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Review Article

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The potential of PGPR in bioremediation of soils with heavy metal contamination

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ABSTRACT
Utilising genetically engineered PGPRs to remediate highly contaminated soil could help to reduce food and fibre production's negative environmental impact. Since the discovery of rhizobia, commercially produced rhizobia inoculants have been available and the usage of PGPR has increased significantly in India recently as a result of improved knowledge about farming techniques. Many substances that are considered hazardous by regulations can be converted into non-hazardous products. The completion of bioremediation can be impacted by a few factors in which abiotic and biotic factors are both included. The most hazardous and chronic contaminants in the soil include heavy metals, metalloids and radionuclides. PGPR was discovered to be effective in combination with certain contaminant-degrading bacteria and another prominent technique for microbially assisted soil remediation is biological reduction. By transferring heavy metal (loids) resistant bacteria to other microbial species, the efficacy of biomedicine can be improved. The development of biofilm helps to detoxify the heavy metals, which is done by enhancement of ability of tolerance of the microbes.
Keywords: PGPR, Heavy metal contamination, Bioremediation, Toxins.

INTRODUCTION
In biogeochemical cycles, soil microorganisms play a key role and hence, have long been exploited in crop production (Rifat et al, 2010). They help crops flourish by providing nutrients, promoting plant growth, controlling or inhibiting plant diseases, and improving soil structure (Burd et al, 2000; Xuliang et al, 2007). *Pseudomonas, Bacillus, Azospirillum, Agrobacterium, Azotobacter, Arthrobacter, Rhizobium,* and *Enterobacter* are some of the PGPR genera that enhance plant growth by direct mechanisms, which include nutrient solubilization, nitrogen fixation, and growth regulatory activity, as well as by indirect mechanisms which include the development of mycorrhizae, selective pathogen exclusion and phytotoxic chemicals' elimination (Usha Bishnoi, 2015; Bashan and de – Bashan, 2010). PGPRs have proved to be an excellent source of biofertilizers as they facilitate volatile organic chemicals, activate bioactivity, and induce systemic disease resistance and water stress resistance. Besides this, PGPR can also be used as biopesticides and bioremediation as well. Rhizobia inoculants have been commercially produced since the discovery of rhizobia in 1886 and due to improved knowledge about farming techniques, the use of PGPR has expanded significantly in India recently (Usha Bishnoi, 2015; Bhattacharyya and Jha, 2011). PGPR can facilitate a variety of positive interactions in plants, resulting in promising agricultural solutions that are both sustainable and environmentally friendly. The use of such GMPs to fix highly contaminated soil could contribute towards minimizing the negative impact of food and fiber production on the environment (Denton, 2007).

Bioremediation can be characterized as the utilization of microbes' metabolism to remove contaminants. Microorganisms must target contaminants enzymatically and convert them to harmless compounds and for that, bacteria and fungi are the most common biological agents, which exploit pollutants as a source of nutrition or energy (Shilpi, 2012; E. Morillo and J. Villaverde, 2017). Biosparging, Bioventing, and Bioaugmentation are examples of in situ bioremediation processes. It is more cost-effective than incineration for renewing activated sludge bioreactors in municipal wastewater treatment. The ex-situ type of bioremediation involves soil-based agriculture, composting process, piling, using bio-reactors, precipitation, membrane filtration, and electrolyzing. The contaminated soil and water fetched from polluted sites are treated with the ex-situ type of treatment by bioreactors (slurry or aqueous) (Shilpi, 2012; Niti and Rakesh, 2013). Bioremediation can be affected by many elements and these elements are either abiotic or biotic factors, for example, pH, temperature, soil humidity, redox potential, and soil type. Many legally defined harmful substances can be turned into harmless goods and the usage of toxic substances can be regulated in one effective way (A. S. Purnomo et al, 2011).

The most toxic and long-lasting contaminants of the soil include heavy metals, metalloids, and radionuclides. Even minimum heavy metal existence can cause significant losses of the diversity of bacteria or microbes. While the usage of plants alone for bioremediation has several drawbacks, the efficiency of these metal-accumulating plants is multiplied when they are enhanced by metal-resistant growth-promoting bacteria. It was discovered that combining PGPR with certain contaminant-degrading bacteria proved to be efficient and *Pseudomonas*, *Acinetobacter*, *Achromobacter*, and *Flavobacterium* are these PGPR that improves plant yield and biomass while also improving soil quality (Eloísa et al, 2011; Sanjeev et al, 2013). Few particular rhizobathe criteria can promote the growth of plants by various methods which include the production of siderophores, IAA, and heavy metal contaminants' antibiotics (Xuliang et al, 2013).

PGPR reduces the heavy metal toxicity issues by eliminating the particular toxicity of plant metal and enhancing the growth and nourishment of the plant. Numerous detoxifying and resistance mechanisms are used to enrich microorganisms from the detrimental effects of heavy metals. A further significant strategy for microbial soil remediation is biological reduction. Such soils like rice paddies have less amount of oxygen, or the reduction conditions that have been artificially produced, for example, the process of reducing such soils can be achieved by adding the electron donor and thus stimulating microbes' development (Mishra et al, 2017; Sandeep et al, 2019; Deyi et al, 2020). While in biosorption, the rhizospheric region of plants has such microbial populations which can secret extracellular polymeric substances like polysaccharides, lipopolysaccharide, proteins, etc. In response to hazardous heavy metal exposure, EPS secreted by certain bacteria induces biofilm development and this Biofilm development helps detoxify heavy metals with increased microbial cell tolerance (Sandeep et al, 2019; Gupta et al, 2016). There are 2 methods by which bioremediation with engineered microorganisms can be done and these methods are defined as bio-stimulation and bio-augmentation. Genetic-engineering strategies can be employed to develop heavy metal (loid) resistance by microbial systems, for example, many successful biofertilizers are generated from microorganisms that enhance plant development, are applied sustainably in agriculture. The transfer of genes to other microbial species from heavy metal (loids)-resistant microorganisms can enhance the efficiency of bioremediation (Deyi et al, 2020; Diep et al, 2018; Valls et al, 2002).

Functions and mechanism

Utilization of any bacterial or any microbial cell to enhance plant development and growth has been employed from decades ago because the soil bacteria used for the purpose of crop production, are very significant in biogeochemical cycles. Plant-bacterial rhizosphere interactions are determinants of soil and plant conditions (Rifat et al, 2010). A study of colonization of the root of rhizosphere suggested that soil bacteria are capable of transformation into plant-useful compounds from atmospheric nitrogen, and establishment of legumes on farmland and soil fertility improvement (Usha Bishnoi, 2015). These Soil bacteria, which are helpful for plant growth, are generally called rhizobacteria (PGPR). They nourish the crops, promote and regulate plant growth, inhibit the pathogenic microorganisms and enhance soil profile and, they can also be used to mineralize organic pollutants in the soil (Middledrop et al, 1990; Burd et al, 2000; Xuliang et al, 2007; Zaidi et al, 2006). Various symbiotic as well as non-symbiotic species of bacteria are now being used to enrich the productivity and progression of the plants. (Rifat et al, 2010). The plant growth-promoting rhizobacteria or PGPR are characterised as the essential component of population of the rhizosphere which can increase host development when cultivated in combination with the host plants. Most plant-associated rhizobacteria are commensals, where bacteria interact with host plants without any prominent effect on the general physiology and growth of host (Bhattacharya and Jha, 2011). The phytopathogenic rhizobacteria, in the negative interactions, secrete some toxic materials like hydrogen cyanide or ethylene, to negatively influence plant growth and physiology. Contrary to these harmful bacteria, certain PGPRs may have positive plant growth via direct mechanisms such as nutrient solubilization, nitrogen fixation, growth regulators production, etc., as well as indirect mechanisms such as stimulation of mycorrhizal growth and phytotoxic substance elimination (Bashan and de-Bashan, 2010).

Pseudomonas, *Bacillus*, *Azospirillum*, *Agrobacterium*, *Azotobacter*, *Arthrobacter*, *Rhizobium*, *Enterobacter*, *Klebsiella*, *Clostridium*, *Xanthomonas*, and *Phyllobacterium* are included in the genera of PGPR and the most widely identified PGPR are *Pseudomonas* and *Bacillus*. The role of these species in plant function and regulation is a major one, as they influence in plants' condition as well as development, either through direct or indirect methods. Direct methods include nitrogen fixation, production and/or modification of plant hormones' concentrations i.e., auxins, cytokinins, gibberellins (GA) or ethylene, solubilization of minerals, synthesis of siderophores and enzymes, and resistance induction. (Usha Bishnoi, 2015). Few experimental pieces of evidence suggest that stimulation of plant's development and progression can be the result of multiple simultaneous mechanisms, PGPR thus is divided into 2 categories: extracellular plant growth-promoting rhizobacteria (PGPR) and intracellular plant growth-promoting rhizobacteria (iPGPR) (Martinez et al, 2010). The ePGPR either exists in the rhizosphere, on the rhizoplane, or in the spaces between the cells of the root cortex, whereas iPGPR generally exists inside the specialized modular structures of root cells. The bacterial genera such as *Agrobacterium*, *Arthrobacter*, *Azotobacter*, *Azospirillum*, *Bacillus*, *Caulobacter*, *Chromobacterium*, *Flavobacterium*, and *Pseudomonas* belong to ePGPR and the iPGPR includes the endophytes (*Allorhizobium*, *Azorhizobium*, *Mesorhizobium*, and *Rhizobium* of the family *Rhizobiaceae*) and *Frankia* species. Both of these species can symbiotically fix atmospheric nitrogen with the plants (Usha Bishnoi, 2015).

PGPR has several significant applications, starting with – PGPR as biofertilizers; As bio-fertilizers, PGPR has proven to be an excellent source. PGPR supports the growth of plants by increasing nutrient access or use in the soil/rhizosphere of a confined nutrient pool (Usha Bishnoi, 2015). This includes nitrogen fixation, phosphorus solubilization, iron absorption, phytostimulation of IAA, Gibberellin, and Cytokinin, and regulation of plant ethylene levels and they also help produce volatile organic compounds, bio elicitation, and resistance to water stress (Bhattacharya and Jha, 2011). Besides this, PGPR can also be used as biopesticides and bioremediation as well. In this article, the role of PGPR as a potential tool for bioremediation is further discussed in detail.

Rhizobia were discovered in 1886 and since the discovery, its inoculants are being utilized for commercial production worldwide. Later in the 1950s, a few research experiments from the different countries predicted that microbes have the potential of being utilized and explored for different plant disease prevention and control, and that led to new opportunities to use PGPR as an alternative to chemical pesticides and to manage the soil microbiota (Usha Bishnoi, 2015). *B. subtilis* was first commercialized in 1985 and the strains were employed to regulate the soil microbiota (Broadbent et al, 1977). The PGPR use in India has recently increased exponentially because of increased awareness of farming techniques.

PGPR inoculants can fulfill a variety of advantageous associations in plants that can result in promising and sustainable agricultural solutions. To reduce possible adverse environmental consequences linked with food and fiber production, a greater understanding of how PGPRs support plant development will lead to expanding exploitation of these biofertilizers (Denton, 2007). A new field of research on Potential mechanisms for rhizosphere colonization will be encouraged by recent developments in molecular biology, as well as in biotechnology. Technologies such as innovative corporate regulation, marketing of products, expanding the education, knowledge, and experiments will be some of the factors on which, the potential and success of the industries manufacturing microbial inoculants, in particular, plant growth-promoting rhizobacterial species shall mostly be depended on. Further optimization of beneficial PGPR strains to be brought into agriculture is necessary for better fermenting and manufacturing procedures (Bhattachraya and Jha, 2011).

Bioremediation: Introduction and different strategies:

Microorganisms' metabolism for the elimination of contaminants is called bioremediation, and it can be done independently (natural suppressed or intrinsic bioremediation) or stimulated to enhance bioavailability through the addition of fertilizers. Microorganisms are further divided into in situ or ex situ categories. In situ method is done at the site of contamination and ex-situ is done on contamination removed from the original site. This method by which bioremediation is done means that organic waste is organically reduced into a controlled state or below the concentration limits imposed by regulatory bodies under controlled conditions. Microorganisms must enzymatically attack and transform the contaminants into harmless compounds to be efficient in bioremediation (Shilpi, 2012). Typically, Bioremediation is better and cheaper than conventional approaches as it reduces clean-up exposure or may be increased exposure to transportation mishaps. Although most of the systems operate under aerobic conditions a system can otherwise permit resistant molecules to be degraded under anaerobic conditions (Colberg and Young, 1995). The primary biological agents used in the process are bacteria and fungi as they utilize pollutants like nutrients and/ or energy sources. Some of the other most important bioremediation aspects are microbial diversity of the site, types of contaminants and some other features of soil i.e. pH, humidity, temperature, etc (E. Morillo and J. Villaverde, 2017). The techniques for bioremediation depend upon three major principles: (1) the effectiveness of the bio-processing pollutants, (2) Pollutants' access to microorganisms, and (3) the possibility for biological activity optimization (Niti and Rakesh, 2013).

The in situ types of bioremediating procedures include Biosparging, Bioventing, and Bioaugmentation. In sparging, air under pressure below water level is injected to raise the concentration of groundwater O_2 and enhance the biodegrading ability of natural bacterial contaminants. Biosparging enhances saturated zonal homogenization and soil-floor connection. Bioventing includes biodegradation of any substances within the soil that are aerobically degradable by oxygen for existing soil microorganisms within the Non-aqueous phase liquids, which only provides enough oxygen to enable microbial activity at low airflow rates. In bio-augmentation, a few natural or genetically modified microbes are introduced to treat contaminated soil or water and are usually employed in municipal wastewater treatment (Shilpi, 2012).

The ex-situ type of bioremediation involves techniques like Land farming, Composting, Biopiles, Bioreactors, Electrodialysis, and Microfiltration. In the farming process, excavated soil is filled with sieves mechanically and the contaminated soil is then layered over pure soil and natural mechanisms are enabled to detoxify and immobilize pollutants. The polluted layer of soil is covered and oxygen is added, while the restoration process can also be supplemented with nutrients and moisture. In the composting process, organic waste, often at high temperatures, is decomposed by micro-organisms. The heat production increases temperatures throughout the degradation process and leads to increased absorption of pollutants and accelerated metabolism in compost (Niti and Rakesh, 2013). Biopile remediation is a complete method that combines excavated soils and soil alterations by treating and also bioremediate them with pumped aeration. Bioreactors can be employed for ex-situ treatment of such polluted land and water. Bioremediation in reactors requires the process by the designed containment system of contaminated materials (soil, sediment, and sludge) or water. Electrodialysis is a method that requires the exchange of cation and anion for the removal of dissolved solids efficiently (Shilpi, 2012). The microfiltration process is performed by the membranes with micro size which conduct the microfiltration and it requires a constant pressure for the removal of dissolved solids (Niti and Rakesh, 2013).

Bioremediation can be affected by several major factors which also influence the bioremediating process of co – contaminated soils i.e., with pesticides, oil spillage, etc (Hanyan et al, 2020). These factors are either abiotic or biotic factors, and the examples of abiotic factors include pH, temperature, humidity, soil profile, redox potential (Eh), cation exchange potential, and pollutants' effects in the soil. Whereas in the case of biotic factors, Bioremediation efficiencies in soil are heavily dependent on inoculum density, colonisation, competitiveness and microbial activity, etc. Eventually, bioremediation can be defined as a highly useful procedure to destroy a broad range of toxins, through which, many legally regarded dangerous substances can be turned into safe substances, and thus, it is an effective way to control or regulate the usage of hazardous materials (A. S. Purnomo et al, 2011).

PGPR: A potential tool for Heavy Metals' Bioremediation

Some of the soil's most harmful and persistent contaminants are heavy metals, metalloids and radioactive nuclides, and even though toxicity issue can be minimised by alterations in mental speculation or bioavailability, metals cannot be decomposed. The heavy metal pollution in soils has a number of significant effects on microbial populations, for example - a decrease in the number of distinct populations of the total microbes and modification of the microbial construct of communities, etc. Even the less concentration of heavy metals also demonstrated that the overall variety of bacteria may decrease significantly. Bioremediation is a potent alternative to most classic physicochemical remediation approaches, and is a significant and sustainable choice for the effective remediation of metal-polluted areas, coupled with other technologies (Eloísa et al, 2011). There are significant limits to the use of plants alone for bioremediation, and hence, if the metal accumulators are supported by bacteria that promote metal resistance development, efficiency is enhanced (Sanjeev et al, 2013). PGPR was first utilized to stimulate plant growth and biocontrol of plant diseases, subsequent considerations of PGPR bioremediation have been given great attention (Xuliang et al, 2007). To date, a range of sites has isolated bacteria that can degrade certain organic toxins such as polychlorinated biphenyls (PCBs) (Brazil et al, 1995). Few significant techniques to optimize the efficiency of degradation and the tolerance of bacteria for soil pollutants have been developed. The use of few selected PGPRs in soil contamination lines with diverse qualities that increase plant performance. But here, the selection of this PGPR strain which also is a native soil microorganism has to be done very carefully for it to conduct the process of bioremediation.

The PGPR enhances plant production and while enhancing soil profile and organic matter and nitrogen content (Eloísa et al, 2011). Light metals, like calcium, sodium, potassium, magnesium, and other heavy metals, like cobalt, chromium, copper, iron, manganese, nickel, or zinc, are important in the life cycle of microbes, while Others like Cd, Hg, and Pb do not carry any identified major role or have harmful effects on microbial cells by activities such as oxidative stress and damaging of DNA (Nies and Silver, 2007). Facing a wide range of pollutants, remediation technology can still be less effective, but it was shown efficient to mix plant growth-promoting species and certain bacteria that can degrade contaminants (Ajithkumar et al, 1998). By synthesizing siderophores, IAA, and heavy-metal contaminants' antibiotics, different from organic pollutants, or by stimulating specific metabolic processes such as fixing nitrogen, phosphorous, S, Mg, Ca, and other nutrients, few rhizobacteria can stimulate plant growth (Xuliang et al, 2007).

Examples of Bioremediation by PGPR

According to Xuliang et al, 2007, heavy metals can accumulate the siderophore synthesis in soil, and these siderophores can mobilize other heavy metals and increase the build-up of metals by resistant bacteria (Sanjeev et al, 2013). When the effects of the rhizobacterial species were observed on Ni absorption, the results showed these species made the nickel secretion easier in soil, hence increasing Ni bioavailability (Abou-Shanab et al, 2006). Few bacterial strains were inoculated in the metal-treated rice as a host plant and toxicities-enhancing activities were observed of the 3 strains of Cd – resistant *Ochrobactrum species*, a Pb - resistant *Bacillus species*, and an As – resistant *Bacillus species*. The inoculation in a system with the rice host metal treatment contributed to the reduction of metal toxicity, therefore enhancing germination, total biomass, amylase, and protease activity (Sanjeev et al., 2013). Another research was done to analyze the effects on uptake, build-up, and translocation of essential nutrients and heavy metals in *Zea mays L* from four plant growth-promoting rhizobacteria: *Pseudomonas putida*, *Bacillus pumilus*, *Lysinibacillus sphaericus*, and *Exiguobacterium aurantiacum*, which were isolated from saline soil. Results showed that the PGPR treatments decreased Cd and Cr accumulation but Pb accumulation was significantly increased in the rhizosphere. While in roots, Cd accumulation was very efficiently decreased by *B. pumilus* and *E. Aurantiacum* (Asadullah et al, 2021). In Cd accumulation on the stem of untreated salt-stressed plants, the decrease was more with *P. putida* inoculation, and hence, *P. putida* was considered as Cd toxicity's most tolerant soil species (Yong et al, 2014). The uptake of Pb was observed significantly low when the corn plants were inoculated with *Bacillus sp.* and *Pseudomonas sp.* (Mohamed et al, 2017). In another experiment, an arsenic-resistant bacterial isolate *Brevibacillus sp.* was obtained from arsenic-contaminated soil and the strain could remove approximately 40% arsenic. In the arsenic-contaminated soil environment, this strain could encourage plant growth by lowering as accumulation in plants after successful colonization on the rhizosphere (Ivy et al., 2014).

Mechanism of PGPR for bioremediation of heavy metals

The concentrations of heavy metals existing in soil are harmful to plant growth and are undesirable, and to remedy that, heavy metal interactions with certain PGPR address toxicity problems and the encouragement of plant growth. By modifying soil's physicochemical characteristics to promote metal biological availability, we can mitigate, detoxify or eliminate heavy metals. (Mishra et al, 2017). PGPR can reduce plant toxins and enhance plant growth and nourishment, and they achieve this in two different ways: first, because of their deamino activity, they assist lesser stress of ethylene in the plants cultivating in metal-contaminated soils. As a result, longer root systems can be developed to make the plants more substantial in early growth phases, and second, The PGPR releases iron compound, which can help plant roots to obtain iron during unfavorable conditions that are polluted with metals (Burd et al, 1998, 2000). Microorganisms carry a broad spectrum of mechanisms that detoxify and resist heavy metals through demobilizing, mobilizing, precipitating, absorbing, bioaccumulation, and biological cycling. (Sandeep et al, 2019).

Bacteria secrete the siderophores which largely transport Fe from low-Fe ground to the targets by particular systems and bind to heavy metals (loids), like Cd, Zn, and Pb. Bacteria are further protected by external membrane proteins, which facilitate the production of bioprecipitation against heavy metals linked to siderophore. because their bioavailability is low and they have low environmental concern (Diels et al, 1999). The other mechanisms of microbial bioremediation are bioleaching and bioprecipitation, for example, sulfuric acid produced by bacteria is being used to release metal ions by mineral dissolution. Dissolving metals with sulphuric acid thereafter enhances the bioavailability of sulphur, which Enables metal bioprecipitation as sulfide for less movement and efficiently removes them. For the bio-leaching of soils' heavy metals, certain bacterial strains linked with the natural sulphur cycle can be exploited i.e., *Pseudomonas spp.*, *Acetobacter spp.*, etc. A further significant pathway to microbial soil remediation is biological reduction, as the heavy metal(s) toxicity relies on the oxidation status. In inundated soil (such as in paddies of rice), in which the levels of oxygen are low, or in reduction conditions that have been artifactually generated, such as those in which a donor of the electron is supplied to stimulate microbial growth (Deyi et al, 2020).

In the case of biosorption, in the rhizosphere, microbial populations secrete polysaccharides, lipopolysaccharides, proteins, etc, which might help eliminate metals in the rhizosphere (Sandeep et al, 2019). These compounds produced by some microbes cause the biofilms creation in contrary to the exposure of heavy metals' toxicity, which helps to detoxify heavy metal by improving the microbial cell tolerance capacity or by turning harmful metal ions into harmless metals (Gupta et al., 2016). The absorption and detoxification of heavy metals are caused through bioaccumulation, which consists, generally, of 2 processes: firstly, the 'passive process' which does not involve metabolism, and then the 'active process' which includes metabolism and energy that used transport and bioaccumulate metals. Soluble metals are reduced or precipitated during bioaccumulation to lower-soluble metal salts. Many PGPRs affect the bioavailability of metals in soil by acidifying, chelating, complexing, precipitation, and redox processes. In acidic pH environments, the availability and adsorption of the heavy metals in the rhizosphere is promoted, while organic acids generated by the lower pH soil microorganisms are used to remove soluble metal ions (Sandeep et al, 2019; Mishra et al, 2017). Biogeochemical reactions can also be influenced by microbes that transform mobile, low-bioavailability heavy metal(loids) into stable compounds through metal adsorption into organic matter, carbonates formation, and sulfides, metal (loids) reductions, stable compounds formation and aluminum, iron, and manganese oxidation and hydrolysis. (Deyi et al, 2020).

Bioremediation by genetically engineered Microbes

Genetically engineered microbial bioremediation can be done by 2 ways, i.e., biostimulation and bioaugmentation. In biostimulation, additional nutrients are provided to the microbiota of soil to enhance their capacity to immobilize and/or degrade soil pollutants, whereas, the process of adding engineered microbial strains to soil is called bioaugmentation process. The approaches employed were heavy metal(loid), gasoline, wide-range hydrocarbons, and radionuclides. Current commercial uses of bio-enhancement involve ambient microorganisms that have been collected and amplified in the laboratory's-controlled conditions. Many excellent biofertilizers are manufactured and applied in the field safely from plant-based microorganisms. The technologies of genetic engineering can help improve heavy metal (loid) resistance to microbial mechanisms (Deyi et al, 2020; Diep et al, 2018). The phytochelatin synthase protein products directly bind to hazardous

Table 1. Some of the examples of PGPR strains that are utilized for heavy metal bioremediation are shown.

Bacterial strain	Heavy metal	PGPR like trait	Reference
Azotobacter chroococcum Bacillus megaterium Bacillus mucilaginosus	Lead, zinc	Stimulation of plant growth Protection of plant from metal toxicity	(Xuliang et al, 2007)
Bacillus pumilus	Cadmium, Nickel, Lead	Increases macro and micronutrients (Na and K)	(Asadullah et al, 2021)
Bacillus subtilis	Nickel	Facilitates Nickle accumulation	(Zaidi et al, 2006)
Brevibacillus spp.	Arsenic	Plant growth promotion Induces IAA production	(Mallick et al, 2014)
Brevundimonas sp.	Cadmium	Direct Cd removal from solution	(Xuliang et al, 2007)
Exiguobacterium aurantiacum	Cadmium, Nickel, Lead	Increases macro and micronutrients (Ca, K and Fe)	(Asadullah et al, 2021)
Kluyvera ascorbate Kluyvera ascorbata	Nickel, lead, zinc	Inhibition of plant development by heavy metals was decreased Metal absorption was not increased in the noninoculated plants	(Burd et al, 2000)
Lysinibacillus sphaericus	Chromium, Nickel	Increases macro and micronutrients (Na and Zn)	(Asadullah et al, 2021)
Mesorhizobium huakuii subspp.	Cadmium	cells' ability to bind to Cd^{2+} was increased	(Xuliang et al, 2007)
Ochrobactrum sp.	Cadmium	Induced germination Relative root elongation	(Sanjeev et al, 2012)
Pseudomonas Fluorescence Pseudomonas spp.	Cadmium	Direct Cd removal from solution	(Xuliang et al, 2007)
Pseudomonas putida	Cadmium, Nickel	Increases macro and micronutrients (Fe and Zn)	(Asadullah et al, 2021)
Rhizobium leguminosarum bv. trifolii	Cadmium	Direct Cd removal from solution	(Xuliang et al, 2007)

composites like Cd, As, Pb and Hg to transform into nontoxic (Deyi et al, 2020). It may enhance the efficacy of bioremediation if heavy metal resistant genes are transferred into some other microbial strains which are adequate as microbial bioremediation (Valls et al, 2002). But overall, it can be said that. This particular field needs further researches to improve and develop more techniques by which bioremediation can be made easier and effective by the cultivation of the laboratory genetically engineered microbes.

CONCLUSION

In a country like India, where agriculture is considered as a backbone, inoculants with PGPR can perform different positive interactions in plants that lead to a promising environmentally friendly and sustainable agriculture solution. The efficiency of these metal-accumulating plants is multiplied when they are supported by microorganisms that promote metal-resistant activity, for that, a mixture of PGPR and pollutant degrading bacteria have been observed to be successful. PGPR bacteria enhance plant production and biomass as well as improve soil profile, organic matter content and nitrogen content. By synthesizing siderophores, IAA, and heavy metal pollutants' antibiotics, several rhizobacteria have a capacity of stimulating plant nutrition and development. Some examples of these Bioremediating PGPR strains have been discussed in this article as well. PGPR solves heavy metal toxicity issues as they eliminate plant metal toxicity and improve plant growth and nutrition. Another important route for microbial soil remediation is the reduction in biological efficiency. It may increase the efficacy of bioremediation if genes are transferred from resistant to heavy-metal microbes to other laboratory cultivated genetically engineered microbes, for which techniques such as biostimulation and bioaugmentation can be applied. Many successful biofertilizers are manufactured from plant-based micro-organisms and are used in the field more safely. Besides that, this field has a lot of room for development and excellent potential for future experiments and researches.

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