European Science Methodical Journal
ISSN (E): 2938-3641
Volume 2, Issue 3, March - 2024

REVIEW (ARTICLE) ON THE ROLE OF FUNGI IN THE BIODEGRADATION OF SOIL CONTAMINATED WITH HEAVY METALS

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Abstract:

Several biodegradation techniques harness a diverse array of microorganisms to remediate contaminated environments. Over the past 15 years, biodegradation has emerged as a powerful tool for environmental cleanup. The extracellular enzymes of algae, bacteria, yeast, and fungi can be harnessed to accelerate the biodegradation process. Fungi, in particular, have shown remarkable adaptability to a variety of pollutants and possess the unique ability to bioabsorb and bioconvert these pollutants into less harmful substances. This inherent potential of fungi in decontaminating polluted environments instills a sense of hope for the future of environmental cleanup.

Keywords: fungi, biodegradation, metals.

Introduction

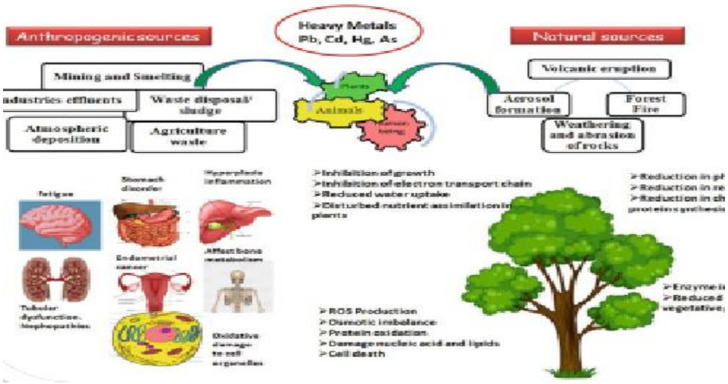
Metals are essential to the biological functions of plants and animals, but at elevated levels (more than the required amount), they contribute to the deleterious effect to organisms. Metals whose density exceeds 5 g/cm^3 are considered heavy metal. Heavy metals such lead (Pb), mercury (Hg), chromium (Cr), zinc (Zn), uranium (Ur), selenium (Se), silver (Ag), gold (Au), nickel (Ni), and arsenic (As) do not have a biological role but become toxic at low concentrations. Heavy metals are being continuously assimilated in land-water and soil. The wide-scale occurrence of these heavy metals leads to adverse health effects such as multiple organ failure and carcinogenic. Looking over the increasing flow of heavy metal in the environment and its adverse health effect to living organisms leads to search an alternative way for metal removal. Biodegradation refers to waste management techniques which employ natural source to convert hazardous substance to innocuous substances. It is mediated by various bacteria, fungi, algae, and plants. Fungi bear indestructible morphology with a specific mechanism that captivates heavy metal into the surface, later on, accumulated inside the fungal cell. Fungi absorb the metal ions into the cell and also chelate on the cell, so that they tolerant heavy metal compounds (1). Generally, detoxifications of heavy metals are possible by compartmentalization and biotransformation into an inactive form of the element (2). Safe sustainable management of metals is required to restore the ecosystem. This article is primarily based on fungal-mediated biodegradation, which is further elaborated by other modes of fungi that detoxify heavy metals. Fungal-mediated decontamination of environments deals with multiple strategies to decontaminate the environment with heavy metals such as bio-sorption, bioaccumulation, bioleaching, and bio-immobilization (3).

2-Heavy Metals

Heavy metals generally exist in the form of carbonates, hydroxides, oxides, sulfides, sulfates, phosphates, silicates, and organic compounds (4). They also exist in their metallic, elemental form, but they are mobilized by the action of human (anthropogenic activity extraction, smelting) or natural phenomenon (weathering and leaching) (5) (Fig. 1). Toxic heavy metals cannot be biodegraded when their concentration is elevated, and their accumulation is found to cause serious diseases and disorders (6). In humans, the toxicity of metal has been linked with birth defects, cancer, skin lesions, retardation leading to disability, liver and kidney damage, and host of other maladies (7). In plants, they reduce plant growth by affecting mineral nutrition and essential enzyme which are necessary to maintain physiological activities. In 2011, World Health Organization (WHO) listed deleterious 11 heavy metals, namely arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin, and titanium. The distribution and concentration of heavy metals in the environments are driven by anthropogenic activities, which ultimately deplete the minerals from naturally confined reservoirs represented in Fig. 2 (8). In 2012, WHO listed arsenic, cadmium, lead, and mercury as challenges for public concern. The United States Environmental Protection Agency (US EPA) and the International Agency for Research on Cancer (IARC) have classified them as either “known” or “probable” human carcinogens (9). A comprehensive review has been widely elaborated on the toxicity of heavy metal and its detrimental effect on humans (10).

3-Microbes Involved in Biodegradation

Biodegradation refers to the cleaning of the ecosystem via natural sources, which comprises plants, bacteria, algae, fungi, etc. (Fig. 3). About 35% of biological remediation is assisted by microbes and 16% is based on plants (11). In the very beginning, (12) presented the idea of using microorganisms to clean the petroleum derivative–contaminated soil, which was the origin of the biodegradation processes. Among microbes, prokaryotes and eukaryotic organisms are capable of detoxifying heavy metals (Fig. 4) (13). But now with the involvement of advanced biotechnologies such as biofilm algae,



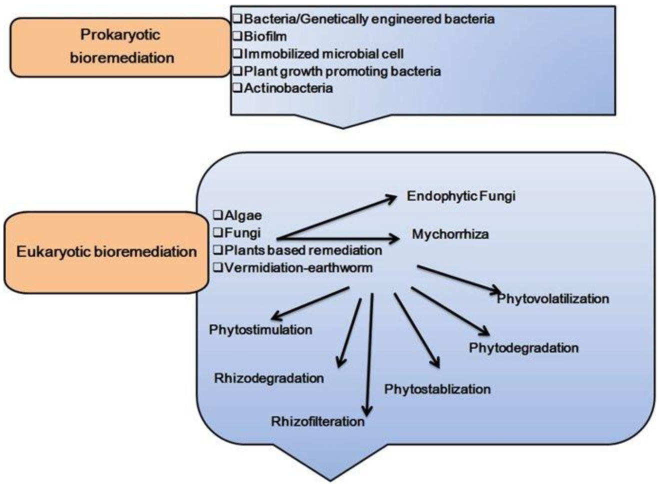


Fig.4 Dendrogram showing different types of prokaryotic and eukaryotic biodegradation of heavy metals

Genetically engineered microbes, and immobilized microbial cells, it has enhanced the approach of bio remediating heavy metals. In addition to this, our plant system is endowed with the various mechanisms at the cellular level to detoxify heavy metals which are termed as phytoremediation . Moreover, the symbiotic associations between plants and Rhizobacteria efficiently improve plant growth by increasing mineral nutrition and alleviating heavy metal toxicity on target plants (14). These Rhizobacteria possess a variety of natural mechanisms to endure the toxicity of heavy metals. Microbes are capable of accumulating metals by binding them as cations to the cell surface in a passive process (15).

4-Advantages of Biological Methods over Conventional Methods

Nowadays, industrial effluents are pre-treated through several conventional technologies before their discharge into the environment. Methods such as chemical pre-capitation, ion exchange, electro-deposition, bio sorption, liquid–liquid extraction, adsorption, membrane separation, reverse osmosis, and coagulation are being used (16). But due to several disadvantages, these methods become less effective in treating pollution. For example, conventional methods become unsuccessful at a higher concentration of heavy metals. These are expensive and produce large quantities of secondary pollutants (sludge) (17). Hence, these conventional physical and chemical methods become non economical as they generate large volumes of chemical waste ultimately. Therefore, an endeavor is made to develop effective alternative techniques which are applicable to the local conditions and must be able to meet with the established permissible limits (18).

5-Biodegradation of Heavy Metals by Different Interaction between Fungi and Metals

5-1Biomineralization

Bio mineralization is a biological method of detoxifying heavy metal along with the bio-recovery process. Microorganisms immobilize heavy metals and convert into insoluble minerals through metabolism to mineralize heavy metal ions, thereby reducing their mobility and bioavailability. Biomineralization fall into two categories: biologically induced mineralization (BIM) and biologically controlled mineralization (BCM)(19). In biologically controlled mineralization (BCM), the physiology of microorganisms controls the nucleation, growth, and morphologies of the biominerals. Whereas in biologically induced mineralization, it depends on the organism modifying its local microenvironment to create appropriate physicochemical conditions for the precipitation of minerals (20). It is generally found that an uratolytic microorganism is effective in immobilizing toxic metal pollutants via calcium carbonate precipitation .The uratolytic organisms can immobilize toxic metals efficiently by precipitation or co-precipitation, independent of metal valence state and toxicity and the redox potential (21).

5-2 Endophytic Fungi-Assisted Biodegradation

In the twentieth century, endophytic fungi are widely studied to their existent, distribution and applications in medicine relevance. Besides this, the researcher has drawn attention to the role of endophytic fungi as heavy metal bioremediators. Endophytic fungi possess structure as extended mycelia networks that have the biological ecological capacity to reduce the risk related to the heavy metal via chemical modification or by changing the chemical availability (22).

Endophytic microorganism lives in mutual association inside the plant that ranges from symbiotic, commensalism and neutral or as latent pathogen. They occur as versatile microorganism to the development stage, nutritional status, and other environmental factors (23). Endophytic fungi especially dark septate endophytes (DSEs) have been reported to be promising bio-sorbent for heavy metal treatment. In addition to drought, heat, low pH, and high salinity, they also showed metal tolerance (24). Simultaneously metal tolerance was found to promote the plant growth under the higher concentration of metals. Several in vitro studies revealed that endophytic fungi can tolerate heavy metals (25).

5-3 Mycorrhizal-Based Biodegradation

Naturally, fungi make symbiotic associations with the roots of the higher plants to combat heavy metal pollution in the environment. This symbiotic association is known as mycorrhiza. Mycorrhiza facilitates host plants to uptake and transport phosphorus (P), and other relatively immobile soil nutrients promote plant growth and enhance their stress tolerance (26). Fungi, such as *Trichoderma*, *Aspergillus*, *Rhizopus* and arbuscular mycorrhizal fungi (AMF) have shown the potential to remove soil contaminants by enhancing phytoremediation (27).

Conclusion and Future Perspective

The continuous increase in anthropogenic interference leads to the uneven distribution of heavy metals in the ecosystem. Microbes can significantly control the distribution of heavy metals (28). Although physical and chemical methods are being used, they inter lots of disadvantages such as high-cost treatment and production of sludge which is toxic and difficult to handle. Therefore, biological treatments are alternative methods that are eco-friendly, best removal, and low-cost methods. In the current chapter, significance of fungi has been described for the removal of heavy metals (29). Fungal microorganisms endowed with robust morphology which makes them suitable to bear the harsh environment imbedded with toxic metals. Fungi utilized biosorption, bioaccumulation, biotransformation, and biomineralization techniques for their continued existence in metal-polluted environments. These strategies have been exploited for remediation procedures. In this article, biosorption appears as an eco-friendly and cost-effective process (30). Despite the occurrence of bioremediating fungi, it is important to modify the techniques based on the biosorption process, since all the remediating processes are based on biosorption. Therefore, researchers are required to work on parameters affecting the biosorption processes such as surface morphology, area, zeta potential, functional groups and particle size (31).

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