Bio-sorbents: A novel technology to mitigate Heavy metal pollution

Abstract

The health of living beings is seriously threatened by the toxicity and bioaccumulation tendency of heavy metals in the environment. Heavy metals cannot be broken down by chemical or biological processes, unlike organic pollutants. They can therefore only be changed into less dangerous species. Heavy metal pollution of the environment has gone above the advised level and is harmful to all life forms. The process of using microorganisms to absorb, precipitate, oxidize, and reduce heavy metals in soil is known as "microbial remediation." The term "bio-sorption" refers to "the ability of biological materials to accumulate heavy metals from waste water through metabolically mediated or physico-chemical pathway of uptake." It has been demonstrated that fungi, yeast, algae, and bacteria are potential metal-biosorbents. To adequately address the major issues involved, a sustainable method must be devised to choose the best bio-sorbent, operating conditions, and effective mechanism of heavy metal removal in industrial effluent.

Keywords*: Bio-accumulation, bio-sorbents, Heavy metals, Microbial remediation*

Introduction

As a result of metal ions' inability to degrade, heavy metal contamination is today a significant environmental issue. The health of living beings is seriously threatened by the toxicity and bioaccumulation tendency of heavy metals in the environment. Heavy metals cannot be broken down by chemical or biological processes, unlike organic pollutants. They can therefore only be changed into less dangerous species. Since heavy metals and metalloids cannot be broken down into non-toxic forms but instead stay in the ecosystem, their accumulation in soils and rivers continues to pose major threats to world health. Heavy metal pollution of the environment has increased above the advised level and is harmful to all life forms (Gaur *et al*., 2014; Dixit *et al.,* 2016 and Tak*et al*., 2013). According to the Indian criteria for heavy metals, the acceptable range for soil is 3-6, 135-270, 75-150, 250-500, and 300-600 mg/kg for Cd, Cu, Ni, Pb, and Zn, respectively (Nagajyoti *et al*., 2010).

Most heavy metals can enter the food chain, where they can accumulate and harm living things. The majority of heavy metals are harmful at low amounts. According to Mani and Kumar (2014), the toxicity of each metal relies on the amount available to organisms, the absorbed dose, the route, and the length of exposure. All metals have the potential to be hazardous at higher concentrations. In order to prevent or limit environmental contamination and the potential for uptake in the food chain, it is crucial to eliminate or reduce heavy metal pollution. To do this, metal stability (speciation) is increased through the use of bioremediation, which also lowers the bioavailability of the metal (Abbas *et al.,* 2014).

When compared to traditional, chemical and physical methods for heavy metal removal and recovery, which are frequently more expensive and unsuccessful, especially for low metal concentrations, bioremediation is an economical and environmentally beneficial method. These traditional techniques also produce a sizable volume of hazardous sludge. Amazing metabolic processes found in microorganisms allow them to use different toxins as a source of energy for growth and development through respiration, fermentation, and cometabolism. They have developed a variety of mechanisms for maintaining homeostasis and resistance to heavy metals in order to adapt to hazardous metals in the ecosystem because of their distinctive degradative enzymes for a particular contaminant (Brar *et al*., 2006). In order to accomplish the absorption, precipitation, oxidation, and reduction of heavy metals in the soil, microbial remediation is defined as the utilization of microorganisms (Su, 2014). Microorganisms can reduce heavy metal contamination through a variety of methods, including bioaccumulation, biomineralization, biosorption, and biotransformation. They have been successfully employed as biosorbents for the removal and recovery of heavy metals because to their properties. Although the majority of heavy metals damage microbial cell membranes, microorganisms are able to protect themselves and counteract the toxic effects. This article provides a brief overview of the ability of bacteria to function as microbial bio-sorbents to reduce heavy metal pollution and safeguard both the environment and the health of people and animals.

Heavy metal toxicity to animals, plants, and microorganisms

The heavy metals that are prevalent in nature usually exist in complicated or precipitated forms that are difficult for plants to absorb or in insoluble forms like those found in mineral structures. Heavy metals that are present naturally have a very high soil adsorption capability. The mechanisms, both anthropogenic and natural, that result in the presence of heavy metals are listed in Table 1 below. Because they are found in soluble and mobile reactive forms, heavy metals from anthropogenic sources have a high bioavailability.

Table 1: Sources of Heavy metals

Natural Sources	Human-made sources
Comets	Production of alloys
Erosion	Aerosol deposition
Volcanic eruptions	battery manufacturing
Weathering of minerals	Inappropriate industrial solid waste stacking and biosolids
Rock sedimentation	Manufacturing explosives and coating
Volcanic dust	Mining and tanning of leather
-	Pigments for printing and photographic materials
-	Steel, electroplating, and smelting industries
-	Preservatives for wood, textiles, and colours
-	Phosphate fertilizers, pesticides, and irrigation using sewage

Heavy metals affect all life forms badly and its effect on humans, plants and microbes are given below in the Table 2.

Table 2. Toxicity of heavy metals to humans, plants and microbes

Metal	Humans	Plants	Microbes	References
Antimony	Cancer, cardiovascular diseases, conjunctivitis, dermatitis, liver diseases, nasal ulceration, respiratory diseases etc.	Decreases synthesis of some metabolites, growth inhibition, inhibit chlorophyll synthesis	Inhibit enzyme activities, reduced growth rate	Blais *et al.*, 2008
Arsenic	Brain damage, cardiovascular and respiratory disorder, conjunctivitis, dermatitis and skin cancer	Damage cell membrane, inhibition of growth, inhibits roots extension and proliferation, interferes with critical metabolic processes, loss of fertility, yield and fruit production, oxidative stress, physiological disorders	Deactivation of enzymes	Blais *et al.*, 2008
Beryllium	Allergic reactions, berylliosis, cancer, heart diseases, lung diseases etc.	Inhibits seed germination	Chromosomal aberration, mutation	Blais *et al.*, 2008
Cadmium	Bone disease, coughing,emphysema, headache,	Chlorosis, decrease in plant nutrient content, growth	Damage nucleic acid, denature protein,	Fashola *et al.*, 2016

	hypertension, itai-itai,kidney diseases, lung and prostate cancer, lymphocytosis, microcytic hypochromic anemia, testicular atrophy and vomiting	inhibition, reduced seed germination	inhibit cell division and transcription, inhibits carbon and nitrogen mineralization	
Chromium	Bronchopneumonia, chronic bronchitis, diarrhea, emphysema, headache, irritation of the skin, itching of respiratory tract, liver diseases, lung cancer, nausea, renal failure, reproductive toxicity, vomiting etc.	Chlorosis, delayed, senescence, wilting, biochemical lesions, reduced biosynthesis germination, stunted growth, oxidative stress	Elongation of lag phase, growth inhibition, inhibition of oxygen uptake	Barakat *et al*, 2011
Copper	Abdominal pain, anemia, diarrhea, headache, liver and kidney damage, metabolic disorders, nausea, vomiting etc.	Chlorosis, oxidative stress, retard growth	Disrupt cellular function, inhibit enzyme activities	Fashola *et al*., 2016
Mercury	Ataxia, attention deficit, blindness, deafness, decrease rate of fertility, dementia, dizziness, dysphasia, gastrointestinal irritation, gingivitis, kidney problem, loss of memory, pulmonary edema, reduced immunity and sclerosis	Affects antioxidative system, affects photosynthesis, enhance lipid peroxidation, induced genotoxic effect, inhibit plant growth, yield, nutrient uptake and homeostasis, oxidative stress	Decrease population size, denature protein, disrupt cell membrane, inhibits enzyme function	Wang *et al*., 2012
Lead	Anorexia, chronic nephropathy, damage to neurons, high blood pressure, hyperactivity,	Affects photosynthesis and growth, chlorosis, inhibit enzyme activities and	Denatures nucleic acid and protein, inhibits enzymes activities and	Wuana *et al*., 2011

	insomnia, learning deficits, reduced fertility, renal system damage, risk factor for Alzheimer's disease, shortened attention span etc.	seed germination, oxidative stress	transcription	
Nickel	Cardiovascular diseases, chest pain, dermatitis, dizziness, dry cough and shortness of breath, headache, kidney diseases, lung and nasal cancer, nausea etc.	Decrease chlorophyll content, inhibit enzyme activities and growth, reduced nutrient uptake	Disrupt cell membrane, inhibit enzyme activities, oxidative stress	Malik , 2004
Selenium	Dysfunction of the endocrine system, gastrointestinal disturbances, impairment of natural killer cells activity, liver damage etc.	Alteration of protein properties, reduction of plant biomass	Inhibits growth rate	Germ *et al.*, 2007
Silver	Argyria and argyrosis, bronchitis, cytopathological effects in fibroblast and keratinocytes, emphysema, knotting of cartilage, mental fatigue, nose, throat and chest irritation and rheumatism	Affects homeostasis, decrease chlorophyll content, inhibits growth	Cell lysis, inhibit cell transduction and growth	Qian *et al.*, 2013
Thallium	Alopecia, ataxia, burning feet syndrome, coma, convulsions, delirium, fatigue, gastroenteritis, hair fall, hallucinations, headache, hypotension,	Inhibits enzyme activities, reduced growth	Damages DNA, inhibits enzyme activities and growth	Babula *et al.*, 2008

	insomnia, nausea, tachycardia and vomiting			
Zinc	Ataxia, depression, gastrointestinal irritation, hematuria, Icterus, impotence, kidney and liver failure, lethargy, macular degeneration, metal fume fever, prostate cancer, seizures and vomiting	Affects photosynthesis, inhibits growth rate, reduced chlorophyll content, germination rate and plant biomass	Death, decrease in biomass, inhibits growth	Gumpu *et al.*, 2015

<u>Bio-sorption and Bio-sorbents</u>

The cutting-edge scientific technology, namely bio-sorption and bioaccumulation, is created for heavy metal cleanup. For bio-sorption, several biological materials' abilities to bind metals are used. The ability of biological materials to absorb heavy metals from sewage via a metabolically mediated or physico-chemical process of uptake is known as biosorption. In 1986, Volesky noted that fungi, yeast, algae, and bacteria have demonstrated their potential as metal-biosorbents. According to Kratochvil and Volesky (1998), the main advantages of biosorption over traditional treatment methods are (i) low cost, (ii) high efficiency, (iii) minimization of chemical or biological sludge, (iv) no additional nutrient requirement, (v) regeneration of biosorbent, and (vi) the potential for metal recovery.

Metals are actively transferred through the cell membrane of living microorganisms after becoming bonded to the cell wall. The biosorptive capacities of distinct microbial biomasses varies, and these capacities also differ significantly within each group. Each biosorbent's capacity for biosorption, however, is influenced by its prehistory, pretreatment, and experimental circumstances. The biosorbent ought to be inexpensive, efficient, and simple to cultivate and harvest. The organism should also be adaptable to changes in the physical and chemical conditions of the bioreactor, as well as the configuration of the bioreactor itself (Fomina *et al*., 2014).

Bacteria have been used as biosorbents because of their commonality, size, ability to grow under controlled settings, and tolerance to a variety of environmental factors (Wang, 2009). Several heavy metals have been studied on bacterial species including Pseudomonas, Enterobacter, Bacillus, and Micrococcus sp. Molds and yeasts are simple to grow, have a high biomass yield, and can be genetically and morphologically modified. According to Wang et al. (2009), they are extensively utilized in numerous large-scale commercial fermentation processes that result in the production of ferrichrome, gallic and kojic acid, as well as enzymes such lipases, glucose, isomerase, pectinases, amylases, and glucanases. They have great abilities for metal uptake and recovery and are widely employed as biosorbents for the removal of hazardous metals from contaminated wastewaters (Dursun *et al.*, 2003). They have a sophisticated defensive mechanism to counteract the harmful effects of heavy metals, and their high sorption capacity makes them excellent biosorbents. In both freshwater and marine habitats, red, green, and brown algae are all easily accessible and have been employed in adsorption investigations (Srivastava *et al.*, 2015).

Due to their autotrophic nature, algae consume fewer nutrients than other microbial biosorbents and generate a significant amount of biomass. They are easily accessible in large numbers and have a high sorption capacity (Abbas *et al*., 2014).

Mechanisms of Heavy Metal Uptake by Microorganisms

Through the cellular structure of a bacterium, microbes can capture heavy metal ions, which they then sorb onto the binding sites of the cell wall (Malik, 2004). It is not a part of the metabolic cycle and is known as biosorption or passive absorption. The kinetic equilibrium and metal composition at the cellular surface determine how much metal is sorbed. Electrostatic contact, ion exchange, precipitation, the redox process, and surface complexation are some of the processes that are involved in the mechanism (Yang *et al*., 2015). The procedure moves quickly and can attain equilibrium in a short period of time. According to Fomina et al. (2014), biosorption can be performed by tissue and cell fragments, dead biomass, or living cells as passive uptake via surface complexation onto the cell wall and other outer layers.

The second way involves a mechanism in which heavy metal ions cross the cell membrane and enter the cytoplasm while going through the metabolic process of the cell. This process is known as active uptake or bioaccumulation. A live cell's ability to accumulate material is based on a number of physical, chemical, and biological factors. These include both internal and extracellular processes, where bio-sorption has a hazy and restricted influence (Fomina *et al*., 2014). The biosorption process can be carried out by tissue and cell fragments, dead biomass, or living cells as passive uptake via surface complexation onto the cell wall and other outer layers, according to Fomina *et al*. (2014).

The second method uses a mechanism through which heavy metal ions pass through the cell membrane and into the cytoplasm while the cell is undergoing metabolism. The term "active uptake" or "bioaccumulation" refers to this process. A number of physical, chemical, and biological factors affect how much material a live cell can store. These processes span both inside-the-cell and outside the cell, and bio-sorption only has a limited and hazy impact on both (Fomina *et al*., 2014).

Conclusion

Bio-sorbents are beneficial to the environment since they are an affordable solution for removing dangerous heavy metals from the environment. Microorganisms can remove heavy metals from the environment through passive as well as active methods. By means of both natural and manmade processes, heavy metals accumulated in the environment. Humans, animals, plants, and the environment are all poisoned by heavy metals. The electrostatic interaction, ion exchange, precipitation, redox process, surface complexation, and other processes involved in bio-sorption.To adequately address the major issues involved, a sustainable method must be devised to choose the best bio-sorbent, operating conditions, and effective mechanism of heavy metal removal in industrial effluent.

References

Abbas, S. H., Ismail, I. M., Mostafa, T. M. and Sulaymon, A. H. (2014). Biosorption of heavy metals: A review. *J. Chem. Sci. Technol*., **3**: 74–102.

Abdul-Wahab, S. and Marikar, F. (2012). The environmental impact of gold mines: Pollution by heavy metals. Open Eng., 2: 304–313.

Babula, P., Adam, V., Opatrilova, R., Zehnalek, J., Havel, L. and Kizek, R. (2008). Uncommon heavy metals, metalloids and their plant toxicity: A review. Environ. *Chem. Lett*., **6**: 189–213.

Barakat, M. (2011). New trends in removing heavy metals from industrial wastewater. *Arab. J. Chem*., **4**:361–377.

Blais, J.; Djedidi, Z.; Cheikh, R.B.; Tyagi, R.; Mercier, G. (2008). Metals precipitation from effluents: Review. *Pract. Period. Hazard. Toxic Radioact. Waste Manag*., **12**: 135–149.

Brar, S. K., Verma, M., Surampalli, R., Misra, K., Tyagi, R., Meunier, N. and Blais, J. (2006). Bioremediation of hazardous wastes—A review. Pract. Period. Hazard. *Toxic Radioact. Waste Manag*., **10**: 59–72.

Dixit, R., Malaviya, D., Pandiyan, K.,Singh, U. B., Sahu, A., Shukla, R., Singh, B.P., Rai, J. P., Sharma, P. K. and Lade, H. (2015). Bioremediation of heavy metals from soil and aquatic environment: An overview of principles and criteria of fundamental processes. Sustainability, **7**: 2189–2212.

Dursun, A., Uslu, G., Cuci, Y. and Aksu, Z. (2003). Bioaccumulation of copper (II), lead (II) and chromium (VI) by growing *Aspergillus niger*. *Process Biochem*., **38**: 1647–1651.

Fashola, M., Ngole-Jeme, V. and Babalola, O. (2016). Heavy metal pollution from gold mines: Environmental effects and bacterial strategies for resistance. *Int. J. Environ. Res. Public Health*, **13**: 1047.

Fomina, M. and Gadd, G. M. (2014). Biosorption: Current perspectives on concept, definition and application. *Bioresour. Technol*., **160**: 3–14.

Gaur, N., Flora, G., Yadav, M. and Tiwari, A. (2014). A review with recent advancements on bioremediation-based abolition of heavy metals. *Environ. Sci. Process. Impacts*, **16**: 180–193.

Germ, M., Kreft, I., Stibilj, V. and Urbanc-Bercic, O. (2007). Combined effects of selenium and drought on photosynthesis and mitochondrial respiration in potato. *Plant Physiol. Biochem*., **45**: 162–167.

Gumpu, M. B., Sethuraman, S., Krishnan, U. M. and Rayappan, J. B. B. (2015). A review on detection of heavy metal ions in water—An electrochemical approach. Sens. *Actuators B Chem*., **213**: 515–533.

Karatochivl, D. and B. Volesky (1998). *Water Res*., **32**: 2760-2768

Malik, A. (2004). Metal bioremediation through growing cells. *Environ. Int*., **30**: 261–278.

Mani, D. and Kumar, C. (2014). Biotechnological advances in bioremediation of heavy metals contaminated ecosystems: An overview with special reference to phytoremediation. *Int. J. Environ. Sci. Technol*., **11**: 843–872.

Mosa, K. A., Saadoun, I., Kumar, K., Helmy, M. and Dhankher, O. P. (2016). Potential biotechnological strategies for the cleanup of heavy metals and metalloids. *Front. Plant Sci*., **7**: 1–14.

Nagajyoti, P., Lee, K. and Sreekanth, T. (2010). Heavy metals, occurrence and toxicity for plants: A review. Environ. *Chem. Lett*., **8**: 199–216.

Qian, H., Peng, X., Han, X., Ren, J., Sun, L. and Fu, Z. (2013). Comparison of the toxicity of silver nanoparticles and silver ions on the growth of terrestrial plant model Arabidopsis thaliana. *J. Environ. Sci*., **25**:1947–1956.

Sharma, P. K., Balkwill, D. L., Frenkel, A. and Vairavamurthy, M. A. (2000). A new Klebsiella planticola strain (Cd-1) grows anaerobically at high cadmium concentrations and precipitates cadmium sulfide. *Appl. Environ. Microbiol*., **66**: 3083–3087.

Srivastava, S., Agrawal, S. and Mondal, M. (2015). A review on progress of heavy metal removal using adsorbents of microbial and plant origin. *Environ. Sci. Pollut. Res*., **22**: 15386–15415.

Su, C. A. (2014). Review on heavy metal contamination in the soil worldwide: Situation, impact and remediation techniques. *Environ. Skept. Crit*., **3**: 24–38.

Tak, H. I., Ahmad, F. and Babalola, O. O. (2013). Advances in the application of plant growth-promoting rhizobacteria in phytoremediation of heavy metals. In Reviews of Environmental Contamination and Toxicology; Springer: New York, NY, USA, 2013; pp. 33–52.

Volesky, B. (1986). Biosorbent materials. Biotechnol. Bioeng. *Symp*., **16**: 121-126

Wang, J. and Chen, C. (2009). Biosorbents for heavy metals removal and their future. *Biotechnol. Adv*., **27**: 195–226.

Wang, J., Feng, X., Anderson, C.W., Xing, Y. and Shang, L. (2012). Remediation of mercury contaminated sites-A review. *J. Hazard. Mater*., **221**:1–18.

Wuana, R. A. and Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. *ISRN Ecol*., **2011**: 1–20.

Yang, T., Chen, M. L. and Wang, J. H. (2015). Genetic and chemical modification of cells for selective separation and analysis of heavy metals of biological or environmental significance. *Trends Anal. Chem*., **66**: 90–102.