

## ROLE OF RHIZOBACTERIA IN PHYTOREMEDIATION OF HEAVY METALS

NADEEM N<sup>1</sup>, ASIF R<sup>1</sup>, AYYUB S<sup>1</sup>, SALMAN S<sup>2</sup>, SHAFIQUE F<sup>1</sup>,\*ALI Q<sup>1</sup>, MALIK A<sup>1</sup>

<sup>1</sup>Institute of Molecular Biology and Biotechnology, The University of Lahore, Lahore, Pakistan

<sup>2</sup>Department of Plant Breeding and Genetics, Faculty of Agriculture, Gomal University, DI Khan, Pakistan

\*The first four authors; Nadeem N, Asif R, Ayyub S and Salman S have equal contribution towards manuscript

\*Corresponding author email: [saim1692@gmail.com](mailto:saim1692@gmail.com)

(Received, 18<sup>th</sup> July 2020, Revised 19<sup>th</sup> October 2020, Published 27<sup>th</sup> October 2020)

**Abstract:** Rhizobacteria, a plant growth promoting rhizobacteria (PGPR) as beneficial microorganism which helps in defense from abiotic and abiotic stresses, colonizes in rhizosphere and played a major role in promoting plant growth and also provides enhance soil fertility. In the highly contaminated soil, the content of metal exceeds the limits of plant tolerance. It is also possible that treatment of plant with PGPR, here increasing the biomass of plant, stabilizing and the remediation of metal polluted soil. The use of rhizobacteria plays an important role in increasing the tolerance of plant towards toxic effects of heavy metals like arsenic, sulphur, mercury, chromium, cadmium, nickel, lead and copper etc. Heavy metal accumulation results in deterioration of soil fertility while PGPR helps to restore soil fertility. The process of phytoremediation has been proved to be the best way to remediate heavy metals from soil. The use of rhizobacteria with plants provides highly efficiency phytoremediation. However, there is still need to understanding the concept of microbial ecological study in rhizosphere and mechanism of detoxification of heavy metals form rhizosphere.

**Keywords:** rhizobacteria, heavy metals, plant growth promoting bacteria, phytoremediation, abiotic stress

### Introduction

Heavy metals may be defined as elements which have metallic features like conductivity, ligand specificity, stability, etc. Metals have been present naturally in the soil with a lot of heavy metals ions accumulated in the form of compounds, or as simple ions and which are essential for plants as micronutrients (Rahmaty and Khara, 2011; Sharma *et al.*, 2003; Tahir *et al.*, 2020). Due to industrial revolution the pollution increased intensely by the toxic heavy metals due to human activities such as electroplating, fuel production, manufacturing and mining of metals, pesticide application etc (Almaroai *et al.*, 2012; Arroyo *et al.*, 2002; Babarinde *et al.*, 2006). Metal pollution has become the most severe problem among the environmental problems nowadays (Cao *et al.*, 2004; Khalil *et al.*, 2020; Seregin *et al.*, 2004; Zubair *et al.*, 2016). Rhizobacteria is plant growth promoting (PGPR) beneficial microorganism which helps in defense from abiotic and abiotic stresses, colonizes in rhizosphere and played a major role in promoting plant growth and also provides enhance soil fertility (Lugtenberg and Kamilova, 2009; Vessey, 2003). Rhizosphere bacterial species play an important role in phytoremediation from heavy metals in contaminated soil, through releasing of chelating

agents heavy metals mobility affect the microbial population and also availability to plant, release of redox changes, phosphate solubilization, acidification and promote phytoremediation (Iqra *et al.*, 2020; Lugtenberg and Kamilova, 2009; Mazhar *et al.*, 2020b; Vessey, 2003). In phytoremediation process rhizobacteria metal adapted able to received extra attention. We need to increase our understanding about mechanisms involved in mobilization and transfer of heavy metals in the contaminated soils (Antoun, 2013). Soils which are polluted with heavy metals cause environmental problems the reason behind is the effects of metals which is highly toxic. There have options for sediments polluted due to metals and reclamation of soil is ex-situ and in-situ techniques (Bååth, 1989; Pamukcu and Kenneth Wittle, 1992; Ross, 1994). The in-situ aims for remediation from soil is that enhance the maintenance of metals either in soil particles. The other methods work on plants to reduce bioavailability or potential mobility of toxic metals from environment. The purpose of ex-situ techniques is that separating and extracting of metals from the soil over series of biological, physical and chemical methods with the help of specifically designed reactor (Dixit *et al.*, 2015; Jansen *et al.*, 1994; Nouri *et al.*, 2009).

Phytoremediation method offers detoxification and removal of contaminants which involved the use of plants to sequester and it is very effective, ecologically gentle, less expensive and also a socially standard technology specifically for pollution elimination (Memon *et al.*, 2001; Schröder *et al.*, 2008). Phytoremediation depends upon the tolerance and ability of plant to accumulate HMs (high concentrations) and also to obtain yield from a large plant biomass (LeDuc and Terry, 2005; Mench *et al.*, 2009). Heavy metals mostly biologically non-degradable but persist indefinitely mostly in under developed and developed countries as contaminations in the environment. Presence of heavy metals in plants harshly effects on growth and crop yield, symbiosis due to high concentrations of heavy metals (Felix, 1997; Giordano *et al.*, 1975; Grytsyuk *et al.*, 2006). The heavy metals are harmful for soil because the heavy metals cannot be degraded biologically but it is likely to transfer from one oxidation state to the alternative state which is less toxic form of the compound (Chu and Wong, 1987; Schmidt, 2003). Degrading capacity of rhizobacteria has been increased the spectrum by using or introducing new techniques such as genetic engineering, phytohormones major chemical which are involved in the uptake of metal. Rhizobacteria plays very important role in phytoremediation and also release essential hormones for plant growth (Garrido *et al.*, 2005; Prasad *et al.*, 2011).

The heavy metal stress caused important impact on plants that's why the plants have to avoid it through some of the mechanisms such as.

1. At root surface metal ion adsorbed.
2. Root cells transversely membrane metals ions help to move into the root cells.
3. In vacuole metal ion immobilized in small proportion.
4. Movement of the metal intracellularly through the vascular tissue of root
5. The accumulation of metallic ions through the root-to-shoot transfer and also from leave tissue.

Mobilization and immobilization of the heavy metals is one of the important roles of rhizobacteria which provide tolerance to heavy metals. Soil pollution is the significant and serious environmental problem and cause negative effect on agriculture as well as also on human health (Gadd, 2000; Lahori *et al.*, 2017; Unz and Shuttleworth, 1996). The significant interface of plant and soil is rhizobacteria, which plays vital role in the phytoremediation of polluted soils through remediating the heavy metals. Extreme gathering of the heavy metals in several plants

species has been found highly toxic (Grytsyuk *et al.*, 2006; Krantev *et al.*, 2008; Lahori *et al.*, 2017). Presence of heavy metal ions at high level in the atmosphere absorbed from root and transferred to the shoot which effect on plant growth and reduced metabolism. Contamination of soil and water due to heavy metals is also a major problem. Moreover, high concentrations of metal in the soil have become the reason of many problems such as decrease in soil fertility, microbial action and also effect on yield production (Henning *et al.*, 2001; Iqra *et al.*, 2020; Ma *et al.*, 2003). Cadmium is a toxic and non-essential heavy metal which is able to reveal the problem and also inhibits shoot and root growth, nutrient uptake disturbs and accumulated rate of important crops. The crop plants which are usually rich in Cadmium and consumed by human and animals causes many harmful diseases. On the other hand, if Cd concentration not controlled then the overtime soil may be ultimately become unstable for the production of crop plants (Das *et al.*, 1997; Hasan *et al.*, 2009; Hou *et al.*, 2007). Heavy metals cause contamination in environment treated by conventional technologies which is based on the physicochemical principles but these technologies are uneconomic and inefficient. On the other hand, removal of metals from aqueous solution is carried with the addition of reagents in the solution which increase the pH and soluble form of metals converts into the insoluble form which causes precipitation in the solution (Cuypers *et al.*, 2011; Martelli *et al.*, 2006; Nagajyoti *et al.*, 2010).

#### **Interactions of rhizobacteria**

##### **Interaction between plant and bacteria**

Root zone of plants colonize with dense population of microorganisms. Rhizosphere is very attractive habitat as compare to bulk soil, organic carbon which is gained from the plant roots (Etesami, 2018; Van Loon, 2007). In Rhizosphere more than 85% organic carbon can be originated from the tissues and sloughed off the root cells. Relationship between plant and bacteria is always naturally symbiotic in this interaction both of them get benefit from each other. In this relationship roots of plants are mainly involved to give benefit to the bacteria (Antoun and Prévost, 2005; Chen *et al.*, 2000; Persello-Cartieaux *et al.*, 2003). Similarly, bacteria help plant in the maintenance of nutrient supply in and in recycling process. Rhizobacteria also maintain soil fertility and also detoxified harmful chemicals which usually released due to toxicity of heavy metals. Plants provide carbon source to the bacteria which reduce phytotoxicity (Requena *et al.*, 1997; Zahran, 1999).

##### **Plant bacteria interaction with respect to soil**

[Citation: Nadeem, N., Asif, R., Ayyub, S., Salman, S., Shafique, F., Ali, Q., and Malik, A. (2020). Role of rhizobacteria in phytoremediation of heavy metals. *Biol. Clin. Sci. Res. J.*, 2020: 35. doi: <https://doi.org/10.54112/bcsrj.v2020i1.35>]

Composition of root and soil conditions plays an important role in the interactions with respect to specificity. Rhizobacteria called as soil tolerated bacteria because it inhibiting rhizosphere. Some of the bacterial species also colonized around the surroundings and to the surface of root such as the endobacteria (Barea *et al.*, 2005; Nadeem *et al.*, 2014; Requena *et al.*, 2001). The interaction can be specific as well as non-specific. Toxic metal inhibits the growth of plant but other factors like water, low-soil fertility, beneficial nutrients, harsh and dry conditions may also be responsible for the inhibition of plant growth (Bhattacharyya and Jha, 2012; Haas and Défago, 2005).

#### **Removal of heavy metals and PGPR interaction**

The removal of heavy metals is very important due to their toxicity. Release of phosphate solubilization, acidification process, chelating agents and redox changes enhance the potential of phytoremediation. There is a need to progress understanding about mechanisms which are involved in the mobilization and also in the transfer of heavy metal so, we can be able to reduce the heavy metals from soil (de Oliveira Mendes *et al.*, 2014; Goldstein, 1995; Halder and Chakrabarty, 1993; Khan *et al.*, 2009). Heavy metals disturb the metabolic processes of plant and animals. Interaction of bacteria with plant affected from these following conditions which are very important for plant and bacteria.

1. Improper supply of water.
2. Harsh climate changes.
3. Deficiency of soil fertility.
4. Lack of nutrients.

#### **Heavy metals effect on plants**

For plant uptake heavy metals present in the soil as soluble components. Some heavy metals require for growth of plant and also for maintenance but if those metals present in high range than it become toxic for plant (Dubey, 2010; McIntyre, 2003; Reichman, 2002). And cause cytoplasmic enzymes inhibition due to oxidative stress damage cell structures. If heavy metals cannot remove from plant than ultimately plant died due to its toxic effects. Copper is important metal for development and growth of plant. The plant growth promoting rhizobacteria (PGPR) are beneficial for the plants and helps to reduce the toxicity level. The higher concentration and long term presence of heavy metals plant become chlorotic and cause deficiency of iron (Khalid *et al.*, 2015; Sayyed *et al.*, 2013; Tank and Saraf, 2009).

#### **Mechanism**

##### **Rhizobacteria secretions**

Rhizobacteria secretion could play a key role for phytoremediation which is assisted by rhizobacteria.

Direct mechanism contains nitrogen fixation synthesis of siderophores or indirect mechanism contains inhibiting phytopathogens from plant growth then development (Kloepper *et al.*, 1980; Van Loon *et al.*, 1998). The microbes promote the plant growth under stress conditions and help in degradation of contaminants. The PGPR has been mostly used for an extensive period assisting plant to uptake large amount of nutrients from soil or preventing plant diseases (Glick, 2012; Saharan and Nehra, 2011; Schippers *et al.*, 1987). PGPR application has been prolonged to bioremediation of organic metal pollutants. Rhizobacteria create metal chelating agents called siderophores and some heavy metals they have main part in acquisition. Organic matters have the result of scavenging  $Fe^{3+}$  increase the bioavailability of soil bound iron (Falkowski and Raven, 2013; Hughes and Poole, 1989; Schroth and Hancock, 1982). Lived in the metal polluted soils are often iron deficient in plant growth, the microbial siderophore are used in iron chelating agents they set the accessibility of iron in the plant rhizosphere (Bruins *et al.*, 2000; Gavrilescu, 2004; Raffi *et al.*, 2010). The plants required minor iron concentrations for the normal growth than do microbes but binding affinity of Phyto siderophores for iron is less than affinity of microbial siderophores. Root growth stimulated by different species of plants and has 1-aminocyclopropane-1-carboxylate (ACC) deaminase enzymes which control the amount of ACC by decreasing or hydrolyzing and ethylene a plant hormone precursor biosynthesis of plant by ethylene (Hontzeas *et al.*, 2006; Ma *et al.*, 2003; Madhaiyan *et al.*, 2007). Removal of ACC from seeds or roots is taken up through the bacteria and cleaved by ACC deaminase to ammonia. The inner and outer level ACC the plant need exude increase amount of ACC (Jia *et al.*, 2000; Nascimento *et al.*, 2014).

##### **Transform toxic heavy metals**

The decrease in growth due to heavy metals among 25% to 40% depending on the type of metal both in root tissue as well as shoot when plants have ability to create a very significant diminution of accumulation for heavy metals particularly in the plant roots while than 50% decrease in addition of Cd, Pb and Zn in the roots (Hansda *et al.*, 2014; Mushtaq *et al.*, 2020; Saleem *et al.*, 2007; Singh *et al.*, 2019). The bioavailability of metals in soil to plant is also influenced the phytoremediation to productivity of plant. Bacteria can convert toxic heavy metals to form that are additional readily taken up into plant roots. Bacteria can increase the concentration of Selenium and organ selenium forms such as Smet are known to be taken at faster rates

(Khan and Bano, 2018; Ojuederie and Babalola, 2017). The comparative change of organic bound with Cu, Pb and Zn were separately +5% +3% and +23% while in the infected rhizosphere 0.8%, -2% and -3% in the non-infected rhizosphere respectively. So, a huge amount of Cu, Zn and Pb bounded by organic matter in the infected rhizosphere (Abbaszadeh-Dahaji *et al.*, 2016; Guarino *et al.*, 2020). Chemical properties like pH of organic matter are directly affected the metal bioavailability through moving their soil rhizobacteria. The *Pseudomonas melophilia* reduced the mobile and toxic  $\text{Cr}^{3+}$  into nontoxic  $\text{Cr}^{6+}$  and also to reduce environmental mobility for additional toxic ions  $\text{Hg}^{2+}$ ,  $\text{Pb}^{2+}$  (Jeevanantham *et al.*, 2019; Li *et al.*, 2019).

#### **Inhibition of plant pathogens**

PGPR provides different ways to suppress plant viruses. It involves the competition of nutrients and an anti-bacterial environment for the manufacture of antibiotics and the production of siderophores that reduce the availability of the iron needed for bacterial growth (Glick and Stearns, 2011; Ma *et al.*, 2011; Tak *et al.*, 2013). Another mechanism similar to the production of lytic enzymes B-1,3-glucanases and chitinases plays a vital role in the reduction of glucan and chitin in the fungal cell wall. PGPR showed resistance to heavy metal during phytoremediation process. It has been shown that inoculating plants with plant growth that promotes rhizobacteria or by treating microbes with plant microscopic plantings may be effective in promoting plant growth (He and Yang, 2007; Kong and Glick, 2017; Nie *et al.*, 2002).

#### **Stimulation of transport protein**

Transport protein participating in the passage of ions. The protein might support in the change of substances by means of facilitated diffusion. Plants flourishing in tiny pots are usually considerably smaller than those expanding in large, at the same time when they have superficially suitable sources of water and nutrients (Salt *et al.*, 1998; Singh *et al.*, 2003; Zhao and McGrath, 2009). Bacteria persistence and propagation in the atmosphere furthermore within numerous hosts are censoriously reliant on the uptake and appropriation of conversion metals like zinc, iron, and manganese. For instance, cells might rigorously standardize intracellular zinc concentration while the elevated concentration of zinc is always noxious for cellular purpose which developed numerous types of protein implicated in attachment and transfer of zinc ions (Hall, 2002; Pilon-Smits, 2005; Wuana and Okieimen, 2011). The bacteria might also accelerate sulfate move proteins placed in the root cell or plasma membrane which similarly stimulates selenite mineral. The inorganic

Hg absorbance elevated in plants has not been correctly inspected but has been associated to the inactive acceptance of lipophilic chloride facilities in phytoplankton (Hutchinson, 1973; Thomas *et al.*, 1980).

#### **Speciation versus bioavailable of heavy metal in soils**

Soil rhizobacteria can also directly affect the melting of iron by altering the specificity of heavy metals in rhizosphere. The mycorrhiza played an important role in iron deficiency from the rhizosphere and it has impact on increasing plant tolerance in trapping heavy metals from soil (Li *et al.*, 2015; Marschener, 1998; Watteau and Berthelin, 1990). Although high heavy metal concentration is usually harmful to microbial physiological aspects, therefore the tracking of heavy metals amount and number of different heavy metals is very necessary for the normal bacterial growth for reducing redox and cellular activity. Bacterial interactions with heavy metals depend on metal forms and the availability of bioavailability (González-Guerrero *et al.*, 2016; Xie and Tang, 2019). The interaction of plant bacteria can promote the production of chemicals that can alter the chemical properties of the soil in rhizosphere and improved the accumulation of heavy metals in the plants body. The availability of bioavailability depends on a variety of factors such as soil pH, cation exchange rate, soil content of organic matter, mineral and iron content, water and heat content, biological properties of soil, chemical properties of metals and microbial activities under soil and climate conditions. In addition, the availability for heavy metal ions increases under low anaerobic oxidizing pH condition (Joshi and Juwarkar, 2009; Marsh Jr *et al.*, 1963; Ullah *et al.*, 2015).

#### **PGPB mechanisms to control heavy metals stress**

The heavy metals cannot be decomposed which can be harmless to bacteria. A few microorganisms have evolved to develop ways of removing toxins from the towards combat the harmless effects of these inanimate metals (Sgroy *et al.*, 2009). Heavy metals such as Al, Pb, Cd, do not production any role in nature and are harmless to living organisms. There are several ways to protect against heavy metal resistance by microbial cells. These processes are the outer barrier of cells, the outer division of cells, and the active transport of metallic ions, the inner cell structure, and the reduction of metallic ions (Ahemad, 2019; Begum *et al.*, 2019). Metal filtration that exceeds biological requirements prevents the growth of bacteria or bacteria that react to high levels of metals through various forms of resistance against heavy metal toxicity. Bacterium which increase the

[Citation: Nadeem, N., Asif, R., Ayyub, S., Salman, S., Shafique, F., Ali, Q., and Malik, A. (2020). Role of rhizobacteria in phytoremediation of heavy metals. *Biol. Clin. Sci. Res. J.*, 2020: 35. doi: <https://doi.org/10.54112/bcsrj.v2020i1.35>]

growth of plants such as Rhizobium, Brad rhizobium and Pseudomonas have been exposed to  $\text{Co}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Mo}^{2+}$  and the sensitivity of these metals has been tested in vivo which has shown that Rhizobium legumin Sarum spots are very sensitive to  $\text{Cu}^{2+}$  and  $\text{Co}^{2+}$  as compare with rhizobium (Islam *et al.*, 2016; Rajkumar and Freitas, 2008). This flexible metal resistance method was tested by examining the areas exposed to anthropogenic or natural metal contamination for a long time. Acquisition of heavy metals by microorganisms occurs by bioaccumulation which is an active process or by adsorption which is a synthetic process (Bashan and De-Bashan, 2010; Dodd *et al.*, 2010; El-Meihy *et al.*, 2019). Many micro-organisms such as fungi, bacteria and algae have been used to clean contaminating areas by heavy metals. Bacteria use two types of heavy ion detection methods. The initial mechanism of chemiosmosis gradient throughout the cytoplasmic membrane is rapid and undetectable. Another method is a specific substrate, which slows down and undergoes ATP hydrolysis. The most important methods are physical isolation, exclusion and difficulty (Bunow, 1978; Lane *et al.*, 2010; Silver and Phung, 2005; Taj and Rajkumar, 2016).

When heavy metals attached to the extracellular cell material, they can immobilize metals and blockage of its intake with the help of bacterium cells. On the cell surface, most of metals bind to the functional group that is anionic. By forming the effective barrier around the cell, heavy metals bind to extracellular polymers i-e proteins, polysaccharide etc. which helps to detoxify them. Siderophores minimize the bioavailability of metal here performs the toxicity reducing. Specific production metabolites result in precipitation of heavy metals (Ahemad, 2015; Pajuelo *et al.*, 2011; Sher and Rehman, 2019; Zubair *et al.*, 2016). Different types of bacteria manifest efflux for the transporters with higher level of substrate affinities because of which they can expel toxic metals with high concentrations which expelled outside of the cell. The plasmid encoded energy dependent system which involves chemiosmosis ion pumps. Along with the ATPase that are reported for acceptance of cadmium and chromium (De la Torre *et al.*, 1999; Lakra *et al.*, 2006; Pratap and Bonga, 1993). There is another method for toxicity of heavy metals in which ions may be converted into innocuous form which follow the entry into bacterial cells. This whole mechanism is known as mechanism of cytosolic sequestration. This allows the uptake of heavy metals with high concentration; for instance, metallothionein's synthesis. They have low molecular weight. The metal binding protein that is

cysteine has high metal affinity e.g., copper, cadmium, silver and the mercury (Canli *et al.*, 2001; Tanwir *et al.*, 2015; Tiwari *et al.*, 2009). As an alternative, some of the bacteria utilize methylation method that involves the methyl group which is transferred to the metal and metalloids. There is a limitation that only a few metals can be methylated. There is also a method used for the toxicity of heavy metals is decontamination of soil which involved the heavy metals reduction (Bordajandi *et al.*, 2004; Karadede-Akin and Ünlü, 2007). The species of bacteria responsible for the reduction of heavy metals referred as dissimilator of metal reducing bacterium. Those bacterial strains help in detoxification of chromium which involves the reduction of Cr by the strains of bacteria which plays a significant role in the acquisition of severely heavy metals (Liu *et al.*, 2006; Viti *et al.*, 2003; Wang and Shen, 1995).

#### **Significance of rhizobacteria in phytoremediation**

For improving the growth of plant e.g., wheat, we have to screen PGPR. The study has suggested that the potential for biosynthesis of auxin through rhizobacteria which could be used as a tool for screening the effective PGPR strains (Deshwal and Kumar, 2013; Wani *et al.*, 2009). A new combination of in vitro screening method which include microplate assay with plant i-e strawberry seedling to test the PGP strain which have more efficient potential biological controlling agents which has been developed successfully. To screen the effective PGPR strain ACC deaminase trait could be used as an efficient tool. It could be successfully used as bio-fertilizers which increase the growth of inoculated plants (Mazhar *et al.*, 2020a; Wani *et al.*, 2015). In the soil, the high levels of heavy metals decrease the microbial activity and it affects the production of crop by getting accumulated in plant organs. Metal ions are present in the soil and these are absorbed by the roots which transported to various plant organs. The enzymes and proteins in the cells which have higher affinity of heavy metals they rendered them inactive and also lost their function (Hansda *et al.*, 2014; Liu *et al.*, 2015). When they interact with heavy metals the structure of protein change and affect the plant growth by photo-system inactivation. At the end the free radicals produced oxidative effect that has adverse effect on biochemical and the physiological processes of plants. Reduction in growth and also development happens due to the disturbance in photosynthetic and also respiratory mechanism (Chaudhary and Khan, 2018; Qi *et al.*, 2018; Tirry *et al.*, 2018). The mechanism of PGPB to overcome the metallic stress, bacteria including the PGPB have several resistance mechanisms they can

be immobilize, transform the metals, as well as reducing the toxicity which tolerate the uptake of heavy metal ions. PGP Bacteria help the plants to grow and these bacteria grow in soil or on the roots of plant. Plant will grow by helping the certain nutrients, modulating the hormone levels of plant and also protecting the plant from any type of pathogen (Saharan and Nehra, 2011; Zhu *et al.*, 2015).

The quality of bacteria that respond to heavy metals plays an important role in utilization for bio-remediation of accumulation of toxic metals in plants. In agronomic processes, these bacteria express the unique ability of metal detoxification along with the growth promoting agent's property (Ayangbenro and Babalola, 2017; Zaidi *et al.*, 2009). Researchers had reported many applications of bacteria i.e., *Sphingomonas macrogoldabidus*, micro bacterium *lique-faciens* and the micro bacterium *arabino-galactanolyticum* inoculated to the plants; the *A-murale* which gives significant results by increased of Ni-uptake by plants as compared to the untreated plants. Carrillo-Castaneda reported that the potential of PGP in the protection of alfalfa (*Medicago sativa*) seeds from the accumulated copper due to the absorption by the roots to the shoots in the seedlings of these plants (Silver and Phung, 2005; Vacheron *et al.*, 2013). It has been reported that Hydroxamate siderophores shown that besides the presence of heavy metals which increase the iron uptake by plants. Iron is the essential micro-nutrients for plants and also for microbes. Under anaerobic conditions such as flooded soil, high concentration of  $Fe^{2+}$  ions which are generated through reduction of  $Fe^{3+}$  ions and due to excessive uptake of iron leads to iron toxicity for plant cells. In aerobic conditions solubility of iron is low here limiting the supply of iron for different forms of life (Van Loon, 2007; Watteau and Berthelin, 1990). Bacteria can overcome the limitation of nutritional iron by using the chelatoragents known as siderophores. Through various ways the PGPB play a beneficial role in the growth of plant. For example, from PGPB siderophores prevent some pathogens from sufficient amount of iron hereby limiting the ability to proliferate. Nitrogen fixation is another important role of PGPB in the field of biology. Under the conditions of low soil moisture, the rhizobia are sensitive to drought stress resulting the decrease in nitrogen fixation. These studies gave an insight to the role PGPB, under the heavy metals stress increasing the biomass of plants (Saleem *et al.*, 2007; Salt *et al.*, 1998; Sayyed *et al.*, 2013).

#### **Transformation and the uptake of heavy metals**

The mechanisms which are involved in transformation of metal ions in soil leads to wards the loss of heavy metals (uptake of plant, leaching and the volatilization reactions). The most of the metals do not undergo the volatilization related losses. Actually, the fate of metalloids in soil totally depends upon its properties and its environmental factors (Khan and Bano, 2018; Marschener, 1998; Ross, 1994). The availability and the mobility of metals in soil affected by microbes and they can be done through certain steps, acidification, changes of redox, production of iron chelators and the siderophores, mobilizing the metal phosphates. Actually the heavy metal in soil which are bound to both organic and inorganic substances or these are present as insoluble precipitates that are not available for root uptake, siderophores of bacteria produce (Sayyed *et al.*, 2013) PGPB which have the ability to solubilize the heavy metals having Fe and make them available for roots of plants to take up. These PGPB helps to reduce the metals toxicity by bio-sorption method because of the bacterial cells absorb high amount of heavy metals. The environmental factors that affect the growth of plant include water, light, and the temperature, nutrition and also humidity. Soil hardness affects the growth of roots (Gadd, 2000; Haas and Défago, 2005; Khan and Bano, 2018).

#### **Approach by genetically engineered**

Various genetically engineered approaches have been developed and these are used to optimize the enzymes, organisms that are relevant for biodegradation, and also metabolic pathways. With the molecular method allow the characterization of structure of microbial community and the activities. There are a large number of proteins which bind to different heavy metals with whole range with greater affinity (Saharan and Nehra, 2011; Vessey, 2003; Zaidi *et al.*, 2009). The metal binding proteins are at the outer membranes in plants and microbes where they will interact with metal ions in environment here ensuring the transport of metal ions to cytosol. And by the metal-cochaperones these are transferred to suitable receptor proteins. Plants respond high levels of heavy metals by synthesizing (Abbaszadeh-Dahaji *et al.*, 2016; Ayangbenro and Babalola, 2017). Heavy metals are being accumulated in soil through sewage disposal and the industrial wastes. Among various traditional soil remediation technologies phytoremediation use to clean up the metal contaminated sites has increasing the attention as co-friendly as well as inexpensive. Improvement of metal accretion plants traits like genetic engineering necessary perspectives of certain many biological processes implemented in it by roots from the soil sap

and then transferred to shoots. Metal contaminated soil by phytoremediation can be done by different forms of genetically engineered rhizobacteria (Canli *et al.*, 2001; Dodd *et al.*, 2010; Joshi and Juwarkar, 2009). Phytoremediation is an eco-friendly and the emerging technology that has gained the wide acceptance by, any regulatory authorities. Its use is limited time taken to achieve the clean-up goal (Cuypers *et al.*, 2011; Lahori *et al.*, 2017; Li *et al.*, 2015). Currently it is the area of the active research in plant biology. Number of metal accumulated by plants has been identified as the potential candidates to Phytoremediate the metal polluted soil. Various types of strategies have been applied to generate the plants that are help to grow in environmental conditions and to transfer the number of metals (Dubey, 2010; Halder and Chakrabarty, 1993). The use of genetic engineering helps to modify the plant for enhanced efficacy of phytoremediation strategies. Plants are involved in this process and there are many chances of food chain being distributed.

### Conclusion

When evaluating the rhizobacteria effects in phytoremediation of toxic metals from contaminated soil, the process carried out both by bacteria and plants while to protect plants from heavy metal toxicity. Certain bacteria use special developmental processes for phytoremediation of heavy metals. Scientist are working to access the role of PGPR but still not understanding the concept of phytoremediation. There are of few questions which needs to be answered yet,

1. There is need to investigate the microbes induced changes in rhizosphere of plant related to accumulation of metal, and also the contaminated soil.
2. There is need to quantify the effect of phytoremediation process on phytoavailability of heavy metals.
3. There is need to examine the accumulation and the distribution of toxic metals.
4. The role played by the bacteria from solution of soil in plant and the uptake of cadmium is poorly understood yet.
5. There is need to understand the mobilization and the transfer of metals. Here we develop the strategies and the optimization of phytoextraction process. There is more need to understand the role of soil rhizobacteria for phytoremediation.

### Conflict of interest

The authors declared absence of any conflict of interest.

### References

- Abbaszadeh-Dahaji, P., Omidvari, M., and Ghorbanpour, M. (2016). Increasing phytoremediation efficiency of heavy metal-contaminated soil using PGPR for sustainable agriculture. In "Plant-Microbe Interaction: An Approach to Sustainable Agriculture", pp. 187-204. Springer.
- Ahemad, M. (2015). Phosphate-solubilizing bacteria-assisted phytoremediation of metalliferous soils: a review. *3 Biotech* **5**, 111-121.
- Ahemad, M. (2019). Remediation of metalliferous soils through the heavy metal resistant plant growth promoting bacteria: paradigms and prospects. *Arabian Journal of Chemistry* **12**, 1365-1377.
- Almaroai, Y. A., Usman, A. R., Ahmad, M., Kim, K.-R., Moon, D. H., Lee, S. S., and Ok, Y. S. (2012). Effects of synthetic chelators and low-molecular-weight organic acids on chromium, copper, and arsenic uptake and translocation in maize (*Zea mays* L.). *Soil Science* **177**, 655-663.
- Antoun, H. (2013). Plant-growth-promoting rhizobacteria. *Brenner's Encyclopedia of Genetics, 2nd edition, Volume 5*.
- Antoun, H., and Prévost, D. (2005). Ecology of plant growth promoting rhizobacteria. In "PGPR: Biocontrol and biofertilization", pp. 1-38. Springer.
- Arroyo, M. d. M. D., Cots, M. Á. P., HORNEDO, R. M. D. I., Rodríguez, E. M. B., Beringola, L. B., and Sánchez, J. V. M. (2002). Sewage sludge compost fertilizer effect on maize yield and soil heavy metal concentration. *Revista internacional de contaminación ambiental* **18**, 147-150.
- Ayangbenro, A. S., and Babalola, O. O. (2017). A new strategy for heavy metal polluted environments: a review of microbial biosorbents. *International journal of environmental research and public health* **14**, 94.
- Bååth, E. (1989). Effects of heavy metals in soil on microbial processes and populations (a review). *Water, Air, and Soil Pollution* **47**, 335-379.
- Babarinde, N. A., Babalola, J. O., and Sanni, R. A. (2006). Biosorption of lead ions from aqueous solution by maize leaf. *International Journal of Physical Sciences* **1**, 23-26.
- Barea, J.-M., Pozo, M. J., Azcon, R., and Azcon-Aguilar, C. (2005). Microbial co-operation in the rhizosphere. *Journal of experimental botany* **56**, 1761-1778.

[Citation: Nadeem, N., Asif, R., Ayyub, S., Salman, S., Shafique, F., Ali, Q., and Malik, A. (2020). Role of rhizobacteria in phytoremediation of heavy metals. *Biol. Clin. Sci. Res. J.*, **2020**: 35. doi: <https://doi.org/10.54112/bcsrj.v2020i1.35>]

- Bashan, Y., and De-Bashan, L. E. (2010). How the plant growth-promoting bacterium *Azospirillum* promotes plant growth—a critical assessment. In "Advances in agronomy", Vol. 108, pp. 77-136. Elsevier.
- Begum, N., Hu, Z., Cai, Q., and Lou, L. (2019). Influence of PGPB inoculation on HSP70 and HMA3 gene expression in switchgrass under cadmium stress. *Plants* **8**, 504.
- Bhattacharyya, P. N., and Jha, D. K. (2012). Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. *World Journal of Microbiology and Biotechnology* **28**, 1327-1350.
- Bordajandi, L. R., Gómez, G., Abad, E., Rivera, J., Fernández-Bastón, M. d. M., Blasco, J., and González, M. J. (2004). Survey of persistent organochlorine contaminants (PCBs, PCDD/Fs, and PAHs), heavy metals (Cu, Cd, Zn, Pb, and Hg), and arsenic in food samples from Huelva (Spain): levels and health implications. *Journal of Agricultural and Food Chemistry* **52**, 992-1001.
- Bruins, M. R., Kapil, S., and Oehme, F. W. (2000). Microbial resistance to metals in the environment. *Ecotoxicology and environmental safety* **45**, 198-207.
- Bunow, B. (1978). Chemical reactions and membranes: A macroscopic basis for facilitated transport, chemiosmosis and active Transport part I: Linear analysis. *Journal of theoretical biology* **75**, 51-78.
- Canli, M., Kalay, M., and Ay, Ö. (2001). Metal (Cd, Pb, Cu, Zn, Fe, Cr, Ni) concentrations in tissues of a fish *Sardina pilchardus* and a prawn *Peaenus japonicus* from three stations on the Mediterranean Sea. *Bulletin of environmental contamination and toxicology* **67**, 75-82.
- Cao, Y., Huang, R., Jiang, W., and Cao, Z. (2004). Effect of heavy metal lead and cadmium on grain quality of maize. *Journal of Shenyang Agricultural University* **36**, 218-220.
- Chaudhary, K., and Khan, S. (2018). Role of plant growth promoting bacteria (PGPB) for bioremediation of heavy metals: an overview. In "Biostimulation Remediation Technologies for Groundwater Contaminants", pp. 104-125. IGI Global.
- Chen, C., Belanger, R. R., Benhamou, N., and Paulitz, T. C. (2000). Defense enzymes induced in cucumber roots by treatment with plant growth-promoting rhizobacteria (PGPR) and *Pythium aphanidermatum*. *Physiological and molecular plant pathology* **56**, 13-23.
- Chu, L., and Wong, M. H. (1987). Heavy metal contents of vegetable crops treated with refuse compost and sewage sludge. *Plant and soil* **103**, 191-197.
- Cuypers, A., Karen, S., Jos, R., Kelly, O., Els, K., Tony, R., Nele, H., Nathalie, V., Yves, G., and Jan, C. (2011). The cellular redox state as a modulator in cadmium and copper responses in *Arabidopsis thaliana* seedlings. *Journal of plant physiology* **168**, 309-316.
- Das, P., Samantaray, S., and Rout, G. (1997). Studies on cadmium toxicity in plants: a review. *Environmental pollution* **98**, 29-36.
- De la Torre, F. R., Salibián, A., and Ferrari, L. (1999). Enzyme activities as biomarkers of freshwater pollution: Responses of fish branchial (Na<sup>+</sup> K)-ATPase and liver transaminases. *Environmental Toxicology: An International Journal* **14**, 313-319.
- de Oliveira Mendes, G., de Freitas, A. L. M., Pereira, O. L., da Silva, I. R., Vassilev, N. B., and Costa, M. D. (2014). Mechanisms of phosphate solubilization by fungal isolates when exposed to different P sources. *Annals of Microbiology* **64**, 239-249.
- Deshwal, V. K., and Kumar, P. (2013). Effect of Heavy metals on Growth and PGPR activity of *Pseudomonads*. *Journal of Academia and Industrial Research (JAIR)* **2**, 286.
- 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.
- Dodd, I., Zinovkina, N., Safronova, V., and Belimov, A. (2010). Rhizobacterial mediation of plant hormone status. *Annals of Applied Biology* **157**, 361-379.
- Dubey, R. (2010). Metal toxicity, oxidative stress and antioxidative defense system in plants. *Reactive oxygen species and antioxidants in higher plants* **15**, 177-203.
- El-Meihy, R. M., Abou-Aly, H. E., Youssef, A. M., Tewfike, T. A., and El-Alkshar, E. A. (2019). Efficiency of heavy metals-tolerant plant growth promoting bacteria for alleviating heavy metals toxicity on sorghum. *Environmental and Experimental Botany* **162**, 295-301.

- Etesami, H. (2018). Can interaction between silicon and plant growth promoting rhizobacteria benefit in alleviating abiotic and biotic stresses in crop plants? *Agriculture, Ecosystems & Environment* **253**, 98-112.
- Falkowski, P. G., and Raven, J. A. (2013). "Aquatic photosynthesis," Princeton University Press.
- Felix, H. (1997). Field trials for in situ decontamination of heavy metal polluted soils using crops of metal-accumulating plants. *Zeitschrift für Pflanzenernährung und Bodenkunde* **160**, 525-529.
- Gadd, G. M. (2000). Bioremedial potential of microbial mechanisms of metal mobilization and immobilization. *Current opinion in biotechnology* **11**, 271-279.
- Garrido, S., Del Campo, G. M., Esteller, M., Vaca, R., and Lugo, J. (2005). Heavy metals in soil treated with sewage sludge composting, their effect on yield and uptake of broad bean seeds (*Vicia faba* L.). *Water, Air, and Soil Pollution* **166**, 303-319.
- Gavrilescu, M. (2004). Removal of heavy metals from the environment by biosorption. *Engineering in Life Sciences* **4**, 219-232.
- Giordano, P., Mortvedt, J., and Mays, D. (1975). Effect of municipal wastes on crop yields and uptake of heavy metals. *Journal of Environmental Quality* **4**, 394-399.
- Glick, B. R. (2012). Plant growth-promoting bacteria: mechanisms and applications. *Scientifica* **2012**.
- Glick, B. R., and Stearns, J. C. (2011). Making phytoremediation work better: maximizing a plant's growth potential in the midst of adversity. *International journal of phytoremediation* **13**, 4-16.
- Goldstein, A. H. (1995). Recent progress in understanding the molecular genetics and biochemistry of calcium phosphate solubilization by gram negative bacteria. *Biological Agriculture & Horticulture* **12**, 185-193.
- González-Guerrero, M., Escudero, V., Saéz, Á., and Tejada-Jiménez, M. (2016). Transition metal transport in plants and associated endosymbionts: Arbuscular mycorrhizal fungi and rhizobia. *Frontiers in plant science* **7**, 1088.
- Grytsyuk, N., Arapis, G., Perelyatnikova, L., Ivanova, T., and Vynograd's' Ka, V. (2006). Heavy metals effects on forage crops yields and estimation of elements accumulation in plants as affected by soil. *Science of the Total Environment* **354**, 224-231.
- Guarino, F., Miranda, A., Castiglione, S., and Cicatelli, A. (2020). Arsenic phytovolatilization and epigenetic modifications in *Arundo donax* L. assisted by a PGPR consortium. *Chemosphere* **251**, 126310.
- Haas, D., and Défago, G. (2005). Biological control of soil-borne pathogens by fluorescent pseudomonads. *Nature reviews microbiology* **3**, 307-319.
- Halder, A., and Chakrabarty, P. (1993). Solubilization of inorganic phosphate by *Rhizobium*. *Folia microbiologica* **38**, 325-330.
- Hall, J. á. (2002). Cellular mechanisms for heavy metal detoxification and tolerance. *Journal of experimental botany* **53**, 1-11.
- Hansda, A., Kumar, V., Anshumali, A., and Usmani, Z. (2014). Phytoremediation of heavy metals contaminated soil using plant growth promoting rhizobacteria (PGPR): A current perspective. *Recent Research in Science and Technology*.
- Hasan, S. A., Fariduddin, Q., Ali, B., Hayat, S., and Ahmad, A. (2009). Cadmium: toxicity and tolerance in plants. *J Environ Biol* **30**, 165-174.
- He, Z.-l., and Yang, X.-e. (2007). Role of soil rhizobacteria in phytoremediation of heavy metal contaminated soils. *Journal of Zhejiang University Science B* **8**, 192-207.
- Henning, B., Snyman, H., and Aveling, T. (2001). Plant-soil interactions of sludge-borne heavy metals and the effect on maize (*Zea mays* L.) seedling growth. *Water SA* **27**, 71-78.
- Hontzeas, N., Hontzeas, C. E., and Glick, B. R. (2006). Reaction mechanisms of the bacterial enzyme 1-aminocyclopropane-1-carboxylate deaminase. *Biotechnology advances* **24**, 420-426.
- Hou, W., Chen, X., Song, G., Wang, Q., and Chang, C. C. (2007). Effects of copper and cadmium on heavy metal polluted waterbody restoration by duckweed (*Lemna minor*). *Plant physiology and biochemistry* **45**, 62-69.
- Hughes, M. N., and Poole, R. K. (1989). "Metals and Micro-organisms," Chapman and Hall.
- Hutchinson, T. (1973). Comparative studies of the toxicity of heavy metals to phytoplankton and their synergistic interactions. *Water Quality Research Journal* **8**, 68-90.

[Citation: Nadeem, N., Asif, R., Ayyub, S., Salman, S., Shafique, F., Ali, Q., and Malik, A. (2020). Role of rhizobacteria in phytoremediation of heavy metals. *Biol. Clin. Sci. Res. J.*, **2020**: 35. doi: <https://doi.org/10.54112/bcsrj.v2020i1.35>]

- Iqra, L., Rashid, M. S., Ali, Q., Latif, I., and Malik, A. (2020). Evaluation for Na<sup>+</sup>/K<sup>+</sup> ratio under salt stress condition in wheat. *Life Science Journal* **17**, 43-47.
- Islam, F., Yasmeen, T., Arif, M. S., Riaz, M., Shahzad, S. M., Imran, Q., and Ali, I. (2016). Combined ability of chromium (Cr) tolerant plant growth promoting bacteria (PGPB) and salicylic acid (SA) in attenuation of chromium stress in maize plants. *Plant Physiology and Biochemistry* **108**, 456-467.
- Jansen, E., Michels, M., Van Til, M., and Doelman, P. (1994). Effects of heavy metals in soil on microbial diversity and activity as shown by the sensitivity-resistance index, an ecologically relevant parameter. *Biology and Fertility of soils* **17**, 177-184.
- Jeevanantham, S., Saravanan, A., Hemavathy, R., Kumar, P. S., Yaashikaa, P., and Yuvaraj, D. (2019). Removal of toxic pollutants from water environment by phytoremediation: A survey on application and future prospects. *Environmental Technology & Innovation* **13**, 264-276.
- Jia, Y.-J., Ito, H., Matsui, H., and HONMA, M. (2000). 1-aminocyclopropane-1-carboxylate (ACC) deaminase induced by ACC synthesized and accumulated in *Penicillium citrinum* intracellular spaces. *Bioscience, biotechnology, and biochemistry* **64**, 299-305.
- Joshi, P. M., and Juwarkar, A. A. (2009). In vivo studies to elucidate the role of extracellular polymeric substances from *Azotobacter* in immobilization of heavy metals. *Environmental science & technology* **43**, 5884-5889.
- Karadede-Akin, H., and Ünlü, E. (2007). Heavy metal concentrations in water, sediment, fish and some benthic organisms from Tigris River, Turkey. *Environmental Monitoring and Assessment* **131**, 323-337.
- Khalid, S., Asghar, H. N., Akhtar, M. J., Aslam, A., and Zahir, Z. A. (2015). Biofortification of iron in chickpea by plant growth promoting rhizobacteria. *Pak J Bot* **47**, 1191-1194.
- Khalil, M., Rashid, M., Ali, Q., and Malik, A. (2020). Genetic Evaluation for Effects of Salt and Drought Stress on Growth Traits of *Zea mays* Seedlings. *Genetics and Molecular Research* **19**.
- Khan, A. A., Jilani, G., Akhtar, M. S., Naqvi, S. M. S., and Rasheed, M. (2009). Phosphorus solubilizing bacteria: occurrence, mechanisms and their role in crop production. *J agric biol sci* **1**, 48-58.
- Khan, N., and Bano, A. (2018). Role of PGPR in the phytoremediation of heavy metals and crop growth under municipal wastewater irrigation. In "Phytoremediation", pp. 135-149. Springer.
- Kloepper, J. W., Leong, J., Teintze, M., and Schroth, M. N. (1980). Enhanced plant growth by siderophores produced by plant growth-promoting rhizobacteria. *Nature* **286**, 885-886.
- Kong, Z., and Glick, B. R. (2017). The role of plant growth-promoting bacteria in metal phytoremediation. In "Advances in microbial physiology", Vol. 71, pp. 97-132. Elsevier.
- Krantev, A., Yordanova, R., Janda, T., Szalai, G., and Popova, L. (2008). Treatment with salicylic acid decreases the effect of cadmium on photosynthesis in maize plants. *Journal of plant physiology* **165**, 920-931.
- Lahori, A. H., Zhang, Z., Guo, Z., Mahar, A., Li, R., Awasthi, M. K., Sial, T. A., Kumbhar, F., Wang, P., and Shen, F. (2017). Potential use of lime combined with additives on (im) mobilization and phytoavailability of heavy metals from Pb/Zn smelter contaminated soils. *Ecotoxicology and environmental safety* **145**, 313-323.
- Lakra, N., Mishra, S., Singh, D., and Tomar, P. C. (2006). Exogenous putrescine effect on cation concentration in leaf of *Brassica juncea* seedlings subjected to Cd and Pb along with salinity stress. *Journal of Environmental Biology* **27**, 263-269.
- Lane, N., Allen, J. F., and Martin, W. (2010). How did LUCA make a living? Chemiosmosis in the origin of life. *BioEssays* **32**, 271-280.
- LeDuc, D. L., and Terry, N. (2005). Phytoremediation of toxic trace elements in soil and water. *Journal of Industrial Microbiology and Biotechnology* **32**, 514-520.
- Li, C., Zhou, K., Qin, W., Tian, C., Qi, M., Yan, X., and Han, W. (2019). A review on heavy metals contamination in soil: effects, sources, and remediation techniques. *Soil and Sediment Contamination: An International Journal* **28**, 380-394.
- Li, J.-F., He, X.-H., Li, H., Zheng, W.-J., Liu, J.-F., and Wang, M.-Y. (2015). Arbuscular mycorrhizal fungi increase growth and phenolics synthesis in *Poncirus trifoliata* under iron deficiency. *Scientia horticulturae* **183**, 87-92.
- Liu, Y.-G., Xu, W.-H., Zeng, G.-M., Li, X., and Gao, H. (2006). Cr (VI) reduction by *Bacillus* sp.

[Citation: Nadeem, N., Asif, R., Ayyub, S., Salman, S., Shafique, F., Ali, Q., and Malik, A. (2020). Role of rhizobacteria in phytoremediation of heavy metals. *Biol. Clin. Sci. Res. J.*, **2020**: 35. doi: <https://doi.org/10.54112/bcsrj.v2020i1.35>]

- isolated from chromium landfill. *Process Biochemistry* **41**, 1981-1986.
- Liu, Z.-f., Ge, H.-g., Li, C., Zhao, Z.-p., Song, F.-m., and Hu, S.-b. (2015). Enhanced phytoextraction of heavy metals from contaminated soil by plant co-cropping associated with PGPR. *Water, Air, & Soil Pollution* **226**, 29.
- Lugtenberg, B., and Kamilova, F. (2009). Plant-growth-promoting rhizobacteria. *Annual review of microbiology* **63**, 541-556.
- Ma, W., Sebastianova, S. B., Sebastian, J., Burd, G. I., Guinel, F. C., and Glick, B. R. (2003). Prevalence of 1-aminocyclopropane-1-carboxylate deaminase in *Rhizobium* spp. *Antonie Van Leeuwenhoek* **83**, 285-291.
- Ma, Y., Prasad, M., Rajkumar, M., and Freitas, H. (2011). Plant growth promoting rhizobacteria and endophytes accelerate phytoremediation of metalliferous soils. *Biotechnology advances* **29**, 248-258.
- Madhaiyan, M., Poonguzhali, S., and Sa, T. (2007). Characterization of 1-aminocyclopropane-1-carboxylate (ACC) deaminase containing *Methylobacterium oryzae* and interactions with auxins and ACC regulation of ethylene in canola (*Brassica campestris*). *Planta* **226**, 867-876.
- Marschener, H. (1998). Role of root growth, arbuscular mycorrhiza, and root exudates for the efficiency in nutrient acquisition. *Field Crops Research* **56**, 203-207.
- Marsh Jr, H., Evans, H., and Matrone, G. (1963). Investigations of the role of iron in chlorophyll metabolism I. Effect of iron deficiency on chlorophyll and heme content and on the activities of certain enzymes in leaves. *Plant physiology* **38**, 632.
- Martelli, A., Rousselet, E., Dycke, C., Bouron, A., and Moulis, J.-M. (2006). Cadmium toxicity in animal cells by interference with essential metals. *Biochimie* **88**, 1807-1814.
- Mazhar, R., Ilyas, N., Arshad, M., Khalid, A., and Hussain, M. (2020a). Isolation of Heavy Metal-Tolerant PGPR Strains and Amelioration of Chromium Effect in Wheat in Combination with Biochar. *Iranian Journal of Science and Technology, Transactions A: Science* **44**, 1-12.
- Mazhar, T., Ali, Q., and Malik, M. (2020b). Effects of salt and drought stress on growth traits of *Zea mays* seedlings. *Life Science Journal* **17**.
- McIntyre, T. (2003). Phytoremediation of heavy metals from soils. In "Phytoremediation", pp. 97-123. Springer.
- Memon, A. R., Aktoprakligil, D., Özdemir, A., and Vertii, A. (2001). Heavy metal accumulation and detoxification mechanisms in plants. *Turkish Journal of Botany* **25**, 111-121.
- Mench, M., Schwitzguébel, J.-P., Schroeder, P., Bert, V., Gawronski, S., and Gupta, S. (2009). Assessment of successful experiments and limitations of phytotechnologies: contaminant uptake, detoxification and sequestration, and consequences for food safety. *Environmental Science and Pollution Research* **16**, 876.
- Mushtaq, Z., Asghar, H. N., and Zahir, Z. A. (2020). Comparative growth analysis of okra (*Abelmoschus esculentus*) in the presence of PGPR and press mud in chromium contaminated soil. *Chemosphere* **262**, 127865.
- Nadeem, S. M., Ahmad, M., Zahir, Z. A., Javaid, A., and Ashraf, M. (2014). The role of mycorrhizae and plant growth promoting rhizobacteria (PGPR) in improving crop productivity under stressful environments. *Biotechnology advances* **32**, 429-448.
- Nagajyoti, P. C., Lee, K. D., and Sreekanth, T. (2010). Heavy metals, occurrence and toxicity for plants: a review. *Environmental chemistry letters* **8**, 199-216.
- Nascimento, F. X., Rossi, M. J., Soares, C. R., McConkey, B. J., and Glick, B. R. (2014). New insights into 1-aminocyclopropane-1-carboxylate (ACC) deaminase phylogeny, evolution and ecological significance. *PLoS One* **9**, e99168.
- Nie, L., Shah, S., Rashid, A., Burd, G. I., Dixon, D. G., and Glick, B. R. (2002). Phytoremediation of arsenate contaminated soil by transgenic canola and the plant growth-promoting bacterium *Enterobacter cloacae* CAL2. *Plant Physiology and Biochemistry* **40**, 355-361.
- Nouri, J., Khorasani, N., Lorestani, B., Karami, M., Hassani, A., and Yousefi, N. (2009). Accumulation of heavy metals in soil and uptake by plant species with phytoremediation potential. *Environmental Earth Sciences* **59**, 315-323.
- Ojuederie, O. B., and Babalola, O. O. (2017). Microbial and plant-assisted bioremediation of heavy metal polluted environments: a review. *International journal of environmental research and public health* **14**, 1504.
- Pajuelo, E., Rodríguez-Llorente, I. D., Lafuente, A., and Caviedes, M. Á. (2011). Legume-

[Citation: Nadeem, N., Asif, R., Ayyub, S., Salman, S., Shafique, F., Ali, Q., and Malik, A. (2020). Role of rhizobacteria in phytoremediation of heavy metals. *Biol. Clin. Sci. Res. J.*, **2020**: 35. doi: <https://doi.org/10.54112/bcsrj.v2020i1.35>]

- rhizobium symbioses as a tool for bioremediation of heavy metal polluted soils. In "Biomangement of metal-contaminated soils", pp. 95-123. Springer.
- Pamukcu, S., and Kenneth Wittle, J. (1992). Electrokinetic removal of selected heavy metals from soil. *Environmental Progress* **11**, 241-250.
- Persello-Cartieaux, F., Nussaume, L., and Robaglia, C. (2003). Tales from the underground: molecular plant–rhizobacteria interactions. *Plant, Cell & Environment* **26**, 189-199.
- Pilon-Smits, E. (2005). Phytoremediation. *Annu. Rev. Plant Biol.* **56**, 15-39.
- Prasad, A., Kumar, S., Khaliq, A., and Pandey, A. (2011). Heavy metals and arbuscular mycorrhizal (AM) fungi can alter the yield and chemical composition of volatile oil of sweet basil (*Ocimum basilicum* L.). *Biology and Fertility of Soils* **47**, 853.
- Pratap, H., and Bonga, S. W. (1993). Effect of ambient and dietary cadmium on pavement cells, chloride cells, and Na<sup>+</sup>/K<sup>+</sup>-ATPase activity in the gills of the freshwater teleost *Oreochromis mossambicus* at normal and high calcium levels in the ambient water. *Aquatic Toxicology* **26**, 133-149.
- Qi, G., Pan, Z., Sugawa, Y., Andriamanohiarisoamanana, F. J., Yamashiro, T., Iwasaki, M., Kawamoto, K., Ihara, I., and Umetsu, K. (2018). Comparative fertilizer properties of digestates from mesophilic and thermophilic anaerobic digestion of dairy manure: focusing on plant growth promoting bacteria (PGPB) and environmental risk. *Journal of Material Cycles and Waste Management* **20**, 1448-1457.
- Raffi, M., Mehrwan, S., Bhatti, T. M., Akhter, J. I., Hameed, A., Yawar, W., and ul Hasan, M. M. (2010). Investigations into the antibacterial behavior of copper nanoparticles against *Escherichia coli*. *Annals of microbiology* **60**, 75-80.
- Rahmaty, R., and Khara, J. (2011). Effects of vesicular arbuscular mycorrhiza *Glomus intraradices* on photosynthetic pigments, antioxidant enzymes, lipid peroxidation, and chromium accumulation in maize plants treated with chromium. *Turkish Journal of Biology* **35**, 51-58.
- Rajkumar, M., and Freitas, H. (2008). Influence of metal resistant-plant growth-promoting bacteria on the growth of *Ricinus communis* in soil contaminated with heavy metals. *Chemosphere* **71**, 834-842.
- Reichman, S. (2002). "The Responses of Plants to Metal Toxicity: A Review Forusing on Copper, Manganese & Zinc," Australian Minerals & Energy Environment Foundation Melbourne.
- Requena, N., Jimenez, I., Toro, M., and Barea, J. (1997). Interactions between plant-growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi and *Rhizobium* spp. in the rhizosphere of *Anthyllis cytisoides*, a model legume for revegetation in mediterranean semi-arid ecosystems. *New Phytologist* **136**, 667-677.
- Requena, N., Perez-Solis, E., Azcón-Aguilar, C., Jeffries, P., and Barea, J.-M. (2001). Management of indigenous plant-microbe symbioses aids restoration of desertified ecosystems. *Applied and environmental microbiology* **67**, 495-498.
- Ross, S. M. (1994). "Toxic metals in soil-plant systems," Wiley Chichester.
- Saharan, B., and Nehra, V. (2011). Plant growth promoting rhizobacteria: a critical review. *Life Sci Med Res* **21**, 30.
- Saleem, M., Arshad, M., Hussain, S., and Bhatti, A. S. (2007). Perspective of plant growth promoting rhizobacteria (PGPR) containing ACC deaminase in stress agriculture. *Journal of industrial microbiology & biotechnology* **34**, 635-648.
- Salt, D. E., Smith, R., and Raskin, I. (1998). Phytoremediation. *Annual review of plant biology* **49**, 643-668.
- Sayyed, R., Chincholkar, S., Reddy, M., Gangurde, N., and Patel, P. (2013). Siderophore producing PGPR for crop nutrition and phytopathogen suppression. In "Bacteria in Agrobiolgy: Disease Management", pp. 449-471. Springer.
- Schippers, B., Bakker, A. W., and Bakker, P. A. (1987). Interactions of deleterious and beneficial rhizosphere microorganisms and the effect of cropping practices. *Annual review of Phytopathology* **25**, 339-358.
- Schmidt, U. (2003). Enhancing phytoextraction: the effect of chemical soil manipulation on mobility, plant accumulation, and leaching of heavy metals. *Journal of Environmental Quality* **32**, 1939-1954.
- Schröder, P., Daubner, D., Maier, H., Neustifter, J., and Debus, R. (2008). Phytoremediation of organic xenobiotics–Glutathione dependent

[Citation: Nadeem, N., Asif, R., Ayyub, S., Salman, S., Shafique, F., Ali, Q., and Malik, A. (2020). Role of rhizobacteria in phytoremediation of heavy metals. *Biol. Clin. Sci. Res. J.*, **2020**: 35. doi: <https://doi.org/10.54112/bcsrj.v2020i1.35>]

- detoxyfication in Phragmites plants from European treatment sites. *Bioresource technology* **99**, 7183-7191.
- Schroth, M. N., and Hancock, J. G. (1982). Disease-suppressive soil and root-colonizing bacteria. *Science* **216**, 1376-1381.
- Seregin, I., Shpigun, L., and Ivanov, V. (2004). Distribution and toxic effects of cadmium and lead on maize roots. *Russian Journal of Plant Physiology* **51**, 525-533.
- Sgroy, V., Cassán, F., Masciarelli, O., Del Papa, M. F., Lagares, A., and Luna, V. (2009). Isolation and characterization of endophytic plant growth-promoting (PGPB) or stress homeostasis-regulating (PSHB) bacteria associated to the halophyte *Prosopis strombulifera*. *Applied microbiology and Biotechnology* **85**, 371-381.
- Sharma, D., Sharma, C., and Tripathi, R. (2003). Phytotoxic lesions of chromium in maize. *Chemosphere* **51**, 63-68.
- Sher, S., and Rehman, A. (2019). Use of heavy metals resistant bacteria—a strategy for arsenic bioremediation. *Applied microbiology and biotechnology* **103**, 6007-6021.
- Silver, S., and Phung, L. T. (2005). A bacterial view of the periodic table: genes and proteins for toxic inorganic ions. *Journal of Industrial Microbiology and Biotechnology* **32**, 587-605.
- Singh, O., Labana, S., Pandey, G., Budhiraja, R., and Jain, R. (2003). Phytoremediation: an overview of metallic ion decontamination from soil. *Applied microbiology and biotechnology* **61**, 405-412.
- Singh, S. K., Singh, P. P., Gupta, A., Singh, A. K., and Keshri, J. (2019). Tolerance of heavy metal toxicity using PGPR strains of *Pseudomonas* species. In "PGPR Amelioration in Sustainable Agriculture", pp. 239-252. Elsevier.
- Tahir, M., Rashid, M., Ali, Q., and Malik, A. (2020). Evaluation of Genetic Variability in Wheat and Maize under Heavy Metal and Drought Stress. *Genetics and Molecular Research* **19**.
- Taj, Z. Z., and Rajkumar, M. (2016). Perspectives of plant growth-promoting actinomycetes in heavy metal phytoremediation. In "Plant Growth Promoting Actinobacteria", pp. 213-231. Springer.
- 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 Volume 223", pp. 33-52. Springer.
- Tank, N., and Saraf, M. (2009). Enhancement of plant growth and decontamination of nickel-spiked soil using PGPR. *Journal of Basic Microbiology* **49**, 195-204.
- Tanwir, K., Akram, M. S., Masood, S., Chaudhary, H. J., Lindberg, S., and Javed, M. T. (2015). Cadmium-induced rhizospheric pH dynamics modulated nutrient acquisition and physiological attributes of maize (*Zea mays* L.). *Environmental Science and Pollution Research* **22**, 9193-9203.
- Thomas, W. H., Hollibaugh, J. T., and Seibert, D. L. (1980). Effects of heavy metals on the morphology of some marine phytoplankton. *Phycologia* **19**, 202-209.
- Tirry, N., Joutey, N. T., Sayel, H., Kouchou, A., Bahafid, W., Asri, M., and El Ghachtouli, N. (2018). Screening of plant growth promoting traits in heavy metals resistant bacteria: prospects in phytoremediation. *Journal of genetic engineering and biotechnology* **16**, 613-619.
- Tiwari, K., Dwivedi, S., Singh, N., Rai, U., and Tripathi, R. (2009). Chromium (VI) induced phytotoxicity and oxidative stress in pea (*Pisum sativum* L.): biochemical changes and translocation of essential nutrients. *J Environ Biol* **30**, 389-394.
- Ullah, A., Heng, S., Munis, M. F. H., Fahad, S., and Yang, X. (2015). Phytoremediation of heavy metals assisted by plant growth promoting (PGP) bacteria: a review. *Environmental and Experimental Botany* **117**, 28-40.
- Unz, R. F., and Shuttleworth, K. L. (1996). Microbial mobilization and immobilization of heavy metals. *Current Opinion in Biotechnology* **7**, 307-310.
- Vacheron, J., Desbrosses, G., Bouffaud, M.-L., Touraine, B., Moëgne-Loccoz, Y., Muller, D., Legendre, L., Wisniewski-Dyé, F., and Prigent-Combaret, C. (2013). Plant growth-promoting rhizobacteria and root system functioning. *Frontiers in plant science* **4**, 356.
- Van Loon, L. (2007). Plant responses to plant growth-promoting rhizobacteria. In "New perspectives and approaches in plant growth-promoting Rhizobacteria research", pp. 243-254. Springer.
- Van Loon, L., Bakker, P., and Pieterse, C. (1998). Systemic resistance induced by rhizosphere bacteria. *Annual review of phytopathology* **36**, 453-483.

[Citation: Nadeem, N., Asif, R., Ayyub, S., Salman, S., Shafique, F., Ali, Q., and Malik, A. (2020). Role of rhizobacteria in phytoremediation of heavy metals. *Biol. Clin. Sci. Res. J.*, **2020**: 35. doi: <https://doi.org/10.54112/bcsrj.v2020i1.35>]

- Vessey, J. K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and soil* **255**, 571-586.
- Viti, C., Pace, A., and Giovannetti, L. (2003). Characterization of Cr (VI)-resistant bacteria isolated from chromium-contaminated soil by tannery activity. *Current Microbiology* **46**, 0001-0005.
- Wang, Y.-T., and Shen, H. (1995). Bacterial reduction of hexavalent chromium. *Journal of industrial microbiology* **14**, 159-163.
- Wani, P. A., Zaidi, A., and Khan, M. S. (2009). Chromium reducing and plant growth promoting potential of Mesorhizobium species under chromium stress. *Bioremediation journal* **13**, 121-129.
- Wani, P. A., Zainab, I. O., Wasiiu, I. A., and Jamiu, K. O. (2015). Chromium (VI) reduction by Streptococcus species isolated from the industrial area of Abeokuta, Ogun State, Nigeria. *Research Journal of Microbiology* **10**, 66.
- Watteau, F., and Berthelin, J. (1990). Iron solubilization by mycorrhizal fungi producing siderophores. *Symbiosis*.
- 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 Ecology* **2011**.
- Xie, X., and Tang, M. (2019). Interactions between Phosphorus, Zinc and Iron Homeostasis in Non-mycorrhizal and Mycorrhizal Plants. *Frontiers in plant science* **10**, 1172.
- Zahran, H. H. (1999). Rhizobium-legume symbiosis and nitrogen fixation under severe conditions and in an arid climate. *Microbiology and molecular biology reviews* **63**, 968-989.
- Zaidi, A., Khan, M., Ahemad, M., and Oves, M. (2009). Plant growth promotion by phosphate solubilizing bacteria. *Acta microbiologica et immunologica Hungarica* **56**, 263-284.
- Zhao, F.-J., and McGrath, S. P. (2009). Biofortification and phytoremediation. *Current opinion in plant biology* **12**, 373-380.
- Zhu, D., Ouyang, L., Xu, Z., and Zhang, L. (2015). Rhizobacteria of Populus euphratica promoting plant growth against heavy metals. *International journal of phytoremediation* **17**, 973-980.
- Zubair, M., Shakir, M., Ali, Q., Rani, N., Fatima, N., Farooq, S., Shafiq, S., Kanwal, N., Ali, F., and Nasir, I. A. (2016). Rhizobacteria and phytoremediation of heavy metals.

*Environmental Technology Reviews* **5**, 112-119.



**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2021