Vicinity of a Lead Smelter. *Science Total Environment,* 76, 129-138.

Lepsova, A., Mejestrık, V. (1988), Accumulation of Trace Elements in Fruiting Bodies of Macrofungi in the Krusne Hory Mountains Czecholovakia. Science Total Environment, 76, 117-128.

Leumann, C. D., Rammelt, R. and Gupta, S. K. (1995), Soil Remediation by Plants: Possibilities and Limitations. *Science Total Environment,* 2, 431-434.

Mahavi P. (2005), Use of Tea Waste as Bioabsorbent for Removal of Heavy Metals from Waste Water. *Chemosphere,* 54, 1522-29.

Manzi, P., Aguzzi, A., Pizzoferranto, L. (2001), Nutritional Value of Mushrooms Widely Consumed in Italy. *Food Chemistry,* 73, 321-325.

Manzi, P., Aguzzi, A., Vivanti, V., Paci, M. and Pizzaferrato, L. (1999), Mushrooms as a Source of Functional Ingredients. In Europe. Food Chemistry. X European Conference on Functional Food, a New Challenge for Food Chemist. 22-24. September, Budpest, Hungary, 1, 86-93.

Mc Creight, J. D. and Schroeder, D. B. (1977), "Cadmium, Lead, and Nickel Content of Lycoperdon Perlatum Pers in a Roadside Environment." *Environmental Pollution,* 13, 265-268.

Mıchelot, D., Siobud, E., Dore, J. C., Viel, C., and Poirier, F. (1998), Uptade on Metal Content Profiles in mushrooms-toxicological implications and tentative approach to the mechanisms of bioaccumulation. Toxicon, 36, 1997-2012.

Mitra, A. K.(1994), Studies on the Uptake of Heavy Metalpollutents by Edible Mushrooms and its Effect on their Growth, Productivity and Mammalion Systems, Phd Thesies, University of Calcutta.

Nordberg, M. (1998), Metallothioneins: Historical Review and State of Knowledge – Talanta, 46, 243-253.

Omer, I., Ibrahim, T., Mahfuz, E., Mustafa (2004), Analysis of Heavy Metals in Some Wild Grown Edible Mushrooms from the Middle Black Sea Region, *Turkey Food Chemistry,* 86, 547-552.

Penninckx, M. J. (2002), An Overview on Glutathione in *Saccharomyces*. *Plant Physiology,* 48, 523-544.

Poitou, M., Oliveier J. M. (1990), Effect of Copper on Mycelium of 3 Edible Ectomycorrhizal Fungi. *Agric Ecosys Emviron,* 28(4), 199-202.

Saeed, M. W., Akhter, M. Iqbal (2005), Removal and Recovery of Heavy Metals from Aqueous Solution Using Papaya Wood as a New Biosorbent. *Purification Technologies,* 45 25-31.

Salt, D. E., Prince, R. C., Pickering, I. J., Raskin, I. (1995), Mechanisms of Cadmium Mobility and Accumulation in Indian Mustard. *Plant Physiology,* 109, 1427-1433.

Sanglimsuwan, S., Naoto, Y., Tsutomu, M., Yoshikatsu, M. (1993), Resistance to and Uptake of Heavy Metals in Mushrooms. *Journal of Fermentation and Bioengineering,* 75(2), 112-114.

Schnoor, J. (1997), Phytoremediation: Groundwater Remediation Technologies Analysis Center Technology. Evaluation Report, 1, 62.

Seeger, R. (1982), Toxische Schewermetalle in Pilzen. Deutshe Apothekeb Zeitschrift, 122, 1835-1844.

Seregin I. V., Ivanov, V. B. (2001), Physiological Aspects of Cadmium Microbiological Society Yeast Research, 2, 295-305.

Sharma, R., Rakesh, K., Akhilesh, K. P. (2010), Dynamics of Acid Phosphatase Production of the Ectomycorrhizal Mushroom Cantharellus Tropicalis. *Journal of Biotechnology,* 15, 1563-1564.

Smith, P. G. (2007), Arsenic Speciation Analysis of Cultivated White Button Mushrooms (Agaricus bisporus) Using High Performance Liquid Chromatography Inductively Coupled Plasma Mass Spectrometry and X-ray Absorption Spectroscopy. *Environmental Science and Technology,* 5, 546-553.

Svoboda, L., Zimmermannova, K., Kalac, P. (2000), Concentration of Mercury, Cadmium, Lead and Copper in Fruiting Bodies of Edible Mushrooms in an Emission Area of a Copper Smelter and a Mercury Smelter. *Sci Total Environ,* 246, 61-67.

Thomet, U., Vogel, E., Krahenbuhl, U. (1999), The Uptake of Cadmium and Zinc by Mycelia and their Accumulation in Mycelia and Fruiting Bodies of Edible Mushroom. *Eur Food Res Technol,* 209, 317-324.

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

Tyler, G. (1982), Accumulation and Exclusion of Metals in Collybia Peronata and Amanita Rubescens. *Trans B. Mycol Soc.,* 79(2), 239-245.

Vanho, A., Mcveyward, D., Kaplan, J. (2002), Transition Metal Transport versus Non-conventional Yeasts– *Federation European,* 65, 675-677.

Yamac, M., Yıldız, D., Sarıkürkcü, C. (2007), Heavy Metals in Some Edible Mushrooms from the Central Anatolia, Turkey. *Food Chem,* 103, 263-267.

Yilmaz, F., Isiloglu, M., Merdivan, M. (2003), Heavy Metal Levels in Some Macrofungi, *Tus. J. of Botany,* 27, 45-56.

Zhang, D., Gao, T., Pei, M. A., Luo Ying., Pengcheng, S. U. (2008), Bioaccumulation of Heavy Metal in Wild Growing Mushrooms from Liangshan Yi Nationality Autonomous Prefecture, China. *Journal of Natural Science*, 3, 0267-06.

Zhu, F. Qu, L, Fan, W. Qiao, M. Hao, H., Wang, X. (2010), Assessment of Heavy Metals in Some Wild Edible Mushrooms Collected from Yunnan Province, *China. Environ Monit.*, 6, 1725-1728.

Zizka, Z., Gabriel, J. (2008), Autofluroscence of the Fruiting Body of the Fungus *Macrolepiota rhacodes*. Folia Microbial, 53(6), 537-539.

Hockertz, S., Plonzig, J., Auling, G. (1987), Impairment of DNA Formation is an Early Event in *Aspergilltls niger* Under Manganese Starvation. *Appl Microbiol Biotechnol,* 90, 1420-1425.

Auling, G. (1994), Manganese: Function and Transport in Fungi. *In Metal Ions in Fungi,* 6 215-236.