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Prospective Function of Endophytic Bacteria in Phyto-remediation of Hazardous Heavy Metals from Industrial Waste Effluents

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Abstract

Global industrialization and rapid population growth are the main causes of heavy metal pollution, which builds up in food webs and poses a serious risk to human health. The pulp and paper, distillery, and tannery industries have rapidly industrialized, resulting in a considerable volume of wastewater and solid waste that is heavily contaminated with various residual organic and inorganic pollutants along with heavy metals. Using plants and the microorganisms that live in them, a novel technique called phytoremediation uses plants to remove poisons from the soil, water, and air. In recent years, there has been much suggestion to use bacterial endophytes to clean up soil contaminated with metals. Through their unique metal resistance mechanism, endophytic bacteria may reduce the toxicity of metals to plants and improve plant development under metal stress. Hence, bacterial endophytes aid in phytoremediation. By secreting low-molecular-weight organic acids and metal-specific ligands like siderophores, which change the pH of the soil and increase binding activity, endophytic bacteria are more likely to increase metal and mineral solubility. In order to assess the possibilities and prospects for industrial wastewater detoxification, this review examined the role of endophytes in bioremediation. This paper presents many pathways that lead to the encouragement of plant development and the detoxification of plants from heavy metals.

Keywords: Heavy Metals; Industrial Effluents; Phytoremediation; Endophytic Bacteria

1. Introduction

Environmental pollution is increasing due to a multitude of dangerous pollutants from different sources, such as industrial effluent or swedge, as a result of human needs and activities, industry, globalization, and population increase that is continuing (Verma and Kuila, 2019). One of the most notable sources of heavy metal contamination in soil, water, and the atmosphere is industrial effluents or wastes
(Kumar and Sharma, 2021). Living things in ecosystems are increasingly concerned about the presence of heavy metal contamination in the environment. Heavy metal contamination is a significant environmental issue due to its bioaccumulation and non-biodegradability in the environment (Igiri et al., 2018). We are aware that food quality is impacted by environmental pollution, especially when it comes to crops that are harvested near hazardous areas. We are now searching for cutting-edge, affordable, and long-term ways to lessen the amount of metal and heavy metal pollution in the atmosphere. The bioremediation procedure is employed for this reason (Stępniewska and Kuźniar, 2013). A biotechnical waste management technique called bioremediation uses microorganisms to eliminate or clean up environmental contaminants. In essence, it's a procedure to change hazardous heavy metals into non-hazardous forms in order to lessen

the amount of heavy metal pollution in soil, water, and other environmental materials (Igiri et al., 2018). One kind of bioremediation that can assist plants in removing or reducing the heavy metal contamination in their soils is phytoremediation. This process is less expensive and toxic, and it has gained more attention recently as one of the most cutting-edge bioremediation techniques linked with using microorganisms and plants to remove heavy metal contaminants. Both endophytes and bacterial endophytes essentially aid in this bioremediation process (Ma et al., 2016). Numerous endophytic bacteria have been shown to be able to break down or decompose organic contaminants and to be resistant to heavy metals as shown in Fig.1.

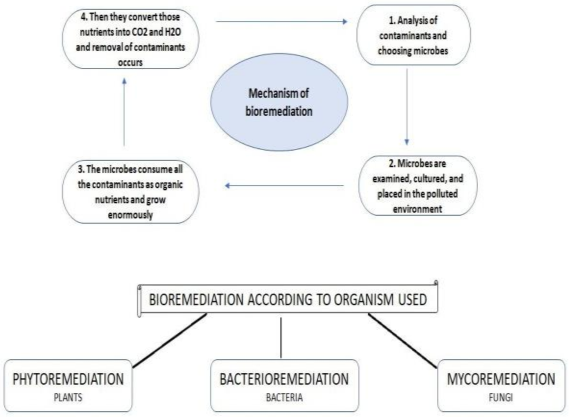

Fig. 1: Mechanism of bioremediation by microbes

During heavy metal phytoremediation, endophytic bacteria that are resistant to heavy metals can enhance plant development, lessen metal phytotoxicity, and control the movement and build-up of metals in plants. Because of their deeper ties to their host plants, bacterial endophytes may be able to enhance phytoremediation more successfully (Lietal, 2012) as shown in Table 1. Endophytes are microorganisms that reside inside plant tissue. They help plants develop more quickly and become more resilient to diseases, droughts, and other environmental stresses without endangering the host's health (Doty, 2008). De Bary coined the term "endophyte" for the first time in 1886. Following that, in 1887, Victor Gallipe postulated that healthy plant cells might be penetrated by soil microbes; for this reason, understanding colonization pathways is crucial (Stapniewska and Kuniar, 2013). According to Li et al. (2012), endophytes are essentially endophytic bacteria, endophytic fungi, and endophytic actinomycetes. Bacterial endophytes are thought to be a sustainable strategy for promoting plant growth and disease resistance. According to Sharma and Kumar (2021), these bacteria have the potential to enhance plant health, environmental health, and sustainable crop yield. However, current studies have demonstrated that a large number of endophytes are resistant to metals, capable of promoting plant development and breaking down organic contaminants, and that endophytes have been utilized in phytoremediation with success (Li et al., 2012). Endophytes have been successfully introduced into a habitat polluted with heavy metals. biomagnification and other immune reactions, as well as being efficient in enzymatic activity (Sharma and Kumar, 2021). Depending on how they live, endophytic bacteria are classified as either facultative or obligatory. While facultative endophytes are endophytes that spend a portion of their life cycle outside of their host plants, obligatory endophytes are entirely dependent on their host plant for growth and development and spread vertically or through vectors to other plants. The root zone is often where endophytes enter plant cells, yet aerial plant portions such as stems and cotyledons, in addition to flowers, can be employed as gateways (Li et al., 2012; Rajkumar et al., 2009). Furthermore, bioremediation employing endophytic bacteria possessing diverse attributes that promote plant growth, including detoxification, sequestration, accumulation, transformation, and metal resistance, can reduce metal phytotoxicity and alter the phytoavailability of heavy metals in contaminated soil, rendering it appropriate for research on microbially assisted phytoremediation (Ma et al., 2016). Heavy metals are toxic to plants, yet certain plants and hyperaccumulators have been found to exhibit metal-tolerant behavior. Several hyperaccumulators linked to metal-resistant endophytes (Li et al., 2012). A thorough understanding of the metal resistance characteristics of the endophytic microbiome is necessary for the development of effective metal bioremediation. Numerous plants include endophytes, which have been shown to support plant growth in the face of salt and heavy metal stress.These kinds of metal-resistant endophytes, ideally endophytic bacteria, are becoming more and more common and are employed in both phytoremediation and bioremediation processes for heavy metal removal in agricultural settings (Sharma and Kumar, 2021). Numerous endophytes linked with hyperaccumulators and endophytic bacteria resistant to heavy metals have been documented in certain hyperaccumulating plants, including as *Thlaspi caerulescens*, *Alnus firma*, *Brassica napus*, *Alyssum bertolonii*, *Nicotiana tabacum*, and *Solanum nigrum*. Recently, metal-resistant endophytes have also been found in a few non-hyperaccumulating plants, including *Symplocos paniculata*, *Acacia decurrens*, and *Arabis hirsuta* (Li et al., 2012). Hyperaccumulator plants possess unique endophytic bacterial flora that confers high degrees of heavy metal tolerance. According to Ma et al. (2016), a few advantageous endophytes were thought to be promising natural resources for enhancing phytoremediation of metal-polluted soil of their biotechnological applications in metal bioremediation. Thus, the present review has provided an insight of phytoremediation based function of endophytic bacteria for heavy metal bioremediation from industrial waste effluents

2. Plant growth promoting endophytic bacteria

Endophytic bacteria are considered as aneco-friendlytoolwhichhelptheplantspeciesforgrowthand development and also helps to resistdisease.Endophyticbacteriaresemblesmallaccumulatesscatteredinplant body where mineralsornutrientsaretransferred,increasingboththemicroorganism'smetabolicactivityandthe host plant's metabolic actions (Sharma and Kumar, 2021). Current study reported some bacterial endophytes which are found in poplar trees and they are growing at the site for the phytoremediation of the polluted soil contaminated with toluene and with the aim of this study to identifying candidates for enhancing phytoremediation of toluene, ethylbenzene, xylene (BTEX) compounds as well as heavy metals (Ryan et al., 2008). Bacterial endophytes were shown to assist host plants adapt to adverse soil conditions and improve phytoremediation capacity by increasing plants growth, reducing metal stress, lowering metal phytotoxicity, modifying metal bioavailability in soil, and altering metal translocation in plants (Ma et al., 2016) as shown in Fig.2.

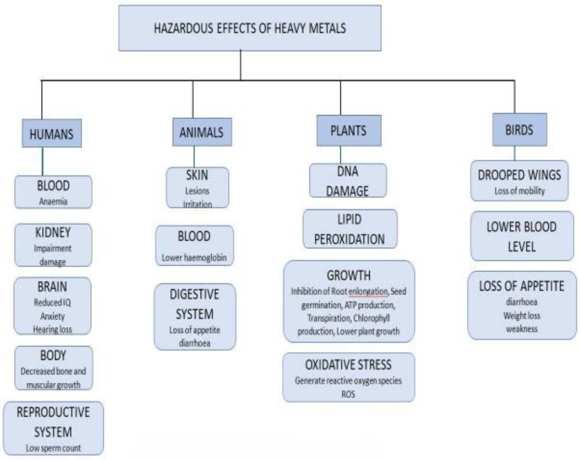

Fig. 2: Hazardous effects of lead on all life forms

3. Major reservoirs of heavy metals and their impacts

The number of different heavy metals in the environment, including soil and water, is rising as a result of ongoing human activity and fast industrialization. Because of their high solubility and mutagenic and carcinogenic effects, heavy metals that are consumed by humans and animals through the food chain can have serious negative health impacts on both human and animal health (Sharma and Kumar, 2021). Heavy metals are basically pollutants in the soil and water environment due to their excessive creation by natural and man-made activities, discharge of large concentrations of metal waste through industries, and increased bioavailability. In developing countries like India, modern agricultural enterprises including tanneries, pulp-paper mills, olive mills, and distilleries are becoming a major contributor to heavy contamination (Sharma and Kumar, 2021). Two types of adverse impacts that heavy metals can cause are "direct" and "indirect" harm."Indirect" damage is the formation of reactive oxygen and nitrogen species, such as superoxide radicals, hydrogen peroxide, nitric oxide, and others, while "direct" damage is the structural alterations in biomolecules brought on by exposure to heavy metals. As seen in Fig. 3, the current state of water management demonstrates the contamination brought on by industrial wastewater, which includes significant concentrations of hazardous heavy metals or metalloids (Sharma and Kumar, 2021).

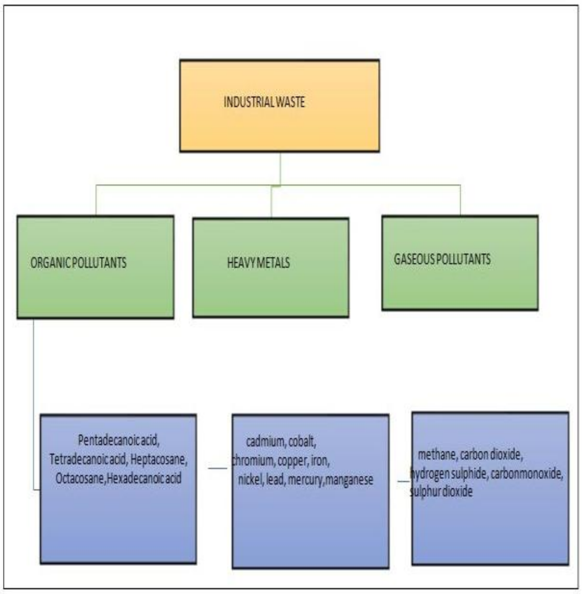

Fig. 3: Different types of industrial wastes

4. Phytoremediation by endophytic bacteria

Innovative and reasonably priced green technologies are being employed to reduce harmful pollution because pollution is becoming a big global issue (Sharma and Kumar, 2021).The plant's interaction with endophytes in the rhizosphere can break down toxic pollutants (Stępniewska and Kuźniar, 2013). Endophytes have been shown to be important for host plant tolerance to contaminated environments, in addition to aiding in phytoremediation by, among other things, promoting plant development, lowering phytotoxicity, enhancing metal tolerance, and decomposing or inactivating toxins in the soil (Li et al., 2012). Endophytic bacteria have been widely employed in recent years to treat a wide range of poisons, including heavy metals, by cleaning up environmental pollutants.Kumar and Sharma, 2021). According to Stępniewska and Kuźniar (2013), the endophytic microbial population may also help with phytoremediation of petroleum by phytoremediation of the heavy metals.It was recently noted that B. napus was vaccinated. Compared to the dead bacterial-inoculation control, the inoculation of N. tabacum with Cd-resistant endophyte Sanguibacter sp. increased Pb uptake into the shoot from 76% to 131% (P. fluorescens) and from 59% to 80% (Microbacterium sp.).These kinds of investigations lead to the conclusion that it ought to be able to enhance plants' capacity for extracting metals. Numerous plant-assisted bacterial species, particularly endophytic bacteria, have been described as helping their host plants avert or significantly battle abiotic and biotic stress. These beneficial bacterial endophytes that promote plant growth and carry out phytoremediation in soils contaminated with metals are currently receiving more attention from researchers (Maetal.,2016).Endophytic bacteria mostly carry out this mode of plant growth promotion, either directly or indirectly. Plant growth promoting endophytes (PGPE) can aid in the development of plant growth through a variety of possible ways. Nitrogen is a part of this mechanism. fixing, solubilizing minerals, producing phytohormones, producing certain enzymes, and producing siderophores. They can fix nitrogen and supply it to the plants; they can produce siderophores, which can take up iron from the soil and transfer it to plant cells so they can absorb the bacterial siderophore-iron complex; they can synthesize various phytohormones, such as auxins, cytokinins, and gibberelins, among others, which can aid in the promotion of plant growth; they can solubilize minerals like phosphorus, which is important for many different enzyme reactions in plants; they can synthesize enzymes like 1-aminocyclopropane-1-carboxylate (ACC) deaminase, which can lower the concentrations of ethylene in plants; and bacterial endophytes can produce various types of siderophores, which can aid in the growth of plants in soil contaminated with metals. Approximately 83% of these bacteria can be stimulated by heavy metals.

Any of these can be utilized by an endophytic bacterium mechanisms of this kind for the development and growth of plants (Glick, 2010; Ma et al., 2016).
When plants are exposed to phytotoxic substances such heavy metals, polycyclic aromatic hydrocarbons (PAHs), and halogenated hydrocarbons, phytoremediation may be impeded.It has been discovered that endophytes possess a variety of traits that can influence the toxicity of contaminants by producing siderophores, organic acids, iron chelators, and other degrading enzymes (Li et al., 2012). By generating organic acids, plant-associated bacterial species may be able to enhance phytoextraction as well as the transport of heavy metals and nutrients. In cases where there is an iron shortage, siderophores act as solubilizers of iron, enabling more effective absorption from minerals or organic materials. The concentration of metal soluble compounds is increased when a siderophore is attached to a metal. There have been reports of various bacterial endophytes that produce siderophores that enhance plant growth in low-nutrient situations. Furthermore, certain endophytes' production of low-molecular-mass organic acids has been shown to enhance the absorption of heavy metals (Li et al., 2012) as shown in Fig.4.

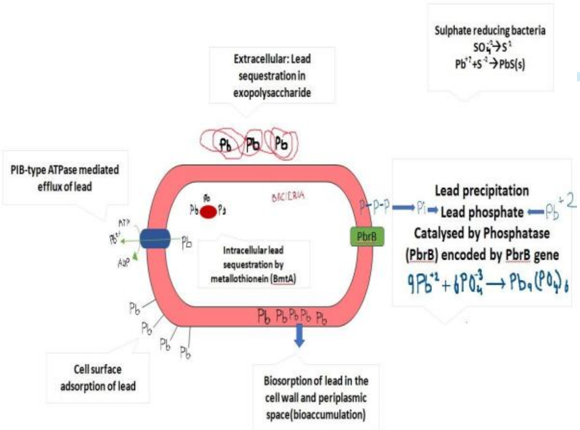

Fig. 4 Detailed mechanism of Lead resistance in Bacterial endophytes

5. Phytoremediation strategy

A novel bioremediation technique called phytoremediation allows plants to clean up or eliminate pollutants like heavy metals from soil and water. In addition to site cleanup, phytoremediation offers a high degree of social acceptance by utilizing naturally occurring plant mechanisms and improving soil and plant health. A number of types of hyperaccumulator plants are explored for phytoremediation applications (Redfern and Gunsch, 2016). The phytotoxicity of heavy metals is a significant issue impeding the phytoremediation process. In order for endophyte-host relationship to overcome metal stress, a variety of endophytic bacterial-mediated pathways have been involved as depicted in Table 2, either by reducing metal toxicity or supplying plant metal resistance (Ma et al., 2016).

5.1. Phytofiltration

One of the biggest environmental risks in the modern world is heavy metal contamination. According to the analysis, there are numerous methods for removing heavy metals from areas where industrial waste is dumped. Plant roots filter heavy metal pollution from their environment by a process called phytofiltration, also referred to as rhizofiltration. Phytofiltration is one possible low-cost treatment for industrial sites where wastewater contaminated with heavy metals is dumped. The methods that are used most frequently are chemical precipitation, ion exchange, and microbiological precipitation. Phytofiltration is the process of removing metals, metalloids, and radionuclides from wastewater by means of terrestrial and aquatic plants. Precipitation, adsorption, or absorption are potential techniques for reducing these elements in their roots or shoot tissues (Sharma et al., 2020).

5.2. Phytoaccumulation

This procedure is employed when contaminants or heavy metal contaminations build up in the roots or other plant tissues. One economical and environmentally beneficial way to get rid of organic pollutants and heavy metals from industrial waste is through phytoaccumulation. Recent studies have shown that these bacterial endophytes have a high metal absorption capacity and a high metal tolerance activity, both of which are important for the generation of biomass (Sharma et al., 2020).

5.3. Phytoextraction

Phytoextraction is the process of removing contaminants from soilbyusingpollutant-accumulatingplants.The transmission and buildup of metallic and organic contaminants from soil to above soil surface is favoured by these plants(Sharmaetal.,2020).Bythisprocessendophyticbacteriadothehyperaccumulationandextraction of the heavy metals. Phytoextraction is sometime also term as biomining or phytomining. As plants uptake and translocate pollutants to the core plant biomass, these mechanisms can directly remove organic and metallic elements from soils. There are a different hyperaccumulating plants bacterial endophytes are reported that can be utilized to extract metals.

5.4. Phytovolatilization

In this process release of metals into the atmosphere in volatile forms (Ma et al., 2016). Plants interact with a variety of chemical components, both organic and inorganic, at the same time through direct or indirect phytovolatilization. Certain endophytic bacteria are currently archiving the volatilization of metals like As, Se, and Hg as well as organic molecules like petroleum hydrocarbons. Several endophytic bacteria like *Pseudomonas aeruginosa, Pseudomonas putida, Pseudomonas stutzeri, Rhodococcus wratislaviensis, Acinetobacter sp., Burkholderia sp., Gordonia sp., Dietzia sp., Gordonia sp., Mycobacterium sp., Nocardioides sp., Novosphingobium sp., Ochrobactrum sp., Polaromonas sp., Rhodococcus sp., Sphingomonas sp.* etc. which are involved in the phytovolatization process (Sahoo et al., 2017).

5.5. Phytostabilization

Metal can absorb and sequester in plant roots during this process. The phytostabilization process demonstrates how adsorption, precipitation, and complexation work in plants. Through these processes, plants may be able to remove heavy metal pollutants from soil. Plants thereby prevent pollution from entering the environment and lessen soil and environmental damage. Similar to a reaction, phytostabilization lessens the harm that soil pollution does to the environment. The phytostabilization technique, which aids in heavy metal cleanup, makes use of plants such as *Sorghum sp., Eucalyptus urophylla, Eucalyptus saligna,* and *Vigna unguiculata* (Sharma et al., 2020).*Novosphingobium sp., Ochrobactrum sp., Polaromonas sp., Rhodococcus sp., Sphingomonas sp.* etc. which are involved in the phytovolatization process (Sahoo et al., 2017).

5.6. Phytodegradation

Related bacteria work in tandem with plants to facilitate the bioremediation of both organic and inorganic pollutants. It is possible to apply this tactic to break down pollutants at disposal locations for waste. Plant roots work in tandem with rhizospheric microorganisms, and bacterial endophytes in particular, to restore soils contaminated by both organic and inorganic pollutants (Sharma et al., 2020). Phytotransformation is another name for this process. By this process, several enzymes from the plant bacterial endophytes are produced, which aids in the metabolization and breakdown of organic molecules in the soil's surface, groundwater, sediments, and sludges. As shown in Fig. 5, a similar mechanism was identified in the air purification process of plants (Sharma et al., 2020).

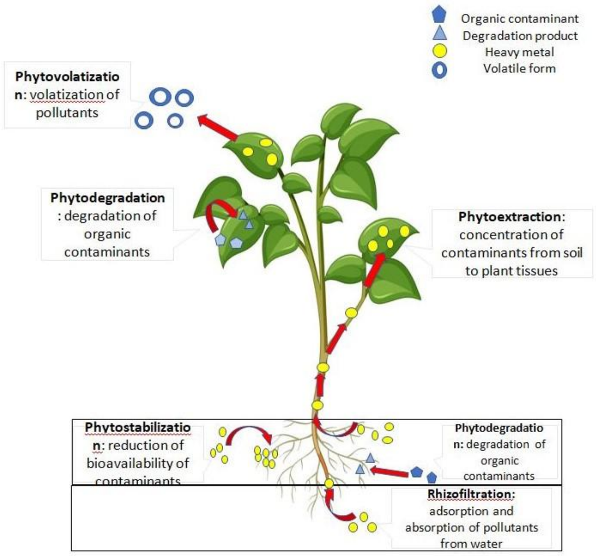

Fig. 5 Phytoremediation mechanism by endophytic bacteria

6. Future Perspectives

Symbiotic creatures called endophytic bacteria live inside the tissues of plants without causing harm to their hosts. The growth-promoting characteristics and beneficial activities of plants were studied through the use of endophytic bacteria connected to plants that are experiencing abiotic stress. This technique works very well at eliminating pollutants from industrial effluents in a way that is acceptable to the environment. Microbial endophytes can function as plant development enhancers by supplying siderophores and plant hormones, as well as solubilizing minerals like zinc, potassium, and phosphate (Sharma and Kumar, 2021). Endophytes possess an advantageous edge over the native community due to their development of metabolic pathways that enable them to exclusively consume contaminants (Ijaz et al., 2016). There are very few options available for the purification and treatment of heavy metal contamination from industrial waste. accessible. An affordable and sustainable solution to the problem of industrial waste-derived organometallic compound contamination may be found in phytoremediation. A significant amount of heavy metals, EDCs, and compounds that cause cancer are released into the environment through industrial waste. To address such wastes, plant bacterial endophytes may present a significant opportunity for insitu phytoremediation of heavy metals and other organic contaminants (Sharma et al., 2020). Endophytes have the ability to increase pollutant accumulation, phytotoxicity reduction, nutrient absorption, heavy metal mobilization, and plant development. Further research on the role of naturally adapted indigenous endophytes is needed because the majority of endophyte-assisted phytoremediation studies were from in vitro studies, and the phytoremediation process may be altered by a range of environmental factorsrequired (Li et al., 2012). Endophytes, which have distinct metabolic pathways, are valuable bioremediation tools. Methane assimilation, nitrogen fixation, metal bioremediation, chemical biotransformation (e.g., propylene to epoxypropane) and chiral alcohol synthesis are among the applications for which they can be employed. By bioremediating metals from industrial wastewater using endophytes, it may be possible to reduce environmental issues without having to remove and dispose of contaminated soil (Sharma and Kumar, 2021). As a result, further research on the mechanism of endophytes is an intriguingtopic.

7. Conclusion

This study focused on the latest scientific advancements in the application of biotechnological methods for endophyte-assisted bioremediation, which is a technique for detoxifying industrial effluents and preventing environmental contamination. Although highly effective microorganisms have been documented for many purposes, the bioremediation capacity of endophyte bacteria remains unexplored. based on endophytic bacteria
It has been demonstrated that rhizome interaction, bioremediation, biological therapies for pollutants, and heavy metal detoxification are all viable methods for clearing the contaminated environment. Pollutant

availability to rhizospheric bacteria due to rapid absorption into the plants, as well as phytotoxicity to plants due to growing buildup in plant tissues, often inhibit plants and the microorganisms associated with them. Conversely, endophytes inhabit plants and are able to increase and decrease phytotoxicity. An environmentally friendly way to address the contamination of industrial wastes, both liquid and solid, with organometallic compounds may be by phytoremediation. In situ phytoremediation of heavy metals to control such industrial pollution may be greatly enhanced by endophytic bacteria.

Table 1

Table 1: Sources of heavy metals and their effects on human health

Pollutants	**Major Sources**	**Effects on Human Health**	**Permissible Levels (mg/L)**	**References**
Pb	Paint, pesticides, smoking,automobile emission, mining, burning of coal	Mental retardation in children, developmental delay, fatal infant encephalopathy, chronic damage to nervoussystem,liver,kidneydamage	0.1	(Sharma and Kumar2021)
Cd	Welding,electroplating, pesticides, fertilizer	Renaldysfunction,lungdisease,lung cancer,bonedefects,kidneydamage, bonemarrow	0.06	(Sharma and Kumar 2021)
As	Pesticides,fungicides, metal smelters	Bronchitis,dermatitis,poisoning	0.02	(Sharma and Kumar 2021)
Mn	Welding,fueladdition, ferromanganese production	Inhalationorcontactdamagetocentral nervous system	0.26	(Sharma and Kumar 2021)
Hg	Pesticides,batteries, paper industry	Tremors, gingivitis, protoplasm poisoning,damagetonervoussystem, spontaneous abortion	0.01	(Sharma and Kumar 2021)
Cu	Mining, pesticide production,chemical industry	Anemia,liverandkidneydamage, stomach irritation	0.1	(Sharma and Kumar 2021)
Zn	Refineries, brass manufacture,metal plating	Damagetonervoussystem,dermatitis	15	(Sharma and Kumar2021)
Cr	Mine,mineralsources	Damagetonervoussystem,irritability	0.05	(Sharma and Kumar 2021)

Table 2: Role of Endophytic Bacteria in Phytoremediation of heavy metals from industrial effluents

ENDOPHYTES NAME	**SOURCE**	**WASTE COMPONENT**	**MECHANISMS / EFFECTS**	**REFRENCES**
Pseudomonasjessenii M15	*Ricinuscommunis (castoroilplant)*	Ni,Cu,Zn	Accumulatetheheavy metals	(RedfernandGunsch, 2016)
Brevibacillussp.	*Redclover (Trifoliumpratense)*	Pb	Decreasedleaduptake; IAA	(Glick,2010)
Pseudomonassp.	*Chickpea(Cicer arietinum)*	Nickel	Increasedbiomassand decreasedmetal	(Glick,2010)

			uptake; siderophores	
Rahnellaaquatilis	*Indianmustard*	Nickel,chromium	Increasedbiomassand metaluptake;IAA, siderophores,ACC deaminase,phosphate solubilization	(Glick,2010)
Methylobacterium oryzae,Burkholderiasp.	*Tomatoplants*	Nickela nd Cadmi um	Reduced the toxicity of Ni and Cd in tomato plants andimprovedplantgrow th	(Yousafetal.,2014)
Enterobacteraerogen es LRE17	*SolanumnigrumL.*	Cadmium	ACCdeaminase,indole-3- aceticacid(IAA), siderophoresproduction andphosphate	(Yousafetal.,2014)
Thlaspicaerulescens	*Alpinepennycress*	ZincandCadmium	Accumulatetheheavy metals	(RedfernandGunsc 2016)
Paenibacillussp.	*Tridaxprocumben s*	Chromium,Copper, Nickle,Lead,and Cadmium	Producesecondary metabolites,indoleacetic acid, siderophores, ACC deaminase	(Govarthananetal.,2
Pseudomonassp., Microbacteriumsp	*Rumexacetosa*	Mixedheavymetals	Accumulatetheheavy metals	(SharmaandKuma 2021)
Bacillus thuringiensis GDB-1	*Alnusfirma*	Cu,Pb,Ni,andZn	Accumulatetheheavy metalsandincrease the root length	(SharmaandKuma 2021)
Methylobacterium oryzaestrainCBMB20, Burkholderia sp.	Tissuesof*Oryza sativa*	Nickela nd Cadmi um	ACCDactivity, phytohormone production andbioaccumulation	(Rajkumaretal., 200

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Conflict of interests

The authors declare no conflict of interests.

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