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Phytoremediation of heavy metals contaminated soil using plant growth promoting rhizobacteria (PGPR): A current perspective

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Abstract

Increase in industrial, agricultural practices and several anthropogenic activities add a significant amount of heavy metals in soil and water. Heavy metals accumulate in the environment due to their non biodegradable nature and subsequently contaminate the food chain. Presence of these metals beyond the threshold limit poses a serious threat to the environment and human health. To overcome these problems, bioremediation has been getting attention because of its low cost, efficient and eco-friendly nature. Phytoremediation is a promising approach for removal of contaminants from the environment by the use of hyperaccumulator plants. But using plants alone for remediation faces many limitations owing to the heavy metal toxicity. This heavy metal toxicity could be conquered by exploring the association of plant growth promoting rhizobacteria (PGPR) with plants. This association would improve plant growth by facilitating sequestration of toxic heavy metals. Plant growth-promoting rhizobacteria are involved in plant growth promotion and development by colonizing the root or preventing plant diseases via production and secretion of various regulatory chemicals. Metal uptake mechanisms involve special proteins namely metallo-proteins or metal-binding proteins and peptides. This study deals with the role of PGPR in plant growth promotion and acceleration of phytoremediation as well as removal of toxic metals.

Keywords: Bioremediation, heavy metals, plant growth promoting rhizobacteria, phytoremediation.

INTRODUCTION

The continued worldwide industrialization, agricultural practices and several anthropogenic activities has caused extensive environmental problems due to the release of pollutants, such as heavy metals, organic pollutants, etc. Heavy metals are the primary inorganic contaminants accumulate in environment because of their non-biodegradable nature and subsequently contaminate the food chain (Rajkumar et al., 2010). Physical, chemical and biological methods have been used for the elimination of pollutants from the environment. Bioremediation is the application of biological processes for cleanup of pollutants from the environment. It is a cost effective and expedient solution for remediation of heavy metal-contaminated soil in comparison with physico-chemical remediation technologies which are too costly and harmful for soil characteristics (Quartacci *et al.,* 2006).

Phytoremediation is a method of bioremediation process by the help of hyperaccumulator plants. The success of phytoremediation is dependent on the potential of plants to yield elevated biomass and withstand the metal stress. The phytoremediation efficiency can be improved by increasing the heavy metal mobilization or solubility in the soil and increasing plant biomass by promoting plant growth (Zhuang et al., 2007). This can be achieved by developing the association of hyperaccumulator plants with heavy metal resistant bacteria (Figure 1). Among the rhizosphere microorganisms involved in plant interactions with metal-contaminated soil environment, the plant growth promoting rhizobacteria (PGPR) deserve special attention because they can directly improve the phytoremediation process by changing the metal bioavailability through altering pH, release of chelators, production of phytohormones, etc. (Ma *et al.,* 2011).

This review describes the application of PGPR to accelerate plant biomass production and influence plant metal accumulation or stabilization with better performance abilities such as adaptive strategies, metal mobilization, and immobilization mechanisms.

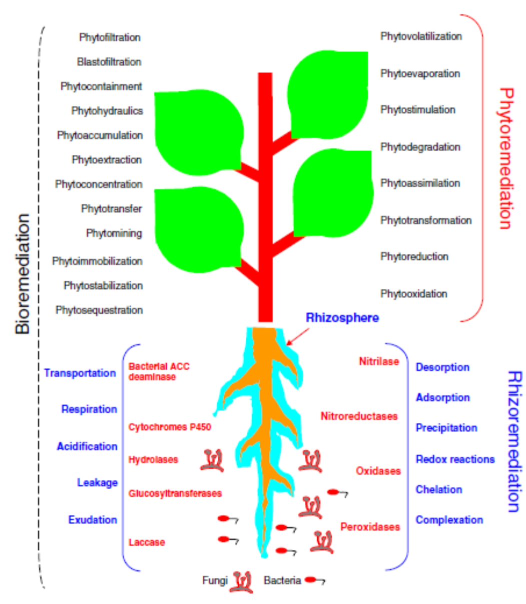

Fig 1. Importance of soil-microbe interactions in bioremediation for the cleanup of metals and organics (Ma et al., 2011).

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Plant-microbe interactions for cleanup of metalliferous soil

Plants which can tolerate and accumulate high concentration of metals are described as hyperaccumulators. Ideal hyperaccumulators for bioremediation require the characteristics of rapid growth and a high amount of biomass (Nie et al., 2002). Plants growing in metal contaminated soil harbor diverse groups of microbes that are capable of tolerating high concentration of metals and provide a number of benefits to both the soil and plant. Among the rhizosphere microorganisms involved in plant interactions with metal-contaminated soil, the plant growth-promoting rhizobacteria (PGPR) deserve special attention because they can directly improve the phytoremediation process by changing the metal bioavailability through altering pH, release of chelators, production of phytohormones, etc. (Ma *et al.,* 2011). Table 1 summarizes few studies on bacterial effects on phytoremediationin metal-contaminated soils as a function of heavy metal, bacteria, and the involved plant.

Table 1. Few examples of PGPR assisted phytoremediation of metal-contaminated soils

Bacteria	Plant	Heavy metal	Condition	Role of PGPR	Reference
Azotobacter chroococcum HKN-5 *Bacillus megaterium* HKP-1 *Bacillus mucilaginosus* HKK-1	*Brassica Juncea*	Lead, Zinc	Pot experiment	-Stimulated plant growth -Protected plant from metal toxicity	Wu et al. (2006)
Bacillus subtilis SJ-101	*Brassica Juncea*	Nickel	Pot experiment	-Facilitated Ni accumulation	Zaidi et al. (2006)
Kluyvera ascorbata SUD165	Indian mustard	Nickel, Lead, Zinc	Pot experiment	-Both strains decreased some plant growth inhibition by heavy metals	Burd et al. (2000)
Kluyvera ascorbata SUD165/26	Canola, Tomato			-No increase of metal uptake with either strain over non-inoculated plants	
*Mesorhizobium huakuii*sub sp.rengei B3	*Astragalus sinicus*	Cadmium	Hydroponics	-Expression of PCS $_{At}$ gene increased ability of cells to bind Cd^{2+}approximately 9- to 19-fold	Sriprang et al. (2003)
Microbacterium oxydans AY509223 (RS)	*Alyssum murale*	Nickel	Pot experiment	-Facilitated Ni uptake (phytoextraction)	Abou-Shanab et al. (2006)
Pseudomonas sp. PsA, *Bacillus* sp. Ba32 (RS)	*Brassica juncea*	Chromium	Pot experiment	-Increase plant growth (phytostabilization)	Rajkumar et al. (2006)
Bacillus subtilis SJ-101	*Brassica juncea*	Nickel	Pot experiment	-Increase shoot length, fresh and dry weights -Increase Ni uptake	Zaidi et al. (2006)
Pseudomonas sp. Ps29C, *Bacillus megaterium* Bm4C (RS)	*Brassica juncea*	Nickel	Pot experiment	-Increase shoot length, plant fresh and dry weight (phytostabilization)	Rajkumar and Freitas (2008)
Achromobacter xylosoxidans Ax10 (RS)	*Brassica juncea*	Copper	Pot experiment	-Increase Ni and Cr uptake (phytoextraction)	Ma et al. (2009)
Pseudomonas fluorescens G10, Microbacterium sp. G16 (EN)	*Brassica napus*	Lead	Pot experiment	-Increased root length, shoot and dry weight -Incease Pb uptake in shoots (phytoextraction)	Sheng et al. (2008)
Pseudomonas chlororaphis SZY6, *Azotobacter vinelandii* GZC24, *Microbacterium lactium*YJ7 (EN)	*Brassica napus*	Copper	Pot experiment	-Root length promotion of copper treated and untreated seedlings (phytoextraction)	He et al. (2010)

Sensitivity and sequestration ability of the microbial community towards heavy metals, make them a potential agent for bioremediation (Kao et al., 2006). Plant associated microorganisms can alter plant cell metabolism, so that upon exposure to heavy metal stress, the plants are able to tolerate high concentrations of metals and thus can better withstand the challenge (Welbaum et al., 2004).

Prompting plant growth

Plant associated bacteria play a key role in host adaptation to a changing environment. The mechanism of plant growth stimulation includes synthesis of ACC deaminase, siderophores and phytohormones production, nutrients uptake, biocontrol agents (Figure 2).Phytohormones are responsible for plant growth as well as metal uptake (Zaidi et al., 2006).

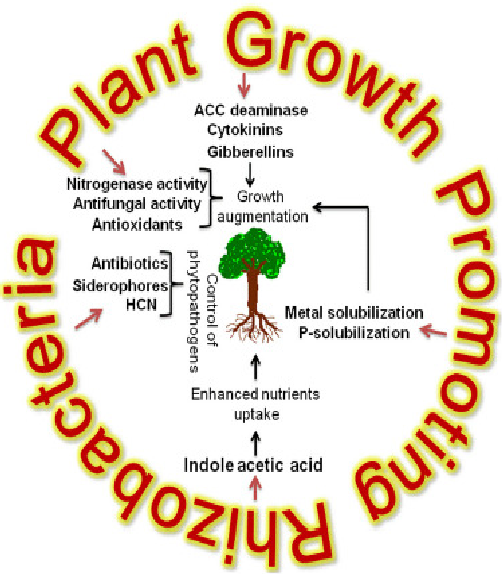

Fig 2. Mechanism of plant growth promotion by rhizobacteria (Ahmed *et al.,* 2013)

Transformation and uptake

Soil microorganisms are known to affect the metal mobility and availability to the plant, through acidification, and redox changes or by producing iron chelators and siderophores for ensuring the iron availability, and/or mobilizing the metal phosphates (Burd et al., 2000). A large proportion of metal contaminants are unavailable for the root uptake by plants, because heavy metals in soils are generally bound to organic and inorganic soil constituents, or alternatively, present as insoluble precipitates. Siderophore producing PGPR solubilize unavailable forms of heavy metal-bearing Fe and also form complexes with bivalent heavy metal ions that can be assimilated by root mediated processes (Braud et al., 2009). The PGPR may also contribute in reducing the metal phytotoxicity by biosorption mechanism (Zaidi et al., 2006).The bacterial cells could adsorb a greater amount of heavy metals either by a metabolism-independent passive, or by a metabolism-dependent active process (Khan et al., 2007). Bacterial biosorption/bioaccumulation mechanism, together with other plant growth promoting features (e.g. production of ACC deaminase and phytohormones) accounted for improved plant growth in metal-contaminated soils (Zaidi et al., 2006).

Genetically engineered approach

Metal binding proteins or metalloproteins are a large group ofproteins which can effectively bind a wide range of heavy metals with high affinity (Ma et al., 2009). In microorganisms and plants, metal binding proteins at the outer membrane, interact with environmental metal ions ensuring their transport in the cytosol, where metallochaperones (specialized proteins chelators) transfer metals to the appropriate receptor protein. In response to toxic levels of heavy metals, plants synthesizemetal binding proteins/peptides such as metallothioneins (MT) and phytochelatins (PC). Different engineered rhizobacteria can be utilized to remediate complex contaminated soil.

CONCLUSION

Phytoremediation is the use of plants to remediate polluted soils, an eco-friendly and cost effective technology that is currently receiving considerable global attention. It preserves the natural properties of soil. The recent researches of PGPR on the remediation of contaminated soils show a brilliant prospect for the successive studies. The above studies imply that it is possible to develop new phytoextraction strategies with an inoculation of plants used for phytoremediation with rhizobial microbes in order to enhance phytoextraction of metals from contaminated soils. When considering approaches to alter heavy metal mobilization, there are several advantages to the use of beneficial microbes rather than chemical amendments because the microbial metabolites are biodegradable, less toxic, and it may be possible to produce them in situ at rhizosphere soils.

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