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Review

Advances in microbe-assisted reclamation of heavy metal contaminated soils over the last decade: A review

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ABSTRACT

Contamination of agricultural soils with trace metals present lethal consequences in terms of diverse ecological and environmental problems that entail entry of metal in food chain, soil deterioration, plant growth suppression, yield reduction and alteration in microbial community. Metal polluted soils have become a major concern for scientists around the globe. Phytoremediation involves the hyper-accumulation of metals in different plant parts. Phytoremediation of metals from polluted soils could be enhanced through inoculation with metal resistant plant growth promoting (PGP) bacteria. These PGP bacteria not only promote plant growth but also enhance metal uptake by plants. There are a number of reports in the literature where PGP bacterial inoculation improves metal accumulation in different plant parts without influencing plant growth. Therefore, there is a need to select PGP bacterial strains which possess the potential to improve plant growth as well as expedite the phytoremediation of metals. In this review, we have discussed the mechanisms possessed by PGP bacteria to promote plant growth and phytoremediation of metals. The central part of this review deals with the recent advances in microbial assisted-phytoremediation of metals.

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1. Introduction

The buildup of toxic metals in various compartments of the environment is hazardous for biotic health including humans due to bioaccumulation and biomagnification of heavy metals in living organisms. Biomagnification refers to the greater tissue concentration of heavy metals (Ali et al., 2013). The continuous rise in the levels of heavy metals in soil ecosystem is the major concern throughout the world (Fuentes et al., 2016; Pandey, 2016). Advancement in technology results in the introduction of novel metal contaminants in the environment such as presence of elevated levels of metallic nanoparticles (Ebbs et al., 2016). Environmental contamination by such compounds is due to their rapid consumption in agriculture, energy, pharmaceuticals and cosmetics. These contaminants damage the environment and health risks associated with their consumption are not fully known. Therefore, these are essential targets for phytoremediation (Van Oosten and Maggio, 2015; Kumari et al., 2016). Developing industrialization and different anthropogenic activities add toxic materials into the air, water and soil. These toxic materials are the major pollutants that are damaging for the environment and living organisms,i.e., microorganisms, plants and animals (Gall et al., 2015; Ullah et al., 2015b). These pollutants are enriched with heavy metals which have density higher than 5 g cm^{-3}. However, this definition of heavy metals varies (Adrees et al., 2015). There are number of sources that add heavy metals to the environment. These sources include combustion of leaded batteries and petrol, medical waste, coal combustion, pesticides, fertilizers, smelting and mining, etc. (Li et al., 2015a,b; Wuana and Okieimen, 2011). Mining areas generally exhibit higher accumulation of heavy metals which pollute soil and water, and restrict plant growth (Sasmaz et al., 2016a,b). Higher concentrations of Hg have particularly been reported in mining areas (Sasmaz et al., 2016a). Use of metal-hyperaccumulator plants is a widely-practiced approach in such areas (e.g. Sasmaz et al., 2008; Selvam and Wong, 2008; Sun et al., 2010; Sasmaz et al., 2015). Microbe-assisted bioimmobilization of heavy metals has been found to be promising approach for remediation of heavy metal contaminated soils under mining activity (Lim et al., 2014; Yang et al., 2016). These sources of toxic heavy metals contaminate surface water, sediments, soils and plants (Islam et al., 2015; Khan et al., 2015a,b).

Among heavy metals, Al (aluminium), Zn (zinc), Mn (manganese), Cr (chromium), Cu (copper), Cd (cadmium), Pb (lead) and Hg (mercury) are the common toxic metals (Emamverdian et al., 2015). In addition, some metalloids are also considered toxic such as As (arsenic) and Sb (antimony). Heavy metals pose significant inhibitory effects on aquatic and terrestrial ecosystems that result in increased physiological health risks (Chen et al., 2015; Roy and McDonald, 2015). Heavy metals have various ways of entrance in the plant body including contact with skin, food, air and water (Dixit et al., 2015; Khan et al., 2015a,b). Heavy metals are the reasons of major health concerns in humans (Khan et al., 2016). For instance, heavy metals may increase the onset of cognitive impairment, cardiovascular diseases, and chronic anemia (Iqbal, 2012), cancer, damage kidneys, brain and nervous system (Järup, 2003; Wuana and Okieimen, 2011). In addition, teeth, bones and skin are also damaged by heavy metals (Ullah et al., 2015a). Therefore, it is imperative to exclude the heavy metals from the environment so as to decrease the health risks. This review focuses on recent progress in remediation of heavy metals (phytoremediation). Phytoremediation of heavy metals may be enhanced through an emerging technology in which plant growth promoting rhizobacteria are used that convert the heavy metals in soluble and bioavailable form.

2. Approaches for remediation of heavy metals

Remediation of toxic heavy metals is mandatory so as to prevent the hazardous effects on the environment and preserve the environment for coming generations (Taj and Rajkumar, 2016). A variety of methodologies have been employed for the elimination of toxic heavy metals. Eliminating heavy metals from the environment is considered as a challenging job with respect to technical complexity and cost (Mahar et al., 2016). A number of strategies to cleanup soil are being used over the years. These strategies are categorized as biological, chemical and physical approaches (Hasegawa et al., 2016; Lim et al., 2014). Metal contaminated soils are traditionally cleaned-up via on-site management or excavation and disposal to landfill sites. However, such approaches only shift the problems elsewhere. Additionally, problems may also arise during the transportation of contaminants to adjacent compartments of the environment (Thakur et al., 2016). Another strategy to eliminate soil metal contaminants involves soil washing which produces pollutant rich residues that require further treatment. However, such soils become unsuitable for plant growth due to removal of biological activities (Gaur and Adholeya, 2004; Tangahu et al., 2011). Chemical and physical methods have limitations, e.g., changes in native soil flora, irreversible alterations in soil properties, intensive labor, and high cost. Likewise, chemical methods are expensive, generate secondary pollution, and produce large quantities of sludge (Tangahu et al., 2011; Zubair et al., 2016).

3. Physiochemical approaches for remediation of heavy metals

Electro-reclamation, leaching, landfill, thermal treatment, excavation are included in physiochemical approaches. However, the above-mentioned approaches are rapid but cost inefficient and also induce harmful effects on soil biological, physical and chemical properties thereby causing secondary pollution (Jegatheesan et al., 2016; Mahar et al., 2016). Physiochemical approaches are not an absolute solution to this problem. These approaches only change the form of the problem and fail to remediate the pollutants thoroughly (Gomes et al., 2016).

4. Biological approaches for remediation of heavy metals

Toxic heavy metals are eliminated from the environment through the biological remediation in which plants and microorganisms are used (Hasegawa et al., 2016). Biological remediation of toxic metals is the convenient method as it is environmental friendly, natural process, inexpensive and has high public acceptance (Kang et al., 2016). Biological approaches entail biostimulation, bioaugmentation, composting, bioreactors, bioleaching, bioremediation, land forming, bioventing and phytoremediation (Mani and Kumar, 2014). Biological approaches are preferred over physiological approaches because these approaches utilize solar energy and conserve natural soil properties (Beškoski et al., 2011; Kang et al., 2016).

Bioremediation is a biological technique in which heavy metals are eliminated from the environment (Chibuike and Obiora, 2014; Gomes et al., 2016). In this context, bacterial strains *Pseudomonas aeruginosa* and *Bacillus* spp. remediate Zn and Cu (Kumar et al., 2011). Bioremediation may be done through biofilters, pumped and treated methods, biostimulation, bioventing, composting, bioreactors, land forming, intrinsic bioremediation, and bioaugmentation (Ullah et al., 2015a,b).

Phytoremediation is also a biological technique and efficiency of phytoremediation can be enhanced if it is coupled with the use of microbes (Afzal et al., 2014; Chang et al., 2014). Metal

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