Fungal Absorption and Tolerance of Heavy Metals

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Abstract: Soil, water, sediments and air are frequently contaminated with heavy metals. In Saudi Arabia, heavy metals contamination may result from petroleum and mining operations, refining ores, sludge, waste treatment, electrical equipment, paints, alloys, pesticides, batteries and fuel transportation. Microbial processes lead to appreciable and even complete remediation of heavy metals contaminated environments. The chief ways, by which such remediation may be accomplished, include biosorption, bioaugmentation, bioventing, biostimulation, bioaccumulation, biosolubilization, bioreduction, bioprecipitation, mineralization and methylation. Other technologies and methods are fully developed and now are being used in practice, such as heavy metals nanotechnology bioremediation. An area of fungal biotechnology currently in vogue is the use of fungal biomass to absorb metal ions from contaminated solutions. Such biological approaches of metal ions recovery can be used to clean up polluted effluents or to recover precious metal ions from solutions. The present review provides information on fungal bioremediation of heavy metal contamination for use in future studies in Saudi Arabia as well as in the Arabian Gulf Region.

Key words: Saudi Arabia, absorption, tolerance, biomass, heavy metals, bioremediation, biosorption, bioaccumulation.

1. Introduction

Environmental issues are of increasing concern, and research is now being directed towards applying technology to ameliorate the effects of environmental pollution. This has led to renewed interest in the use of fungi to detoxify environmental pollutants, such as heavy metals, an approach referred to as bioremediation.

An area of fungal biotechnology currently in vogue is the use of fungal biomass to absorb heavy metals from solutions. Alternatively, metal ions can be removed from solution by passing the effluents through a column containing fungal cell wall components, such as chitin. Such biological approaches of metal ion recovery can be used to clean up polluted effluents or to recover precious metal ions from solution. In both cases, it will be necessary to show that the use of fungal biomass can compete with physicochemical methods. It has yet been conclusively demonstrated that fungal system is economically superior [1].

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The role of fungi in environments in Saudi Arabia and potentially toxic levels of heavy metals have received limited attention, but there is evidence that there are studies in different places of the world [2]. The aim of this study was to observe the effect of heavy metals in the growth of some fungi isolated from Saudi Arabia.

2. Fungi

Fungal species were isolated from heavy metal contaminated and non-contaminated sites from different places of Saudi Arabia and then were identified according to the international references of fungal identifications [3, 4].

It has been shown that copper is toxic to most microorganisms even at low concentrations. *Aspergillus niger*, *Penicillium chrysogenum* and *Rhizopus stolonifer* could survive in a liquid medium containing up to 500 ug/mL of copper. It appears that copper must have been transported in high amounts into the fungal cells. The tested fungi can accumulate copper up to 6,000, 5,300 and 3,250 ug/g, respectively [5].

Hymenosyphus ericae, *Pisolithus tinctorius* and

Vaccinium macrocarpon were able to grow on a liquid media containing levels of 400, 500 and 500 ug/mL of zinc, cadmium and iron, respectively [6, 7].

3. Heavy Metals

Toxicity of manganese to the growth of *Candida albicans* in liquid media up to 400 ug/mL was discussed. *Calbicans* was able to grow and accumulate manganese in the mycelium up to 5,000 ug/g, and the results provide evidence of considerable interspecific differences of manganese within the tested yeast. Removal of manganese probably involved a combination of adsorptive and absorptive mechanisms—the yeast being known to reversibly bind a number of bivalent cations at the cell surface [8]. *Aspergillus niger* and *Penicillium chrysogenum* could survive in a mineral liquid media containing up to 400 ug/mL of aluminium, cadmium, lead and zinc. The results provide evidence that there are considerable interspecific differences in resistance to these metals.

Bioaccumulation mechanism was clearly operated. The results reveal that the tested fungi could be useful as an indicator for heavy metals pollution and evidence for metal ion bioaccumulation, which was seen in the tested fungi [3-6, 9, 10]. Researches in recent years have established that heavy metal biosorption by fungal biomass can be developed into a cost-effective process for removing metal ions or recovering valuable metals from industrial effluents. Of particular interest are abundant fungal biomass types that were produced as a waste by the production of large scale industrial processes which can be very inexpensive sources of metal ions biosorbent.

The role of arsenic on the growth of *Cladosporium herbarum* was investigated. This fungus was able to grow on a mineral liquid media containing up to 200 ug/mL and give level of accumulation as 2,900 ug/g. Several fungi accelerate the oxidation of arsenite to arsenate and are also involved in the methylation and alkylation of arsenic. The methylation of arsenic

conducted by certain fungi under toxic conditions plays a significant role in the release of volatile arsenic from soil to the atmosphere. Wastewater contains high levels of arsenic, so the development of new technologies is required to treat wastewater as an alternative to traditional physicochemical processes. Biosorption, the process of passive cation binding by dead or living fungal biomass, represents a potentially cost-effective way of eliminating toxic heavy metals from industrial wastewater [7, 11].

Sorption experiments using *Alternaria alternata* isolated from Saudi Arabian soil for manganese and zinc were carried out to study the biosorption of these metals at 500 ug/mL in a mineral liquid media and give levels of accumulation as 5,300 ug/g manganese and 6,100 ug/g zinc, respectively. The result provided that the fungi can grow and accumulate manganese and zinc in their biomasses; several mechanisms enable fungi to accumulate metal ions from solution, and these include active transport of ions, ion exchange, complexation, adsorption and inorganic precipitation; metal uptake can be mediated by living or dead mycelium. *Cladosporium hebarum* isolated from soil has been used to study the effect of 25 ug/mL of mercury. The fungus was able to grow and accumulate the metal up to 900 ug/g. Background levels of Hg in soils are not easy to estimate due to widespread Hg pollution. Sources of contamination of soil Hg are related mainly to base metal processing, industries and chemical works as well as the use of fungicide containing Hg, sewage and other wastes. This data advances our knowledge of Hg resistance in fungi and also proves that Hg could use in environmental studies to monitor pollution in Saudi Arabia [12].

Fungal biomass for use in laboratory studies on metal adsorption is usually grown in batch culture. However, this is expensive, and for the industrial application of technology, an economic advantage would be gained from waste mycelium produced by the fermentation industry. For example, *Aspergillus*

niger can selectively remove silver from solutions and usually produce wastes with high concentration. They are important sources of environmental pollution, especially when they contain heavy metals. Influence of iron on the growth of the tomato wilt pathogen *Fusarium oxysporum* can grow up to 400 ug/mL in mineral liquid media. The tested fungus is also able to accumulate iron up to 5,500 ug/g. An adequate supply of iron ions is an important factor in the *Fusarium* wilt process. The severity of the *Fusarium* wilt of tomato's decreases with an increase of iron concentration [13]. The effect of cadmium, cobalt, copper, lead and zinc on the growth of *Alternaria alternata*, *Aspergillus candidus*, *Aspergillus flavus*, *Cladosporium herbarum*, *Curvularia tuberculata*, *Drechslera rostrata*, *Fusarium moniliform* and *Penicillium notatum* were tested in a mineral liquid media at 500 ug/mL. The tested fungi grew well, were resisted to the toxicity of the heavy metals and showed some increase in the mycelium dry weight [10, 12-14]. The phenomena of stimulation by low levels of heavy metals have been noted for several fungi. Stimulation is thought to arise because the fungi tend to inactivate the heavy metals as part of their tolerance mechanism. Fungi possess a mechanism, by which metal cations can be taken up and accumulated [15-18]. There appears to be two main types of metal uptake by fungi. The first involves nonspecific binding of the metal to all surfaces, slime layers and extracellular matrices, while the second involves metabolism-dependent intracellular uptake. Besides, the mechanisms of heavy metals toxicity and resistance are different and they depend on the fungal genera and species [19-21]. In this comprehensive review, the biosorption ability of fungal biomass towards heavy metals is emphasized. A detailed description of adsorption properties and mode of action of fungal biosorbents is offered in order to explain the heavy metals selectivity displayed by these biosorbents. Fungal biomass can also be used in effluent treatment as a mean of adsorbing insoluble particulates from solutions. Most

filamentous fungi can adsorb almost any particulates, such as sulphur, charcoal and clay. Several methods are being used for the removal of heavy metals from aqueous wastes [22-24], including chemical precipitation, ion exchange, electrochemical treatment membrane technologies and activated carbon. Each of these methods has its own merits and demerits [25, 26].

4. Conclusions and Recommendations

This is a review of the achievements about current status of fungal bioremediation and absorption of heavy metals technology, and it hopes to provide insight for future research in Saudi Arabia. The ability of a large number of fungi to bioremediate heavy metals has been evaluated and discussed in different places of the world, but there is still much to be studied in Saudi Arabia.

The economic aspects of the technical application of fungal biomass for heavy metals removal are improved by using waste fungal biomass, and this is very important in Saudi Arabia due to the huge amounts of industrial wastes, such as from the food industry. In recent years, heavy metal pollution has become one of the most serious problems in Saudi Arabia, with the rapid development of many industries, such as mining, energy, fertilizers, fuel producing, pesticides, metallurgy and electro-planting. Also waste containing heavy metals is directly being discharged into the environment, thus causing serious environmental pollution and even threatening human life. Moreover, fungal biosorption of heavy metals can be a good treatment for large amounts of sludge and wastewater in Saudi Arabia. Fungi are now widely used in mineral technologies. Different species of fungi have proved to be particularly effective at leaching metals from their ores, and they can grow in the absence of an organic carbon source by using carbon dioxide. Fungi can be used to dissolve iron from iron rich minerals, such as goethite, limonite or haematite (rich sources in Saudi Arabia). Most of the species tested are members of the genera *Aspergillus*

and *Penicillium* (most studied genera in this review). This is a very important applied technology in Saudi Arabia. Also, several fungi are capable of destroying and *Penicillium* is the most active. This is also very important economic technology especially in the Hail region of Saudi Arabia. Considerable research effort have been devoted worldwide to the possible use of fungi to recover metal ions, and this is very important in Saudi Arabia due to power stations, industrial effluents, chemical and different industrial activities.

References

- [1] Wainright, M. 1992. *An Introduction to Fungal Biotechnology*. New York: Wiley, 417-23.
- [2] Binsadiq, A. 1993. "Soil Analysis and Mycoflora of Industrial Yanbu City, Saudi Arabia." *Arab. Gulf. J. Sci. Res.* 11: 91-3.
- [3] Binsadiq, A. 1993. "Aluminium Tolerance and Uptake by *Aspergillus niger* and *Pencillium chrysogenum*." *Giobios*. 20: 190-4.
- [4] Binsadiq, A., and Al-Homaidan, A. A. 1991. "Metal Analysis of Soil and *Trimania pinopyi* from Saudi Arabia." *Cryptogamic Botany* 2-3: 118-20.
- [5] Binsadiq, A. 1993. "Effect of Arsenic on the Growth of *Cladosporium herbarum*." *Cryptogamic Botany* 3 (4): 307-9.
- [6] Burt, A., Binsadiq, A., Show, G., and Read, D. 1986. "Comparative Analysis of Metal Tolerance in Ercoid Mycroohizal Fungi." In *Physiological and Genetical Aspects of Mycroohizae*, edited by Gianinazzi, P., and Gianinazzi, S. Paris: INRA Publication, 683-7.
- [7] Binsadiq, A., and Khaliel, A. S. 1992. "Manganese Toxicity to *Candida albicans* Isolated from Soudi Arabia." *Geobios*. 19: 280-4.
- [8] Binsadiq, A. 1993. "Effect of Heavy Metals Toxicity on the Growth of *Aspergillus niger* and *Pencillium chrysogenum*." *Saudi Journal of Biological Sciences* 2: 35-45.
- [9] Al-Obaid, A. M., and Binsadiq, A. 1998. "Zinc Tolerance and Accumulation in *Aspergillus oryzae*, *Penicillium citrinum* and *Rhizpous stolonifer* Isolated from Saudi Arabia." *Qatar Univ. J. Sci.* 17 (1): 103-9.
- [10] Binsadiq, A. 1994. "Influence of Arsenic on the Growth of *Aspergillus clavatus* and *Emericella nidulans* Isolated from Saudi Arabian Soil." *Afri. J. Mycol. and Biotech.* 2: 91-7.
- [11] Binsadiq, A., and Kuchari, M. 2001. "Effect of Mercury on the Growth of *Aspergillus niger* Isolated from Saudi Arabian Soil." *Geobios*. 28 (4): 239-41.
- [12] Binsadiq, A., and Bahkali, A. 1994. "Toxicity of Cobalt and Nickel to *Fusarium solani* Isolated from Saudi Arabian Soil." *Qatar Univ. Sci. J.* 14 (1): 63-5.
- [13] Binsadiq, A. 1995. "Soil Analysis and Mycoflora of Jubail Industrial City, Saudi Arabia." *J. K. S. Univ. Sci.* 22: 231-8.
- [14] Binsadiq, A. 1996. "Growth and Adaptation of *Curvularia tuberculata* at Different Cadmium Concentration." *Biol. Sci.* 4: 33-41.
- [15] Binsadiq, A. 1989. "Effect of Copper on the Growth of *Aspergillus niger*, *Pencillium chrysogenum* and *Rhizopus stolonifer*." *Trans. Mycol. Soc. Japan* 30: 111-9.
- [16] Binsadiq, A. 1993. "Mercury and the Growth of *Cladosporium herbarum*." *Cryptogamic Botany* 4: 23-5.
- [17] Binsadiq, A. 1991. "Comparative Analysis of Cadmium Tolerance in *Hymenoscyphus ericae* and *Pisolotus tinctorius*." *Trans. Mycol. Soc. Japan* 32: 417-23.
- [18] Binsadiq, A. 1997. "Effect of Mycorrhizal Infection in the Tolerance of *Pinus contorta* to Zinc." *J. Edu. Sci.* 10: 23-9.
- [19] Binsadiq, A., and Al-Rahmah, A. 1993. "Growth of *Podaxis pistilaria* Collected from Saudi Arabia at Different Concentrations of Cadmium and Lead." *J. King Saud Univ. Sci.* 5 (2): 127-35.
- [20] Al-Yemeni, M. N., and Hashem, A. R. 2006. "Heavy Metals and Microbial Analysis of Soil Samples Collected from Aramco Gulf Operation Company (AGOC), Al-Khafji, Saudi Arabia." *S. J. Biologic. Sci.* 13 (2): 129-33.
- [21] Binsadiq, A. 1995. "Influence of Iron on the Growth of Tomato Wilt Pathogen—*Fusarium oxysporium* Isolated from Saudi Arabia." *J. of Plant Diseases and Protection* 102 (3): 326-30.
- [22] Binsadiq, A. 1995. "The Role of Mycroohizal Infection in the Tolerance of *Vaccinum macrocarpon* to Iron." *Mycroohiza* 5: 451-4.
- [23] Arif, I., and Binsadiq, A. 1998. "Soil Analysis and Mycoflora of Jizan City, Saudi Arabia." *Phyton*. 62: 109-13.
- [24] Binsadiq, A., and Al-Faraj, M. 1997. "Soil Analysis, Fungal Flora and Mineral Content of *Citrulus colocynthis* from Saudi Arabia." *Umm Al-Qura Unvi. J.* 15: 9-26.
- [25] Binsadiq, A. 1996. "Effect of Cobalt on the Growth of Pear Fruit Rot Pathogens *Aspergillus candidus* and *Aspergillus clavatus* Isolated from Saudi Arabia." *Indian Phythopathology* 49 (1): 72-6.
- [26] Binsadiq, A., and Parves, T. 1994. "Mycoflora of Aluminium Rich of Hail Region, Saudi Arabia." *Arab. Gulf. J. Sci. Res.* 12: 341-50.