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Influence of Rhizospheric Bacteria on Growth and Metal Uptake of Heavy Metal Accumulating Plants-A Review

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Abstract- Rhizosphere microorganisms harbour the plant accumulators and contribute to the metal extraction process. Out of bacteria and fungi, bacteria were more tolerant to heavy metals than fungi. A variety of bacteria growing in metalliferous soils helps to accumulate metals in plants in their harvestable parts and have the potential to be used for remediation of heavy metal polluted lands called plant-assisted bioremediation. The present review focuson examining the current concepts and published data on the role of rhizosphere processes, heavy metal pollution, degradation,role of rhizodeposits, plant hormones, plant secondary metabolites, siderophores and carboxylic acids and conclude with major controls that may be used for their management in plant-assisted bioremediation.

Keywords: Rhizosphere microorganisms, metal extraction, remediation, polluted lands, bioremediation.

I. INTRODUCTION

Heavy metal pollution

Human industry, farming, and waste disposal practices have resulted in the large-scale contamination of soil and water with organic compounds and heavy metals, with detrimental effects on ecosystems and human health[1]. Industries bearing heavy metals, such as Pb, Zn, Cr, Cd, Cu, As, and Ni, are a major concern because they are well known to produce a long-term negative impact on soil and water in the surrounding environment [2-3].

Degradation

Conventional methods like chemical precipitation, chemical oxidation or reduction, ion exchange, membrane filtration, electrochemical treatment, reverse osmosis, and evaporation are expensive. Nowadays based on microorganisms new methods like Phytoremediation, Phytodegration, Rhizodegradation, Biodegradation and Bioaugmentation are used because they are cheaper and more effective technologies in order to decrease the amount of industrial waste.

Many microbial species have been reported as Metal and PAH degraders, but their activity has mainly been measured under controlled conditions like pure culture and batch experiments. Few reports have considered their activity in soil and in the rhizosphere [4-5]

Phytoremediation

"Phytoremediation" know-how to do-how is rapidly expanding and is being commercialized by harnessing the phyto-microbial diversity. This technology employs biodiversity to remove/contain pollutants from the air, soil and water [6]. This is an elegant and low-cost approach for the decontamination of polluted sites and has been greeted with a high degree of public acceptance, therefore prompting research into the use of phytoremediation technology to address the large areas of land and water currently affected [7- 9].

Phytodegradation

Phytodegradation, also called phyto-transformation, is the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants surrounding the plant through the effect of compounds (such as enzymes) produced by the plants[10]. Complex organic pollutants are degraded into simpler molecules and are incorporated into the plant tissues (http://www.unep.or.jp/Ietc/Publications/Freshwater/FMS2/2.asp)

The phytodegradation of organic compounds can take place inside the plant or within the rhizosphere of the plant. Many different compounds and classes of compounds can be removed from the environment by this method, including solvents in groundwater, petroleum and aromatic compounds in soils, and volatile compounds in the air[11].

Rhizodegradation

Rhizodegradation, also called phyto-stimulation or plant-assisted bioreme-diation/degradation, is the breakdown of contaminants in the rhizosphere (soil surrounding the roots of plants) through microbial activity that is enhanced by the presence of plant roots and is a much slower process than phytodegradation (http://www.unep.or.jp/Ietc/Publications/Freshwater/FMS2/2.asp). The mechanistic interactions between plants and microbial degradation processes are poorly known.

Biodegradation and Bioaugmentation

Biodegradation is the mineralization of materials as a result of the action of naturally-occurring microorganisms such as bacteria and fungi [12].

Bioaugmentation using a pure culture or a microbial consortium can be an effective and low-cost remediation approach to clean up pesticides in contaminated soil and thus reduce the transportation from soil to surface water and groundwater [13-18]. Although a lot of remediation techniques are available, biodegradation still holds a variety of advantages like low cost, few or no by-products, reusability, ecosystem friendly and so on [19].

II. RHIZOSPHERE MICRO-ORGANISMS

Rhizosphere micro-organisms involve in element uptake activity of the root, the release of compounds that can modify the pH (protons, bicarbonates, organic acids etc) or the exudation of organic ligands (organic acids and phytosiderophores).These processes, which vary with plant species, plant nutritional status and soil conditions, can modify the solubility and the availability of soil major and trace elements.

III. SYMBIOSIS

Pollutant bioavailability in the rhizosphere of phytoremediation crops is decisive for designing phytoremediation technologies with improved, predictable remedial success[20]. Plants can also improve the physical and chemical properties of contaminated soil, and increase contact between the root-associated microorganisms and the soil contaminants. Certain symbiotic relationships between legumes and nitrogen-fixing bacteria are resistant to heavy metals, promoting the dissipation of organic pollutants and enhancing their removal [21-23]. Rhizobia not only fix nitrogen but also promote plant growth, thus increasing plant biomass, soil fertility, the bioavailability, uptake and translocation of pollutants, the degradation of organic contaminants and the phytostabilization of metals[24].

IV. RHIZODEPOSITS ROLE IN MICROBES

Rhizodeposits not only provide a nutrient-rich habitat for microorganisms but can potentially enhance biodegradation in different ways: they may facilitate the co-metabolic transformation of pollutants with similar structures, induce genes encoding enzymes involved in the degradation process, increase contaminant bioavailability (surfactant activity), and/or selectively increase the number and activity of pollutant degraders in the rhizosphere [25].

V. ROLE OF PLANT HORMONES IN SUPPORT TO RHIZOSPHERIC MICROBES

Plant growth in hostile metal polluted environments may be supported by Fe supply from bacterial siderophores by bacterial production of auxin hormones such as indole-3-acetic acid (IAA) in the rhizosphere, and by bacterial 1-amino-cyclopropane-1-

carboxylic acid deaminase (ACC deaminase) activity. ACC deaminase inhibits stress ethylene synthesis and was shown to mitigate stress caused by the presence of heavy metals in plant tissues[26].

VI. ROLE OF TERPENS AND PHENOLSIN SUPPORT TO RHIZOSPHERIC MICROBES

Terpenes (such as cymene, α-pyrene and α-terpinene) and phenolics (such as salicylate) have been shown to induce biphenyl dioxygenase in PCB-degrading bacteria[27]. While phenolic compounds such as naringen, coumarin or catechin, released by roots of certain plants have been shown to support the growth of rhizospheric PCB-degrading bacteria [28].

Table 1. Examples of bacteria which are helpful for plant metal uptake

S.No	Name of the bacteria	Name of the plant	metal	Reference
1	*Pseudomonas sp. BE3dil [AY263472]*	*Salix caprea*	Zn, Cd, Pb	[29]
2	*Janthinobacteriumlividum [AF174648]*	*Salix caprea*	Zn, Cd, Pb	[29]
3	*Flavobacteriumfrigidimaris [AB183888]*	*Salix caprea*	Zn, Cd, Pb	[29]
4	*Streptomyces sp. 10–6 [AB222069]*	*Salix caprea*	Zn, Cd, Pb	[29]
5	*Agromycesterreus DS-10 UMS-101 [EF363711]*	*Salix caprea*	Zn, Cd, Pb	[29]
6	*Serratiamarcescens [AB061685]*	*Salix caprea*	Zn, Cd, Pb	[29]
7	*Azotobacterchroococcum HKN5*	*Brassica napus*	Cd	[10]
8	*Azotobacterchroococcum HKN5, Bacillus megaterium HKP-1,K-solubilising Bacillus mucilaginosus HKK-1*	*Brassica juncea*	Zn and Pb	[10]
10	*Streptomyces sp. strains A5 and M7*	*Zea mays,Salix caprea*	Ni	[30]

Pseudomonas, Janthinobacteriumlividum, Flavobacteriumfrigidimaris, Agromycesterreus, Serratiamarcescens, Azotobacterchroococcum, Bacillus megaterium have the capability to accumulate Cd, Zn and Pb in *Salix caprea*, *Brassica napus* and *Zea mays*[30-31]*Streptomyces* sp. BN2, BN3 strainshown high resistance level to Pb ($0.55\ mg{\cdot}mL^{-1}$) ($26.37\ mg{\cdot}g^{-1}$). Strains of Streptomyces may be well suited for soil inoculation as a consequence of their mycelial growth habit, relatively rapid rates of growth, colonization of semi-selective substrates, and their ability to be genetically manipulated [32]. Hyperaccumulator species like *Stanleyapinnata* (Brassicaceae) and *Astragalusbisulcatus* (Fabaceae), and the related non-accumulators *Physariabellis* (Brassicaceae) and *Medicagosativa* (Fabaceae), revealed that isolates from Se hyperaccumulator species were more resistant to selenate and selenite, could reduce selenite to elemental Se, could reduce nitrite and produce siderophores, and several strains also showed the ability to promote plant growth (Jong et al., 2015). Microorganisms with high Se tolerance and the ability to produce elemental Se would be useful for wastewater treatment and/or the production of Se nanoparticles [33].

Apart from metals *Streptomyces* sp. A5 showed maximum biomass and the highest pesticide removal in REs-lindane assay a successful strategy for the remediation of lindane-contaminated environments. *Ralstoniaeutropha*, *Pseudomonas aeruginosa* and *Enterobacter cloacae* obtained by enrichment on phorate could degrade it up to 73.3% in aqueous medium and 55.4% in a sandy loam soil according to [9] in*B. juncea*. Biodegradation of p-hydroxybenzoic acid in soil by Pseudomonas putida CSY-P1up to 8.3 mg g^{-1}.These potential strains in combination with plants may be useful for phytoremediation and rhizoremediation of such sites.

VII. ROLE OF SIDEROPHORES AND CARBOXYLIC ACID ANIONS IN METAL UPTAKE

Siderophore “iron carriers” are iron-chelating secondary metabolites, which various organisms release under iron-limiting conditions. Five hundred different bacterial siderophores have been described, most commonly called bacterial secondary metabolites[30](30). All siderophores possess higher affinity for Fe (III) than for Fe(II) or any other trace element ion. However, complexes of lower stability are also formed with other trace elements [34-35]. Divalent cations (*e.g.*, Fe^{2+}, Zn^{2+}, Cu^{2+}, Cd^{2+}) form less stable complexes due to their reduced charge density (charge/size ratio). Some siderophores can act on wide range of metals at a time eg. *Streptomyces* strain, producing a siderophore, was capable of sequestering a range of ions including Mn, Co, Cd, Ni, Al, Li, Cu, Zn, and Mg [36].

Carboxylic acids are typically present in soil solution as fully or partially dissociated anions [37].complexation with carboxylic acids in plants particularly malate, citrate but also with the basic amino acid histidine is a mechanism of trace element detoxification [38]. Bacteria producing trace element-chelating organic acids, such as citric, oxalic or acetic acid have been shown to mobilize various trace elements in soil [39].

VIII. CONCLUSIONS

Plants growing in metal contaminated soils are capable of tolerating high concentration of metals and providing a number of benefits to both the soil and the plant. These microorganisms can directly improve the phytoremediation process by changing the metal bioavailability through altering soil pH, release of chelators (e.g., organic acids, siderophores), oxidation/reduction reactions .These studies seem to be highly promising in terms of the creation of fields that encourage the development of bioremediation processes using native microorganisms. More studies should be designed at molecular levels to evaluate and to identify mechanisms involved in the association between metal resistances and accumulation in order to upgrade the bioremediation potential of theses strains. Overall the plant-associated beneficial microbes enhance the efficiency of phytoremediation process directly by altering the metal accumulation in plant tissues and indirectly by promoting the shoot and root biomass production.

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