Heavy metals biosorption by mushrooms

Nilanjana Das
Rural Development Centre
Indian Institute of Technology
Kharagpur – 721 302, West Bengal, India
Correspondent author, E-mail: nilanjana00@lycos.com
Received 12 January 2005; Revised 21 July 2005

Abstract

The use of absorbents of biological origin has emerged in the last decade as one of the most promising alternatives for the control of environmental pollution caused by heavy metals. A number of methods, viz. chemical precipitation, evaporation, electroplating, ion exchange, membrane, processes, etc. exist for the removal of heavy metals from liquid wastes. All these methods are expensive and have shortcomings such as incomplete removal of metals, limited tolerance to *p*H change, moderate or no metal selectivity, production of toxic sludge or other products that also need disposal. Fruiting bodies of macrofungi (mushrooms) may be considered ideal for the purpose of biosorption of heavy metals because their potentiality for heavy metal uptake have already been proved. Biosorption can become a good weapon in the fight against toxic metals threatening the environment. In the present article, selective uptake of heavy metal ions by wild and cultivated mushrooms, factors influencing heavy metal uptake and effects of heavy metal uptake on growth and productivity of mushrooms have been discussed as an important aspects of heavy metal management strategies.

Keywords: Heavy metals, Environmental pollution, Biosorption, Mushrooms.

IPC code; Int. cl.[7] — A01G 1/04, B01D 53/64

Introduction

Presence of heavy metals in soil, air, water and living objects is a severe public health concern and due to detrimental effect of them on man and environment, their removal is deemed important to the protection of environmental health. Unlike many organic wastes, heavy metals can not be degraded biologically to harmless products. 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. Each process has its merits and limitations in application.

Biosorption, the process in which microorganisms are used to remove and recover heavy metals from aqueous solutions, has been known for few decades but has emerged as a low cost promising technology in the last decade. In this process, the uptake of heavy metals and radioactive compounds occurs 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 macrofungi can act as an effective biosorbent of toxic metals. They grow in natural habitat having large, tough texture and other conducive characteristics required for their development into sorbents, thus obviating the need for immobilization or deployment of specialized reactor configuration as required for other microbial sorbents (Costa & Leite, 1991; Macaskie, 1990; Tsezos & Deutschmann,1992; Zhou & Kiff,1991). The present article is a review on uptake of heavy metals by different wild and cultivated mushrooms.

Heavy metals uptake by different mushrooms

Fruiting body of mushrooms consists of cap (pileus) with a spore-forming part (sporophore) and stipe (stem, stalk). Mushroom uptake heavy metals from a substrate via spacious mycelium. Age and the size of the fruiting body are of less importance. The proportion of the metal contents originating from the atmospheric depositions seems to be also of less importance due to the short lifetime of a fruiting body, which is usually 10–14 days. Metal contents in fruiting bodies are considerably affected by the age of mycelium and by the interval between the fructifications (formation of fruiting body). The metals are distributed unevenly within a fruiting body. The highest levels are observed in the spore-forming part, but not in spores, lower contents in the rest of the cap and the lowest in the stipe (Thomet *et al*, 1999). Knowledge of transport mechanisms of the metals from mycelium to the fruiting body is limited. Several scientists have reported following mushrooms as the potential biosorbent of heavy metals. Concentration of heavy metals in fruiting bodies of mushrooms collected from different places has been given in Table 1.

Agaricus bisporus **(J. E. Lange) Sing**: Isildak *et al* (2004) reported that this mushroom could absorb heavy metals like copper, cadmium, lead, zinc, manganese, iron, chromium and nickel. The level of copper was quite high compared to other metal ions. According to Kalac *et al* (2004), cultivated ***A. bisporus*** absorb less amount of cadmium compared to plants growing in wild. Similar report on biosorption of heavy metals was also published by Demirbas (2001) and Sesli & Tuzen (1999). This mushroom is reported to be very susceptible to increasing content of mercury and to a lesser extent of cadmium in substrate and bio-accumulates both the metals and lead in its fruiting bodies (Tuzen *et al*, 1998).

Agaricus bisporus

Boletus edulis

Armillaria mellea **(Vahl ex Fr.) Kummer**: This is an edible species having capacity of bio-accumulation of heavy metals (Kalac *et al*, 1991; Demirbas, 2002).

Boletus edulis **Bull. ex Fr.**: Kalac *et al* (1996) and Tuzen *et al* (1998) reported the accumulation of lead, copper, cadmium, iron, manganese, zinc, etc. in this species.

Lepista nuda

Calvatia excipuliformis **(Schaeff)**: Interesting information on the distribution of mercury in cap and stipe and on the values of the bio-accumulation factor between mercury content and underlying substrate from a depth of 0-10cm was reported by Falandysz *et al* (2003). Surprisingly high bioaccumulation of mercury (factor level of 960-310) was observed in the cap and stipe of ***C. excipuliformis***. Turkekul *et al* (2004) reported that this mushroom also possesses the capability of absorbing other metals.

Calvatia excipuliformis

Lepiota rhacodes **(Vitt.) Quél.** and ***Lepista nuda*** **(Bullard:Fries) Cooke**: Kalac *et al* (1991) reported that accumulation of lead was quite high in ***L. rhacodes*** and ***L. nuda***. Biosorption of mercury, copper, cadmium, lead, etc. in ***L. nuda*** is also reported by Kalac *et al*, 1996; Isildak *et al*, 2004; and Turkekul *et al*, 2004).

Lepiota rhacodes

Paxillus involutus **(Fries) Fries**: Blaudez *et al* (2000) reported that cadmium bound onto cell walls and accumulate in the vascular compartments of this non-edible mycorrhizal mushroom. Accumulation of lead and copper was also reported by Kalac *et al* (1991, 2004) in this mushroom.

Paxillus involutus

***Psalliota campestris* (L. ex Fr.) Quél.**: Zurera *et al* (1988) reported the highest accumulation of lead and cadmium in this mushroom. They also discussed the possible health risk for the Spanish consumers due to daily intake of these mushrooms containing lead and cadmium.

Pleurotus ostreatus* (Jacq.) Kummer**: This mushroom showed maximum uptake of cadmium, minimum of mercury and zinc and no uptake of lead (Lasota, 1990). Heavy metal uptake by ***P. ostreatus has also been reported by Tuzen *et al* (1998) and Demirbas (2001).

Pleurotus sajor-caju* (Fries) Singer**: The uptake of heavy metals by ***P. sajor-caju has been reported by Mitra, 1994. Among the heavy metals tested, zinc accumulation was maximum, while that of lead and cadmium were less.

Russula delica* (Fries)**: Concentration of different heavy metals in the fruit bodies of ***R. delica was reported by Tuzen *et al* (1998), Demirbas (2001) and Yilmaz *et al* (2003).

Tricholoma terreum* (Shaeff) Kummer**: Bio-accumulation of heavy metals like lead, cadmium, mercury, copper, manganese, zinc, etc. have been reported by Tuzen *et al* (1998) and Demirbas (2001). Capacity of heavy metal absorption by ***T. terreum has also been reported by Yilmaz *et al* (2003).

Table 1 : Concentration of heavy metals in fruit bodies of some mushroom species

S. No.	Mushroom Species	Edibility	Heavy metal conc. in fruit bodies	References
1.	*Agaricus bisporus*	Edible	Cu (107), Cd (1.7), Pb (2.1), Zn (57.2), Mn (25.9), Fe (290), Cr (6.5), Ni (7.9)*	Isildak *et al* (2004)
			Cd (3.5)*	Kalac *et al* (2004)
			Pb (2.41), Cd (3.48), Hg (0.60), Cu (5.22), Mn (22.3), Zn (17.8), Fe (126)*	Demirbas (2001)
			Hg (0.03), Pb (0.28), Cd (0.74), Fe (31.3), Cu (13.5), Mn (3.61), Zn (22.5)**	Sesli & Tuzen (1999)
			Pb (0.46), Cd (0.70), Hg (0.04), Fe (15.8), Cu (6.61), Mn (2.27), Zn (9.32) *	Tuzen *et al* (1998)
2.	*Armillaria mellea*	Edible	Pb (1.28), Cd (2.48), Hg (0.91), Cu (21.1), Mn (26.8), Zn (76.8)*	Demirbas (2002)
			Pb (1.6), Cd (11.0), Hg (0.3), Cu (31.0) *	Kalac *et al* (1991)
3.	*Boletus edulis*	Edible	Pb (0.96), Cd (1.03), Hg (0.13), Fe (31.1), Cu (4.7), Mn (2.9), Zn (26.2)*	Tuzen *et al* (1998)
			Hg (32.4), Cu (66.4), Cd (6.58), Pb (3.03)*	Kalac *et al* (1996)
4.	*Calvatia excipuliformis*	Edible	Hg (4.4)*	Falandysz *et al* (2003)
			Fe (924), Cu (25), Mn (28), Zn (58), Pb (1.5), Cd (1.1) *	Turkekul *et al* (2004)
5.	*Lepiota rhacodes*	Edible	Hg (8), Pb (66), Cd (3.7) *	Kalac *et al* (1991)
6.	*Lepista nuda*	Edible	Cu (68.4), Cd (2.9), Pb (3.5), Zn (47.6), Mn (49.3), Fe (321), Cr (10.4), Ni (4.2)*	Isildak *et al* (2004)
			Fe (568), Cu (20), Mn (16), Zn (45), Pb (1.4), Cd (1.1)*	Turkekul *et al* (2004)
			Hg (84.7), Cu (231), Cd (3.26), Pb (15.3)*	Kalac *et al* (1996)

S. No.	Mushroom Species	Edibility	Heavy metal conc. in fruit bodies	References
7.	*Paxillus involutus*	Edible	Pb (1.6.0)*	Kalac *et al* (2004)
			Cu (57.0)*	Kalac *et al* (1991)
8.	*Psalliota campestris*	Edible	Pb (1.85), Cd (5.55) *	Zurera *et al* (1988)
9.	*Pleurotus sajor-caju*	Edible	Pb (7.0), Cd (33.0) **	Mitra (1994)
10.	*Pleurotus ostreatus*	Edible	Pb (3.24), Cd(1.18), Hg (0.42), Cu (13.6), Mn (6.27), Zn (29.8), Fe (86.1)*	Demirbas (2001)
			Pb (0.11), Cd (0.55), Hg (0.31), Fe (48.6), Cu (5.0), Mn (10.3), Zn (19.3)*	Tuzen *et al* (1998)
			Cd (11.2), Hg (1.2), Zn (0.8), Pb (0)*	Lasota *et al* (1990)
11.	*Russula delica*	Edible	Cu (73.0), Zn (57.0), Mn (9.6), Fe (244), Co(1.5), Cd (0.31), Ni (3.2), Pb (2.7) *	Yilmaz *et al* (2003)
			Pb (3.1), Cd (1.1), Hg (0.26), Cu (13.6), Mn (6.6), Zn (32.6), Fe (74.8)*	Demirbas (2001)
			Pb (4.8), Cd (2.0), Hg (0.21), Fe (54.5), Cu (10.8), Mn (12.1), Zn (19.3)*	Tuzen *et al* (1998)
12.	*Tricholoma terreum*	Edible	Cu (25), Zn (179), Mn (19), Fe (744), Co (2.6), Cd (0.56), Ni (5.6), Pb (4.4) *	Yilmaz *et al* (2003)
			Pb (2.4), Cd (1.6), Hg (0.06), Cu (35.8), Mn (24.8), Zn (48.0), Fe (169.0)*	Demirbas (2001)
			Pb (0.69), Cd (0.78), Hg (0.21), Fe (37.0), Cu (51.0), Mn (10.8), Zn (16.8) *	Tuzen *et al* (1998)

*mg/kg dry wt **µg/g dry wt


Armillaria mellea


Psalliota campestris


Pleurotus sajor-caju


Russula delica


Pleurotus ostreatus


Tricholoma terreum

Factors influencing heavy metals uptake in mushrooms

Metal uptake by mushrooms is primarily species dependent, while role of a genus or a family is of lower importance, as is nutritional strategy-mycorrhizal, parasitic or saprophytic. Substrate composition is an important factor. Great differences exist in uptake of individual metals. In case of cultivated white mushroom (***Agaricus bisporus***), metal content has been observed in the initial harvest stage. Metal levels reported in wild growing ***A. bisporus*** are considerably higher than in cultivated fruiting bodies (Kalac *et al*, 2004). Probable explanation is not only in different substrate composition and contamination, but also in different age of mycelium, which may exist for several years in nature, while only for several months in cultivated ones.

High contents of metals have been observed in mushrooms growing in heavily polluted areas, such as close proximity to high ways with heavy traffic, landfills of sewage sludge and emission areas including cities. High metal contents in mushrooms are also reported from areas contaminated by ores mining and processing (Kalac *et al*, 2004). Heavy metal interaction also affects the metal uptake capacity of mushrooms. The uptake of heavy metals from substrate by mushroom mycelia and sporocarps largely depend on the nature of the metallic compound because the availability of cations depends to a greater extent on the respective anions. Yasui *et al* (1988) reported that the growth or the uptake of essential nutrients, viz. zinc, potassium, phosphorus, magnesium, manganese and calcium by Oyster mushrooms was not affected due to supplementation of copper, cadmium and lead in the medium. But Poitou and Olivier (1990) observed that the mycelia of ***Suillus granulatus***, ***Lactarius deliciosus***, ***Tuber melanosporum*** and ***T. brumale*** rapidly accumulated copper ions and the uptake of copper ions affected the absorption of potassium and magnesium ions which were essential for the growth of fungi. Mitra (1994) reported that the interaction of copper and cadmium at low concentration significantly reduced cadmium uptake by ***Volvariella volvacea*** and ***Pleurotus sajor-caju*** but enhanced copper uptake; cadmium was highly inhibitory while copper was least to mycelial growth of ***P. sajor-caju*** and ***V. volvacea***. These findings suggested that cadmium toxicity could be reduced by the supplementation of copper.

Toxic effects of heavy metals on mushroom

Generally heavy metals at low to medium concentrations inhibit mycelial growth. Higher concentration may cause total inhibition of growth or even death of mushrooms. But some heavy metals like zinc and iron may act as growth stimulators. The effects of 5 heavy metals at a uniform concentration were tested on the mycelial growth of ***Volvariella volvacea*** and cadmium was found to be the most toxic (Purkayastha & Mitra, 1992). Production of fruiting bodies (sporocarp) is also affected by the high concentration of heavy metals. Jain *et al* (1988) reported that the higher concentrations of all heavy metals reduced the biological efficiency of sporocarp production in ***Pleurotus sajor-caju***. Cobalt and lead caused maximum reduction in fruit body production of ***V. volvacea*** and ***P. sajor-caju*** (Purkayastha & Mitra, 1992). Reduction in nutritive value i. e. protein content of mushrooms has also been reported due to heavy metal uptake. Lasota *et al* (1990) reported the marked reduction in mycelial protein content of ***A. bisporus*** and ***P. ostreatus*** due to uptake of heavy metals like mercury, cadmium, lead and zinc.

Conclusion

From present review it is evident that lot of mushrooms are available having the capacity of effective biosorption of heavy metals which can be taken as a low cost technology to solve the problem of heavy metal pollution. The main attraction of biosorption is its cost effectiveness. Comprehensive literature is available on biosorption of heavy metals in wild and cultivated mushrooms but very limited data deal with the factors involving the potential risk in human nutrition due to consumption of metal contaminated mushrooms. Thus, a critical assessment of the health risk from mushroom consumption is necessary through screening of both metal accumulating and non-accumulating species of mushroom from polluted and unpolluted sites.

References

1. Blaudez D, Botton B and Chalot M, Cadmium uptake and subcellular compartmentation in the ectomycorrhizal

fungus *Paxillus involutus*, *Microbiology*, 2000, **146**, 1109-1117.

2. Costa ACA and Leite SGC, Metal biosorption by sodium alginate immobilized *Chlorella hemisphere*, *Biotechnol Lett*, 1991, **13**, 559-562.

3. Demirbas A, Concentration of 21 metals in 18 species of mushrooms growing in the east Black Sea Region, *Food Chem,* 2001, **75**, 453-457.

4. Demirbas A, Metal ion uptake by mushrooms from natural and artificially enriched soil, *Food Chem,* 2002, **78**, 89-93.

5. Falandysz J, Kawano M, Swieczkowski A, Brzostowski A and Dadej M, Total mercury in wild grown mushrooms and underlying soil from Wdzydze Landscape Park, northern Poland, *Food Chem,* 2003, **81**, 21-26.

6. Isildak O, Turkekul I, Elmastas M and Tuzen M, Analysis of heavy metals in some wild grown edible mushrooms from the middle black sea region, Turkey, *Food Chem*, 2004, **86**, 547-552.

7. Jain SK, Gujral GS, Jha NK and Vasudevan P, Heavy metal uptake in *Pleurotus sajor-caju*, *Biol Wastes*, 1988, **24**, 275- 282.

8. Kalac P, Burda J and Staskova I, Concentration of lead, cadmium, mercury and copper in mushrooms in the vicinity of a lead smelter, *Sci Total Environ*, 1991, **105**, 109-119.

9. Kalac P, Ni•nanská M, Bevilaqua D and Stašková I, Concentrations of mercury, copper, cadmium and lead in fruiting bodies of edible mushrooms in the vicinity of a mercury smelter and a copper smelter, *Sci Total Environ*, 1996, **177**, 251-258.

10. Kalac P, Svoboda L and Havlickova B, Contents of detrimental metals mercury, cadmium and lead in wild growing edible mushrooms: A Review, *Energy Educ Sci Technol*, 2004, **13**(1), 31-38.

11. Kapoor A and Viraraghavan T, Biosorption of heavy metals on *Aspergillus niger*: Effect of pretreatment, *Biores Technol*, 1998, **63**, 109.

12. Lasota W, Florezak J and Karmanska A, Effects of toxic metals on protein content of mushrooms, *Bromatol Chem Toksykol*, 1990, **23**(3/4), 95-99.

13. Macaskie LE, An immobilized cell bioprocesses for removal of heavy metals from aqueous flows, *J Chem Technol Biotechnol*, 1990, **49**, 330-334.

14. Mitra AK, Studies on the uptake of heavy metal pollutants by edible mushrooms and its effect on their growth, productivity and mammalian systems, PhD Thesis, University of Calcutta, 1994.

15. Poitou M and Olivier JM, Effect of copper on mycelium on three edible ectomycorrhizal fungi, *Agric Ecosys Environ*, 1990, **28**(1-4), 403-408.

16. Purkayastha RP and Mitra AK, Metal uptake by mycelia during submerged growth and by sporocarps of an edible fungus *Volvariella volvacea, Indian J Exp Biol*, 1992, **30**, 1184 -1187.

17. Sesli E and Tuzen M, Levels of trace elements in the fruiting bodies of macrofungi growing in the East Black Sea region of Turkey, *Food Chem*, 1999, **65**, 453-460.

18. Thomet U, Vogel E and Krahenbuhl U, The uptake of cadmium and zinc by mycelia and their accumulation in mycelia and fruiting bodies of edible mushrooms, *Eur Food Res Technol*, 1999, **209**, 317-324.

19. Tsezos M and Deutschmann AA, The use of a mathematical model for the study of important parameters in immobilized biomass biosorption, *J Chem Technol Biotechnol*, 1992, **53**, 1.

20. Tuzen M, Ozdemir M and Demirbas A, Study of heavy metals in some cultivated and uncultivated mushrooms of Turkish origin, *Food Chem*, 1998, **63**, 247-251.

21. Turkekul I, Elmastas M and Tuzen M, Determination of iron, manganese, zinc, lead and cadmium in mushroom samples from Tokat, Turkey, *Food Chem,* 2004, **84**, 389-392.

22. Volesky B, Advances in biosorption of metals: Selection of biomass types, *FEMS Microbiol Rev*, 1994, **14**, 291.

23. Yasui A, Chuichi T, Masonori T and Takeshi M, Uptake of heavy metals by Oyster mushrooms, *J Jpn Soc Food Sci Technol*, 1988, **35**(3), 160-165.

24. Yilmaz F, Isiloglu M and Merdivan M, Heavy metal levels in some macrofungi, *Tur J Bot*, 2003, **27**, 45-56.

25. Zhou JL and Kiff RJ, The uptake of copper from aqueous solution by immobilized fungal biomas, *J Chem Technol Biotechnol*, 1991, **52**, 317-330.

26. Zurera CG, Rincon –Leon F and Pozolara R, Lead and cadmium content in mushroom species belonging to the genus *Psalliota*, *J Food Qual*, 1988, **10**, 311-318.