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Endophytic Microbial Remediation of Heavy Metals: An Overview

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Abstract

Technological explorations (chemical fertilizers, pesticides, timber preservatives, polythene, microelectronic, synthetic textiles, mining extractions, smelting, aerosols, metallurgic extractions, leaching, automobile exhausts, sewage sludge, coal combustion products, pharmaceutical and hospital wastes) are the major source of heavy metal contamination and pollution in the environment). Metal contaminated sites have been effectively cleaned by a process called bioremediation. This bioremediation process has emerged as an effective application to remediate heavy metal pollution. Heavy metal remediation by plants is known as phytoremediation which is time consuming process. Further, high concentrations of pollutants lead to toxicity of the remediating plants. This situation could be overcome by exploring the plant intriguing microbes, which would improve the plant growth by facilitating the appropriation of toxic heavy metals. Through in-situ rhizospheric process, plants can bioconcentrate phytoextraction and bioimmobilize phytostabilization of toxic heavy metals. The properties such as bioavailability and mobility of heavy metal are very critical factors in the rhizosphere where root uptake of heavy metals takes place. These factors affect the rate of phytoextraction and phytostabilization. The uptake of heavy metals can be enhanced significantly by its solubilization in soil through reaction with ligands, which allow the formation of mobile complexes. Endophytic fungi take part in this mechanism of enhancing heavy metal solubilization by producing organic compounds like citric acid and oxalic acid, which form complexes and enhance heavy metal reclamation processes.

Keywords: Heavy Metals; Endophytes; phytoremediation; Antimicrobial activity; Secondary metabolites; Soil pollution

Introduction

Heavy metals causing soil pollution has become one of the most severe worldwide environmental problems. For the last two decades, industrial explorations/activities have been leading to a continuous enhancement in heavy metal (chromium, nickel, lead, mercury and cadmium) discharge into the soil, rivers and ocean. Different sources of heavy metals include Hospital waste, e-waste, batteries, lamps, thermal plants, chlor-alkali plants, pesticide industry, paints, mining, coal industries, thermal industries, sulphuric acid plants, mining, smelting, pyrolysis and pharmaceutical industries [1]. Table 1 clearly denotes the different sources of each and every heavy metal. Continuous increase of metal levels in soil and water poses a health risk to humans and animals through the food chain and or contaminated drinking water. The dispersion of heavymetals through different sources including mining, pesticides, pharmaceutical, crude oil and metal emission was clearly represented in Figure 1, [2].

Different conventional methods such as reverse osmosis, evaporation, adsorption, precipitation, ion exchange and electro chemical methods have been used for the removal as well as treatment of heavy metal contaminating sites [3,4]. However, conventional methods involve application of more reagents, high energy, high cost and result in incomplete and ineffective removal as well as producing toxic metal sludge [2]. Bioremediation has emerged as a potential tool to treat heavy metal contaminated sites [5]. Different microbes are capable of reducing the heavy metal stress on plants, enhance the bioavailability of metal for plant uptakeand promote growth [6]. Fungal endophytes live inside the healthy plant tissues and show significant metal-binding capacity [7] and provide more advantages over bacterial endophytes [8].

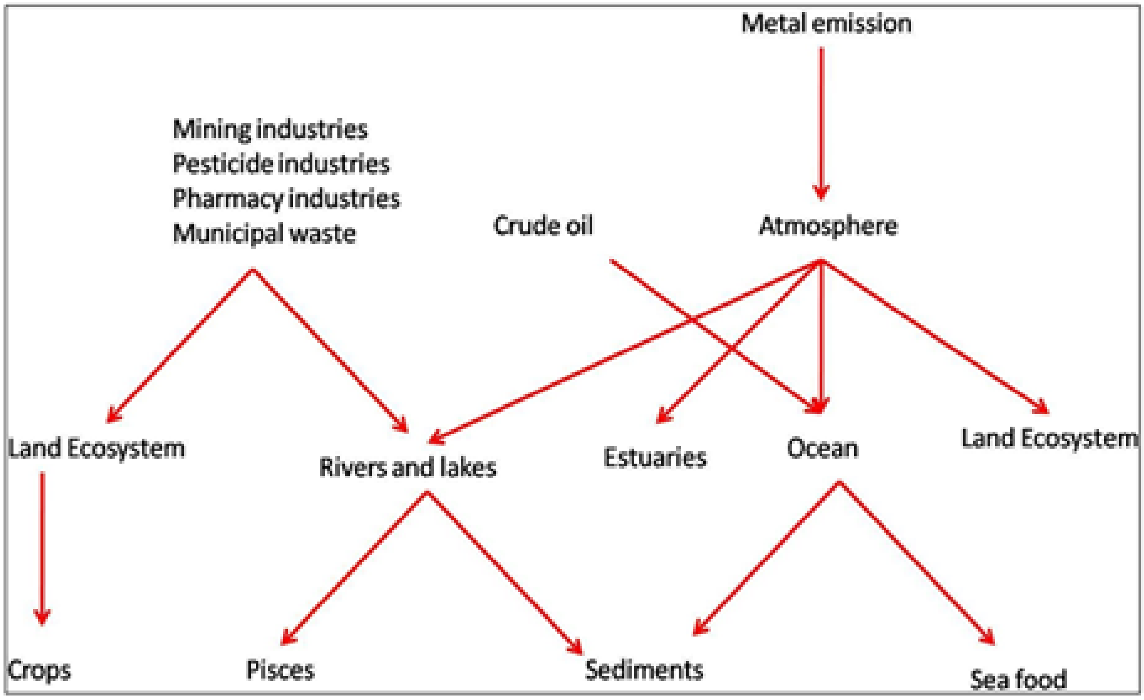

Figure 1: Dispersion of heavy metals.

Table 1: Different sources of heavy metal.

S. No	Heavy metal	Source of heavy metal
1	Lead (Pb)	Paints, batteries, e-waste, smelting, ceramics, coal industry, crude oil
2	Mercury (Hg)	Hospital waste, e-waste, batteries, lamps, thermal plants, chlor-alkali plants, pesticide industry
3	Cadmium (Cd)	Incinerations, fuel combustions, batteries, paints, e-waste, pesticides
4	Chromium (Cr)	Leather tanning, mining, coolants, pharma industries,
5	Nickel (Ni)	Battery industries, thermal plants, pesticides, pharma industry
6	Arsenic (Ar)	Geogenic processes, thermal power plants, mining, smelting, batteries
7	Vanadium (Va)	Sulphuric acid plants, spent catalysis

Heavy Metal Pollution

In our everyday life a wide variety of hazardous materials are released into natural resources from different kinds of industries including chemical, biochemical, pharmaceutical, fertilizer, pesticides, battery industries [9]. Among different pollutants, heavy metals are of major concern to human health due to their cytotoxicity, carcinogenicity, and mutagenicity [10]. Phytoremediation, the use of plants to remediate polluted soils, an eco-friendly and cost- effective approach receiving considerable global attention for a decade [11]. A large number of plant species are capable of hyper accumulation of heavy metals in their tissues; however, phytoremediation in practice has several constraints at the level of sites as these are with a variety of different contaminants [12]. Further, the success of phytoremediation of metals depends upon a plant's ability to accumulate high concentrations of the metals [13]. Heavy metal-host plant- endophyte associations have been the objective of particular attention due to the potential of microbes for bioaccumulation of metals from polluted environment or its effects on metal mobilization/immobilization and consequently enhancing metal uptake and plant growth. The present review explains how the mutual partnerships between plants and their associated endophytes can be exploited as a strategy to accelerate plant biomass production and influence plant metal accumulation through different mechanisms including adaptive strategies, metal mobilization, and immobilization mechanisms.

Endophytic Microbes

Endophytic microbes are intriguing microorganisms present inside the plant tissue with mutual/symbiotic

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relationship. Endophytes provide plant's protection by triggering signaling pathway through the elicitation of signal molecules/ phytohormones/secondary metabolites. Endophytes stimulate plant growth by biosynthesizing plant proteins and other molecules. Endophytes are involved in biotransformation and biocatalytic processes. Endophytes enhance the nutrient solubilization and nutrient uptake by plants. Endophytes stimulate in vitro seed germination, and enhancement of production of plant secondary metabolites. Endophytes act as bio controlling agents, biofertilizers and biopesticides. Further endophytes are involved in pollution control, and heavy metal remediation (bioremediation/phytoremediation) through different mechanisms. Endophytic microbes in different ways affect plant growth. Endophyticmicrobes can actively or passively promote growth through a variety of mechanisms. and there are a large number of soil microorganisms that do not appear to directly affect plantgrowth one way or the other, although this may vary as a result of a range of different rhizosphere soil conditions including organic matter, pH, temperature, nutrients, and pollutants level [14,15]. Endophytes accelerate phytoremediation of metalliferous soils though modulation of plant growth promoting parameters, by providing plants with nutrients, and by controlling disease through the production of antifungal metabolites.

Rhizobacteria

Rhizobacteria, an abundant symbiotic/mutualistic partner of plants, are considered plant growth promoting bacteria [16]. Among the soil microbes, the plant growth promoting bacteria (PGPB) deserves special attention. In general, PGPB migrates from the bulk soil to the rhizosphere of plant and colonize the rhizosphere and roots of plants [17]. The mechanisms behind plant growth stimulation differ between PGPB strains and certainly depend on the various metabolites released by these strains of PGPB. For example, production of different phytohormones such as cytokinins, auxins, gibberellins, and ethylene are mainly attributed to the presence of different strains of PGPB [18,19]. These hormones can alter plant growth together with bacterial secondary metabolites usually in a dose-dependent manner [20,21]. Other beneficial compounds produced by PGPB include organic acids, osmolytes, enzymes, antibiotics, siderophores, biosurfactants, and nitric oxide etc. All of these compounds are responsible for tolerance to abiotic stresses [22,23] associated nitrogen fixation [24] improved mineral uptake [25] suppression of pathogenic microorganisms [26,27] etc. Together, these are responsible for plant higher tolerance to heavy metal stress and stimulate host plant growth via different mechanisms including biological control, production of growth regulators, enhancement of mineral nutrients and water uptake, induction of systemicresistance in plants to pathogens, and nitrogen fixation [28]. Additional benefits due to bacterial endophytes are plant physiological changes including accumulation of osmolytes and osmotic adjustment, stomatal regulation, reduced membrane potentials, and changes in phospholipid content of cell membranes [29-35]. Table 2 denotes metal resistant features of PGPB to the plants.

Table 2: Beneficial effects of PGPB to the plants.

PGPB	Host plant	Beneficial features	Bacterial effects on plants	Reference
Burkh olderia sp. J62 (RS)	Zea mays	Plant growth hormones, siderophor es, P solubilizati on	increases Root and shoot dry weigh P solubilization increases Total root [Pb, Cd] and total shoot [Pb] uptake (Phytoextraction)	[30]
Bradyr hizobi um sp. (vigna) RM8 (RS)	Vine radiata	IAA, siderophor e, HCN, ammonia production	Nodules of green gram grown in metal-contaminated Indian soils. Growth, nodulation, N content, seed yield and seed protein “ [Ni] toxicity and uptake (Phyto stabilization	[31]
B.weih enstep hanens is SM3 (RS)	Helianthus Annuus	IAA, P, solubilizati on, [Cu, Zn, Ni] biosorption and mobilization	Increases Plant fresh and dry weight increases [Cu, Zn] uptake (Phytoextraction	[32]
Burkh olderia cepaci a (RS)	Sedum alfredii	Plant growth regulators, N2 fixation, P-solubilization on	Plant growth (110% with Zn treatment), P (56.1% with Cd treatment)! [Cd, Zn] uptake (243% and 96.3% with Cd and Zn treatment) in shoots, tolerance index (134% with Zn treatment), metal translocation (296% and 135% with Cd and Zn treatment) from root to shoot	[33]
Pseud omona s brassic acearu m Am3,	Pisum sativum	Organic acids, enzymes and osmolytes	Root and shoot biomass, nutrient (N, P, K, Ca, S, Fe) uptake in shoots	[34]
Pseud omona s montei llii (RS)	Sorghum bicolor	Osmolytes, enzymes, growth regulators.	Shoot and total b [Cd] uptake (Phytoextraction) iomass	[35]

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Metal resistance mechanism of PGPB

Iron is a necessary cofactor for many biological reactions and hence is an essential nutrient for all organisms. In aerobic conditions, iron exists predominantly as ferric state (Fe3+) and insoluble hydroxides and oxyhydroxides which are unavailable to plants and microbes. Bacterial siderophores can bind Fe3+ and solubilize this metal for its efficient uptake. Some plants produce phytosiderophores which typically have a lower affinity for iron than bacterial siderophores. Further, heavy metals that are accumulated in plant tissues also cause changes in different vital plant growth processes and also possess negative effects on iron nutrition. Under such conditions, the siderophore producing rhizosphere bacteria is capable of chelating Fe3+ and making it available to plant roots. Then the roots are able to take up iron from siderophores-Fe complexes through different plausible mechanisms [36]. Various instances of increased Fe uptake in plants with co-stimulation of plant growth because of PGPB inoculations have also been reported [37]. Siderophores also promote bacterial IAA synthesis by reducing the detrimental effects of heavy metals through chelation reaction [38]. Phosphorus (P) is one of the major essential macronutrients for biological growth and development. Under stressed conditions, most metal-resistant PGPB can convert these insoluble phosphates into available forms through different mechanisms [39]. An increase inavailability of phosphorous to plants through the inoculation of PSB (phosphate solubilizing bacteria) has been reported in pot experiments [40,41]. In addition, fixation of atmospheric N2 is a metabolic ability of endophytes and rhizobacteria and colonization offer different benefitsto the host plant [42] including the production of enzymes, siderophores [43] and antibioticmetabolites [44] and induction of systemic resistance in plants [45,46]. Some metal-resistant PGPB have been reported to produce enzymes such as chitinase, beta 1,3 glucanase, protease,and lipase, by which they can lysis the cells of fungal pathogens [46]. The interaction of plant–PGPB–phytopathogens in metal contaminated soils remains poorly understood due to both pathogenic and non-pathogenic microbes depend on the properties ofsurrounding environment (rhizosphere/tissue interior of plants) and hence these plant-associated microbes may modulate responses to direct and/or indirect effects of metal toxicity.

Metal mobilization in phytoextraction

Among the various metabolites produced by PGPB, the siderophores play a significant role in metal mobilization and accumulation [47,48]. Siderophores produced by PGPB solubilize unavailable forms of heavy metal-containing Fe and also form complexes with bivalent ions which can be assimilated by root mediated processes [49,50]. Braud *et al* 2009 [50] investigated the exudation of Cr and Pb in soil after inoculation of various PGPB. *Pseudomonas aeruginosa* was able to solubilize large amounts of Cr and Pb in soils. *P. aeruginosa* is used as only a model system since regulatory agencies will never give permission for the release of this bacterium to the environment. Inoculation of Zea mays with *P. aeruginosa* increased Cr and Pb uptake into the shoots. Bacterial culture filtrates containing hydroxamate siderophores secreted by *Streptomyces tendae* F4 significantly enhanced the uptake of Cd by the plant, compared to the control shows that siderophores can help to reduce metal toxicity in bacteria while simultaneously facilitating the uptake of such metals by plants[47]. PGPB has been shown to increase heavy metal mobilization by the secretion of organic acids such as gluconic acid, citrate, oxalate, malate, acetate, and succinate, etc. Production of5-ketogluconic acid by endophytic diazotroph *Gluconacetobacter diazotrophicus*, which dissolves Zn sources such as ZnCO3, Zn3 (PO4)2, and ZnO thus making Zn available for plant uptake [51]. The biosurfactants produced by PGPB have also been demonstrated to enhance heavy metal mobilization in contaminated soils [52]. Sheng et al [53] reported that the inoculation of soils with biosurfactant producing *Bacillus sp.* J119 significantly enhanced Cd uptake in plant tissue and biomass of tomato plants. Fromthe above findings, it can be concluded that inoculating the seeds/soils with selected bacteria, it is possible to improve bioavailable metal concentrations for plant uptake and thereby phytoextraction potential in metal-contaminated soils.

Metal immobilization in phytostabilization

Phytostabilization shows heavy metal tolerance and assists plant growth. Plant-associated bacteria have evolved several mechanisms by which they can immobilize/transform metals and make them inactive. The active mechanisms behind heavy metal resistance in bacteria includingmetal exclusion by active transport from the cell extra cellular sequestration of metals with polymers chemical modification and detoxification makes metal inactive [54]. Binding of metals to ionic functional groups such as sulfhydryl, sulfonate, hydoxyle, carboxyle, amide and amine groups immobilizes the metal and prevents entry into the plant root. Similarly, extracellular polymers such as polysaccharides, proteins, and humic substances detoxify heavy metals by chelation [55]. Organic acids and siderophores can reduce the metal bioavailability and toxicity by chelation mechanism [56,57]. According to Dimkpa et al. [57] the decreasing Ni concentration in cowpea plants is indicative of a Ni binding potential of hydroxamate siderophores. Madhaiyan et al. [58] reported that endophytic bacteria, such as *Magnaporthe oryzae* and *Burkholderia* sp. increased plant growth but reduced the Ni and Cd accumulation in roots and shoots of tomato and also their availability in soil. Bacteria can interact directly with the heavy metals to reduce their toxicity: metal dissolution by strong organic acids produced by bacteria (i.e., H_2SO_4 produced by *Thiobacillus*); production of organic bases resulting in metal hydroxide precipitates; fixation of Fe and Mn on the cell surface in the form of hydroxides; biotransformation via oxidation, reduction methylation, demethylation, volatilization, complex formation [59]. The role of soil microbiota, specifically rhizospheric and endophytic microbes, in the development of phytoremediation techniques has

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to be elucidated in order tospeed up the process and to optimize the rate of accumulation/absorption/mobilization of heavy metal contaminants. The bioavailability ratio of metals to plant roots is considered a criticalrequirement for plant metal bioconcentration or bio immobilization to occur. In this view, it ispossible to employ endophytes to alter the bioavailability of metals for improving phytoremediation of metal contaminants on a large scale.

Role of endophytes in metal remediation

Endophytes are intriguing microorganisms that reside inside the healthy plant tissue and show mutualistic relationship with plants. The symbiotic relationship between plants and endophytes was first reported in 1697. Endophytes play an important role in increasing crop yield by secretion of secondary metabolites which increase the rate of plant metabolism, in turn increasing the crop yield. Endophytes protect plants against many pathogens by secreting secondary metabolites. Endophytes induce multiple benefits to plants by colonizing plant roots [60,61]. By colonizing plant roots, endophytes become part of a symbiotic plant-microbe system.

For instance, the plant growth, metal accumulation/metal tolerance, endophyte colonization, and plant growth promoting potentials must be met for microbial assisted phytoremediation to become effective. Further the concentration of bioavailable metals i.e., bioavailability in the rhizosphere greatly affect the quantity of metal which will be accumulated in plants, because a large proportion of metals are bound to different inorganic and organic components in polluted soil and their availability is closely related to their speciation [62]. The metabolites released by PGPB (e.g., biosurfactants, siderophores, organic acids, and phyto regulators, etc.) can alter the uptake of heavy metals directly and indirectly: directly, through chelation, acidification, immobilization, precipitation, and oxidation–reduction reactions in the rhizosphere. Indirectly, through their effects on plant growth dynamics.

Many studies proved that endophytic mcrobes significantly contribute to their host plant towards many stresses such as high salinity, drought, extreme temperature, and heavy metaltoxicity, and oxidative stress [63]. Endophytic microbes were proved to have potential for phytoremediation and might be utilized as biosorbents for the detoxification of heavy metals[64]. Moreover, recent studies have demonstrated that many endophytes are metal resistant, able to enhance plant growth and able to degrade organic contaminants. Endophytes could promote host plant growth in heavy metal contaminated soils. Heavy metal resistant endophytic microbes are capable of promoting host plant growth, biomass production and enhanced metal extraction. Furthermore, they alleviate the toxic effect of heavy metals by regulating various biochemical processes inside the plant through the production of different metabolites and phytohormones that help the host plant avoid metal stress toxicity [65]. It has been reported that 76 endophytic microbial isolates were isolated from sewage, sludge and industrial effluents.

Four identified microbes screened for their resistance to four heavy metals including cadmium (Cd), chromium (cr), nickel (Ni) and lead (Pb), Cadmium (Cd), Chromium (Cr) and Nickel (Ni) and Copper (Cu). These endophytic microbes were identified as fungal isolates including *Aspergillus niger, A. terreus, Trichoderma viride,* and *T. longibrachiatum* and they showed tolerance to Pb, Cd, Cr, and Ni [66]. In a study by Fazli *et al.* [67] it has been proved that *Aspergillus versicolor* and *Trichoderma* sp. showed tolerance index to Cd. Jenny et al. [68] ninety-three endophytic fungal isolates were identified from *Nypa fruticans* sp. Eight of them showed resistance to metals such as Pb, Cr, and Cu. These eight fungal isolates were closely related to *Pestalotiopsis* sp. and showed tolerance against metals such as Cr, Cu, Zn and Pb. *Scleroderma citrinum* isolated from mining sites, *Pisolithus tinctorius* strains Pt1 and Pt2 isolated from unpolluted sites. The biomass production of *Scleroderma citrinum* was increased in presence of Cd while Pt1 and Pt2 biomass was reduced in presence of Cd. The tolerance index of *S. citrinum* was higher when compared to Pt1 and Pt2. The mycelium of *P. tinctorius* strains Pt1 and Pt2 accumulated more Cd than *S. citrinum* mycelium [69]. Various species of *Penicillium* have been proved to show resistance against heavy metals such as manganese (Mn), aurumn (Au), thorium (Th), uranium (U), cadmium (Cd), nickel (Ni) and lead (Pb). Examples of *Penicillium* in heavy metal removal include *P. italicum, P. oxalicum*, and *P. chrysogenum* [70].

Among the *Penicillium* species, *P. chrysogenum* has been studied the most and *P. chrysogenum* was demonstrated to adsorb Cr(III), Ni, and Zn, as well as Pb, Cd, and Cu [70]. Five endophytes isolated from roots including *P. mustea, P. chrysanthemicola, G. Cylindrosporus, E. Salmonis* and *C. cladosporioides. G. Cylindrosporus* were resistant to Pb, Zn and Cu and exhibited strong growth when compared with other fungi [71]. *niger* has the ability to remove various heavy metals such asPb, Cd, and Cr from aqueous solution [72]. *A. niger* showed potential affinity for binding with Cu, Zn and Ni ions in a single composition system, while it only showed binding properties for Cu and Zn in a multi-metal solution [73]. *Auricularia polytricha* exhibited tolerance to metals such as Pb, Cd, and Cu. FTIR (Fourier transform infrared) analysis indicated that functional groups such as carboxyl, phosphoryl, hydroxyl, amine/amino, and C–N–C were the main functional groups that affect the metal biosorption process. SEM observations showed that the surface of the raw biomass was smooth and uniform with regular and plain structure. The surface of Cd and Cu loaded biomass was changed when compared with control. The surface of Pb loaded biomass was much rougher. The metal ionsas spot-like particles distributed on the surface of the Cd and Pb loaded fruiting body, whileextra flake-like substances distributed on the surface of the Cu loaded biomass [74].

Fusarium solani was found to tolerate a number of heavy metals and other metals such as Cr, Pb, Hg, Ni, Li, Co, Al, Mn, As, Fe, Cu, Zn. Certain morphological changes such as bulbous hyphae, increase in number of spores, thickened cell wall, and changes in the shape and size of the cultures in presence of metals were observed during

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growth of the culture in response to metal. Pigment production also played a role in higher tolerance to metal [75]. Hongmei et al. [76] reported the 53 isolates of endophytic fungi from the roots of *Salixvariegata.* Among them 27 isolates were selected to test their metal tolerance against Cd. Four isolates were further tested for minimum inhibitory concentrations (MICs) against Cd and observed that *Paraphaeosphaeria* sp. was the most tolerant endophyte with highest MIC value. Deng et al. [77] reported that a total number of 33 fungal isolates were isolated from stems of *Portulaca oleracea*. Among them, *Lasiodiplodia* sp was resistant to Cd, Pb and Zn. FTIR analysis revealed that biosorption process of endophytic fungi *Lasiodiplodia* sp. was due to the functional groups such as hydroxyl, carbonyl, amino, and benzene ring on the cell wall.

The inoculation of endophytic fungi increased the biomass of *Brassica napus L,* translocation factor of Cd and the extraction amount of Cd by rape in the Cd and Pb contaminated soils. The endophytic fungi *P. funiculosum* from soybean plant showed resistance to Cd and Cu. The heavy metal resistant *P. funiculosum* association with soybean plants significantly increased the shoot fresh biomass, shoot length, and root fresh biomass when compared with non-inoculated endophyte plants under Cu stress. Protein and chlorophyll content were significantly higher in endophyte inoculated plants as compared to non-inoculated endophyte plants under Cu stress condition. Cu tolerance rate was significantly higher in endophyte inoculated plants compared with non-inoculated endophyteplants. Anzhi Reni *et al.* 2011 [78] reported that endophyte infection of host *Lolium arundinaceum* significantly increased the biomass under Cd stress. Endophytic infection increased Cd accumulation in *L. arundinaceum* and Cd transport from root to shoot was significantly higher when compared with endophyte free plants. The endophyte-plant relationship was a resembling model for endophyte assisted phytoremediation of heavy metal contaminated soils. *Neotyphodium* infected two grass species *Festuca arundinacea* and *F. pratensis* under Cd stress showed increased shoot, root and total biomass than endophyte free plants. Cd accumulation was higher in shoot and root of endophyte infected plants (*F. Pratensis* and *F. arundinacea*) compared with non-infected plants. Cd accumulation was higher in roots compared to shoot. The endophyte infected plants had higher potential to remove Cd from contaminated soil than non-infected plants [79]. Olivier et al. [80] showed that *Glomus intraradices* fungi was inoculated to *Medicago truncatula* under Pb, Cd and Zn stress. The root and shoot biomass were increased compared to non-inoculated plants. Cd and Zn content in shoot was increased in *G. intraradices* fungi inoculated plants when compared with non-inoculated plants. Kanwal et al. [81] also reported that *G. intraradices* inoculated *M. Sativa* plants showed significant increase in chlorophyll content, plant growth and biomass under Cd and Zn toxicity compared to non-inoculated plants. Table 3 shows the different endophytes and their resistance to different heavy metals.

Table 3: Different endophytic fungi and their resistance to heavy metals.

S. No	Endophytic fungi	Host plant	Heavy Metal resistance	Reference
1	*Lasiodiplodia theobromae*	*Boswellia ovalifoliolata*	Cd	[82]
2	*Aspergillus welwitschiae*	*Glycine max L.*	Cr and As	[83]
3	*Piriformospora Indica*	*Nicotiana tabacum*	Cd	[84]
4	*Pestalotiopsis sp*	*Nypa fruticans*	Cr and Pb	[68]
5	*Beauveria bassiana*	*Glycine max L.*	Cd	[85]
6	*Cladosporium sp*	*Dysphania ambrosioides*	Pb and Cd	[86]
7	*Plectosphaerella sp*	*Dysphania ambrosioides*	Pb and Cd	[86]
8	*Verticillium sp*	*Dysphania ambrosioides*	Pb and Cd	[86]
9	*Phoma sp*	*Dysphania ambrosioides*	Pb and Cd	[86]
10	*Peyronellaea sp*	*Dysphania ambrosioides*	Pb and Cd	[86]
11	*Alternaria sp*	*Dysphania ambrosioides*	Pb and Cd	[86]
12	*Penicilium sp*	*Dysphania ambrosioides*	Pb and Cd	[86]
13	*Aspergillus sp*	*Vachellia farnesiana*	Pb	[87]
14	*Neocosmospora isolate*	*Vachellia farnesiana*	Pb	[87]
15	*Aspergillus sp. A31,*	*Zea mays*	Hg	[88]
16	*Curvularia geniculata P1*	*Zea mays*	Hg	[88]
17	*Lindgomycetaceae P87,*	*Zea mays*	Hg	[88]
18	*Westerdykella sp. P71*	*Zea mays*	Hg	[88]
19	*Lasiodiplodia sp*	*Portulaca oleracea*	Pb and Cd	[77]

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Endophytes Role in the Ecosystem

Endophytes play crucial roles in ecosystems by protecting plants against many biotic and abiotic stresses, increasing their resilience, and helping plants to adapt to new habitats [82-89]. Biotic stresses from which endophytes can provide protection include plant pathogens, insects and nematodes. Abiotic stresses include nutrient limitation, drought, salination, and extreme pH values and temperatures. In return, plants provide spatial structure, protection from desiccation, nutrients and, in the case of vertical transmission, dissemination to the nextgeneration of hosts [90,91].

Concluding Remarks and Future Perspectives

Endophytic microbes exhibit remarkable phytoremediation property through various approaches including metal sequestration, metal immobilization, metal absorption and accumulation of heavy metals. Endophytic microbes produce proteins, polysaccharides, organic acids and other bioactive compounds to effectively phytoremediate metal- contaminated soils. Bioavailability of metals to plant roots is considered a critical requirement for bio-concentration/bio immobilization to occur. In this regard, it is suggested to employ beneficial endophytes to alter the bioavailability for improving phytoremediation on large scale.

References

1. Hemambika B, Rani MJ, Kannan VR (2011) Biosorption of heavy metals by immobilized and dead fungal cells: A comparative assessment. J Ecol Nat Environ 3(5): 168-75.
2. Granero S, Domingo JL (2002) Levels of metals in soils of Alcalá de Henares, Spain: Human health risks. Environ Int 28(3): 159-64.
3. Kadirvelu K, Senthilkumar P, Thamaraiselvi K, Subburam V (2002) Activated carbon prepared from biomass as adsorbent: Elimination of Ni (II) from aqueous solution. Bioresour Technol 81(1): 87-90.
4. Luo JM, Xiao X, Luo SL (2010) Biosorption of cadmium (II) from aqueous solutions by industrial fungus Rhizopus cohnii. Trans Nonferrous Met Soc China 20: 1104-1111.
5. Iskandar NL, Zainudin NA, Tan SG (2011) Tolerance and biosorption of copper (Cu) and lead (Pb) by filamentous fungi isolated from a freshwater ecosystem. J Environ Sci (China) 23(5): 824-830.
6. Shin MN, Shim J, You Y, Myung H, Bang KS, et al. (2012) Characterization of lead resistant endophytic *Bacillus sp*. MN3-4 and its potential for promoting lead accumulation in metal hyperaccumulator Alnus firma. J Hazard Mater 199-200: 314-320.
7. Gadd GM (2007) Geomycology: Biogeochemical transformations of rocks, minerals, metals and radionuclides by fungi, bioweathering and bioremediation. Mycol Res 111(1): 3-49.
8. D'Annibale A, Rosetto F, Leonardi V, Federici F, Petruccioli M (2006) Role of autochthonous filamentous fungi in bioremediation of a soil historically contaminated with aromatic hydrocarbons. Appl Environ Microbiol 72(1): 28-36.
9. Mansour SA, Gad MF (2010) Risk assessment of pesticides and heavy metals contaminants invegetables: a novel bioassay method using Daphnia magna Straus. Food Chem Toxicol 48: 377-89.
10. Lim SR, Schoenung JM (2010) Human health and ecological toxicity potentials due to heavymetal content in waste electronic devices with! at panel displays. J Hazard Mater 177(1-3): 251-259.
11. Glick BR (2010) Using soil bacteria to facilitate phytoremediation. Biotechnol Adv 28: 367-374.
12. Wu CH, Wood TK, Mulchandani A, Chen W (2006) Engineering plant–microbe symbiosis forrhizoremediation of heavy metals. Appl Environ Microbiol 72(2): 1129-1134.
13. Grcman H, Velikonja-Bolta S, Vodnik D, Kos B, Leštan D (2001) EDTA enhanced heavy metalphytoextraction: metal accumulation, leaching, and toxicity. Plant Soil 235: 105-114.
14. Glick BR (2003) Phytoremediation: synergistic use of plants and bacteria to clean up theenvironment. Biotechnol Adv 21: 383-393.
15. Harsh P Bais, Tiffany L Weir, Laura G Perry, Simon Gilroy, Jorge M (2006) Vivanco. The role of root exudates in rhizosphere interactions with plants and other organisms. Annual Review of Plant Biology 2006 57(1): 233-266.
16. Kapulnik Y (1991) Plant-growth-promoting rhizobacteria. In: Waisel Y, Eshel A, Kafka" U, editor Plant Roots the Hidden Half. New York: Marcel Dekker Inc pp. 347-362.
17. Kloepper JW, Schroth MN (1978) Plant growth-promoting rhizobacteria on radishes. Proceedings of the 4th International Conference on Plant Pathogen Bacteria pp. 879-82.
18. Forchetti G, Masciarelli O, Alemano S, Alvarez D, Abdala G (2007) Endophytic bacteria in sun!ower (*Helianthus annuus L.*): isolation, characterization, and production of jasmonates and abscisic acid in culture medium. Appl Microbiol Biotechnol 76: 1145-1152.
19. Perrig D, Boiero ML, Masciarelli OA, Penna C, Ruiz OA, et al. (2007) Plant- growt-hpromoting compounds produced by two agronomically important strains of Azospirillum brasilense, and implications for inoculant formulation. Appl Microbiol Biotechnol 75: 1143-1150.
20. Ryu CM, Hu CH, Locy RD, Kloepper JW (2005) Study of mechanisms for plant growthpromotion elicited by rhizobacteria in Arabidopsis thaliana. Plant and Soil 268: 285-292.
21. Aslantas R, Cakmakci R, Sahin F (2007) Effect of plant growth promoting rhizobacteria onyoung apple tree growth and fruit yield under orchard conditions. Sci Hortic 11: 371-377.
22. Sziderics AH, Rasche F, Trognitz F, Sessitsch A, Wilhelm E (2007) Bacterial endophytescontribute to abiotic stress adaptation in pepper plants (*Capsicum annuum L.*). Can JMicrobiol 53(11): 1195-1202.
23. Belimov AA, Dodd IC, Hontzeas N, Theobald JC, Safronova VI, et al. (2009) Rhizospherebacteria containing 1-aminocyclopropane-1-carboxylate deaminase increase yieldof plants grown in drying soil via both local and systemic hormone signalling. New Phytol 181 (2): 413-423.
24. Dobbelaere S, Vanderleyden J, Okon Y (2003) Plant growthpromoting effects of diazotrophs inthe rhizosphere. Crit Rev Plant Sci 22: 107-149.
25. Dimkpa CO, Merten D, Svatoš A, Büchel G, Kothe E (2009) Metal-induced oxidative stressimpacting plant growth in contaminated soil is alleviated by microbial siderophores. Soil Biol Biochem 41(1): 154-162.
26. Chakraborty U, Chakraborty B, Basnet M (2006) Plant growth promotion and induction ofresistance in Camellia sinensis by Bacillus megaterium. J Basic Microbiol 46(3): 186-95.
27. Sikora RA, Schafer K, Dababat AA (2007) Modes of action associated with microbially inducedin planta suppression of plant–parasitic nematodes. Australas Plant Pathol 36: 124-134.

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28. Ryan RP, Germaine K, Franks A, Ryan DJ, Dowling DN (2008) Bacterial endophytes: recent developments and applications. FEMS Microbiol Lett 278: 1-9.

29. Compant S, Reiter B, Sessitsch A, Nowak J, Clement C, et al. (2005) Endophytic colonization of *Vitis vinifera L.* by a plant growth-promoting bacterium, *Burkholderia sp*. StrainPsJN. Appl Environ Microbiol 71: 1685-1693.

30. Jiang CY, Sheng XF, Qian M, Wang QY (2008) Isolation and characterization of a heavy metal resistant *Burkholderia sp*. from heavy metal-contaminated paddy "eld soil and its potential in promoting plant growth and heavy metal accumulation in metal polluted soil. Chemosphere 72: 157-164.

31. Wani PA, Khan MS, Zaidi A (2007) Effect of metal tolerant plant growth promoting *Bradyrhizobium sp*. (vigna) on growth, symbiosis, seed yield and metal uptake by green gram plants. Chemosphere 70(1): 36-45.

32. Rajkumar M, Ma Y, Freitas H (2008) Characterization of metal-resistant plant- growthpromoting Bacillus weihenstephanensis isolated from serpentine soil in Portugal. J Basic Microbiol 48: 1-9.

33. Li WC, Ye ZH, Wong MH (2007) Effects of bacteria on enhanced metal uptake of the Cd/Zn hyperaccumulating plant, Sedum alfredii. J Exp Bot 58: 4173-82.

34. Safronova VI, Stepanok VV, Engqvist GL, Alekseyev YV, Belimov AA (2006) Root associatedbacteria containing 1-aminocyclopropane-1-1carboxylate deaminase improvegrowth and nutrient uptake by pea genotypes cultivated in cadmium supplementedsoil. Biol Fertil Soils 42: 267-272.

35. Duponnois R, Kisa M, Assigbetse K, Prin Y, Thioulouse J, et al. (2006) Fluorescentpseudomonads occurring in Macrotermes subhyalinus mound structures decrease Cdtoxicity and improve its accumulation in sorghum plants. Sci Total Environ 370: 391-400.

36. Rajkumar M, Ae N, Prasad MNV, Freitas H (2010) Potential of siderophore-producing bacteria for improving heavy metal phytoextraction. Trends Biotechnol 28: 142-149.

37. Barzanti R, Ozino F, Bazzicalupo M, Gabbrielli R, Galardi F, et al. (2007) Isolation and characterization of endophytic bacteria from the nickel hyperaccumulator plant Alyssum bertolonii. Microb Ecol 53: 306-16.

38. Dimkpa CO, Svatoš A, Dabrowska P, Schmidt A, Boland W, et al. (2008) Involvement of siderophores in the reduction of metal-induced inhibition of auxin synthesis in *Streptomyces spp*. Chemosphere 74(1): 19-25.

39. Chung H, Park M, Madhaiyan M, Seshadri S, Song J, et al. (2005) Isolation and characterization of phosphate solubilizing bacteria from the rhizosphere of cropplants of Korea. Soil Biol Biochem 37: 1970-1974.

40. Pal SS (1998) Interaction of an acid tolerant strain of phosphate solubilizing bacteria with a few acids tolerant crops. Plant Soil 198: 169-177.

41. Zaida A, Khan MS, Amil MD (2003) Interactive effect of rhizotrophic microorganisms on yieldand nutrient uptake of chickpea (*Cicer arietinum L.*). Eur J Agron 15-21.

42. Dobbelaere S, Vanderleyden J, Okon Y (2003) Plant growthpromoting effects of diazotrophs inthe rhizosphere. Crit Rev Plant Sci 22: 107-49.

43. Miethke M, Marahiel MA (2007) Siderophore-based iron acquisition and pathogen control. Microbiol Mol Biol Rev 71(3): 413-451.

44. Schouten A, van der Berg G, Edel-Hermann V, Steinberg C, Gautheron N, et al. (2004) Defense responses of Fusariumoxysporumto 2,4-diacetylphloroglucinol, a broad-spectrum antibiotic produced by Pseudomonas! uorescens. Mol Plant–microbe Interact 17: 1201-1211.

45. Kloepper JW, Ryu CM, Zhang S (2004) Induced systemic resistance and promotion of plant growth by *Bacillus species*. Phytopathology 94: 1259-1266.

46. van Loon LC, Bakker PAHM, Pieterse CMJ (2004) Systemic resistance induced by rhizosphere bacteria. Annu Rev Phytopathol 36: 453-483.

47. Dimkpa CO, Merten D, Svatos A, Büchel G, Kothe E (2009) Siderophores mediate reduced andincreased uptake of cadmium by Streptomyces tendae F4 and sun!ower (Helianthus annuus), respectively. J Appl Microbiol 107: 1687-1696.

48. Rajkumar M, Ae N, Prasad MNV, Freitas H (2010) Potential of siderophore-producing bacteriafor improving heavy metal phytoextraction. Trends Biotechnol 28: 142-149.

49. Carrillo-Castañeda G, Munoz JJ, Peralta-Videa JR, Gomez E, et al (2003) Plant growth-promoting bacteria promote copper and iron translocation from root to shoot in alfalfa seedlings. J Plant Nutr 26: 1801-1814.

50. Ahemad M, Kibret M (2014) Mechanisms and applications of plant growth promoting rhizobacteria: current perspective. Journal of King saud University-science 26(1): 1-20.

51. Saravanan VS, Madhaiyan M, Thangaraju M (2007) Solubilization of zinc compounds by thediazotrophic, plant growth promoting bacterium Gluconacetobacter diazotrophicus. Chemosphere 66(9): 1794-1798.

52. Braud A, Jézéquel K, Vieille E, Tritter A, Lebeau T (2006) Changes in extractability of Cr and Pb in a polycontaminated soil after bioaugmentation with microbial producers ofbiosurfactants, organic acids and siderophores. Water Air Soil Pollut 6: 3-4.

53. Sheng XF, He LY, Wang QY, Ye HS, Jiang C (2008) Effects of inoculation of biosurfactant producing *Bacillus sp*. J119 on plant growth and cadmium uptake in a cadmium amended soil. J Hazard Mater 155: 17-22.

54. Rouch DA, Lee BT, Morby AP (1995) Understanding cellular responses to toxic agents: a model for mechanism-choice in bacterial metal resistance. J Ind Microbiol 14(2): 132-141.

55. Pulsawat W, Leksawasdi N, Rogers PL, Foster LJR (2003) Anions effects on biosorption of Mn (II) by extracellular polymeric substance (EPS) from Rhizobium etli. Biotechnol Lett 25: 1267-1270.

56. Tripathi M, Munot HP, Shouche Y, Meyer JM, Goel R (2005) Isolation and functionalcharacterization of siderophore-producing lead- and cadmium-resistant Pseudomonasputida KNP9. Curr Microbiol 50: 233-237.

57. Dimkpa C, Svatoš A, Merten D, Büchel G, Kothe E (2008) Hydroxamate siderophoresproduced by Streptomyces acidiscabies E13 bind nickel and promote growth in cowpea (*Vigna unguiculata L.*) under nickel stress. Can J Microbiol 54: 163-172.

58. Madhaiyan M, Poonguzhali S, Sa T (2007) Metal tolerating methylotrophic bacteria reduces nickel and cadmium toxicity and promotes plant growth of tomatoes (*Lycopersicon esculentum L.*). Chemosphere 69(2): 220-228.

59. Chen H, Cutright TJ (2003) Preliminary evaluation of microbial mediated precipitation of cadmium, chromium, and nickel by rhizosphere consortium. J Environ Eng 129(1): 1-4.

60. Harman GE (2000) Myths and dogmas of biocontrol changes in perceptions derived from research on Trichoderma harzinum T-22," Plant Disease 84 (4): 377-393.

61. Harman GE, Howell CR, Viterbo A, Chet I, Lorito M (2004) Trichoderma species-opportunistic, avirulent plant symbionts," Nature Reviews Microbiology 2(1): 43-56.

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62. McBride MB, Environmental Chemistry in Soils. Oxford: Oxford Univ. Press; 1994. 406.

63. Rodriguez RJ, Henson J, Van Volkenburgh E et al. (2008) Stress tolerance in plants via habitat- adapted symbiosis. ISME J 2(4): 404-416.

64. Deng Z, Zhang R, Shi Y, Tan H, Cao L (2014) Characterization of Cd-, Pb-, Zn-resistant endophytic *Lasiodiplodia sp.* MXSF31 from metal accumulating Portulaca oleracea and its potential in promoting the growth of rape in metal-contaminated soils. Environ Sci Pollut Res 21(3): 2346-2357.

65. Redman RS, Kim YO, Woodward CJDA, Greer C, Espino L, (2011) Increased fitness of rice plants to abiotic stress via habitat adapted symbiosis: a strategy for mitigating impacts of climate change. PLoS One 6: e14823.

66. Joshi P K, Anand Swarup, Sonu Maheshwari, Raman Kumar, Namita Singh (2011) Bioremediation of Heavy Metals in Liquid Media Through Fungi Isolated from Contaminated Sources. Indian J Microbiol 51(4): 482-487.

67. FazliMehran Mohammadian, Negin Soleimani, Mohammadreza Mehrasbi, Sima Darabian, Jamshid Mohammadi, et al. (2015) Highly cadmium tolerant fungi: their tolerance and removal potential. Journal of environmental health science & engineering 13: 19.

68. Jenny Choo, Nuraini Binti Mohd Sabri, Daniel Tan, Aazani Mujahid, Moritz Müller (2015) Heavy Metal Resistant Endophytic Fungi Isolated from Nypa fruticans in Kuching Wet land National Park Ocean Sci J 50(2): 1-9.

69. Rogelio Carrillo-González, Ma del Carmen A, González-Chávez (2012) Tolerance to and Accumulation of Cadmium by the Mycelium of the Fungi Scleroderma citrinum and Pisolithus tinctorius. Biol Trace Elem Res 146(3): 388-395.

70. Tan T, Cheng P (2003) Biosorption of metal ions with Penicillium chrysogenum, Applied Biochemistry and Biotechnology, 104: (2) 119-128.

71. Ban Y, Tang M, Chen H, Xu Z, Zhang H, et al. (2012) The response of dark septate endophytes (DSE) to heavy metals in pure culture. PLoS One 7(10): 47968.

72. Wang LK, Chen JP, Hung YT, Shammas NK (2009) Heavy Metals in the Environment. Advances in Industrial and Hazardous Wastes Treatment, CRC Press.

73. Filipović-Kovačević Ž, Sipos L, Briški F (2000) Biosorption of chromium, copper, nickel and zinc ions onto fungal pellets of Aspergillus niger 405 from aqueous solutions. Food TechnolBiotechnol 38: 211-216.

74. Huang Haiwei, Lixiang Cao, Yuxuan Wan, Renduo Zhang, Wenfeng Wang (2012) Biosorption behavior and mechanism of heavy metals by the fruiting body of jelly fungus (Auricularia polytricha) from aqueous solutions: Applied microbiology and biotechnology 96(3): 829-840.

75. Kowshik M, Nazareth S (2000) Metal tolerance of Fusarium solani. Ecol Env and Cons 6: 391-395.

76. Hongmei AN, Yan Liu, Xinfei Zhao, Qian Huang, Shenhong Yuan, et al. (2015) Characterization of cadmium-resistant endophytic fungi from Salixvariegata Franch. in Three Gorges Reservoir Region, China. Microbiological Research 176: 29-37.

77. Deng Zujun, Renduo Zhang, Yang Shi, Li‟ao Hu, Hongming Tan, et al. (2014) Characterization of Cd-, Pb-, Zn-resistant endophytic *Lasiodiplodia sp.* MXSF31 from metal accumulating Portulaca oleracea and its potential in promoting the growth of rape in metal-contaminated soils .Environ Sci Pollut Res 21(3): 2346-2357.

78. Anzhi Ren, Chuan Li, Yubao Gao (2011) endophytic fungus improves growth and metal uptake of lolium arundinaceum darbyshire ex. schreb. Int J Phytoremediation 13: 233-243.

79. Mohsen Soleimani, Mohammad A Hajabbasi, Majid Afyuni, Aghafakhr Mirlohi, Ole K Borggaard, et al. (2010) Effect of Endophytic Fungi on Cadmium Tolerance and Bioaccumulation by Festuca Arundinacea and Festuca Pratensis. Int J Phytoremediation 12(6): 535-549.

80. Olivier Paul Redon, Thierry Béguiristain, Corinne Leyval (2009) Differential effects of AM fungal isolates on Medicago truncatula growth and metal uptake in a multi metallic (Cd, Zn, Pb) contaminated agricultural soil. Mycorrhiza 19:187-195.

81. KanwalSadia, Asma Bano, Riffat Naseem Malik (2015) Effects of Arbuscular Mycorrhizal Fungi on Metals Uptake, Physiological and Biochemical Response of Medicago Sativa Lwith Increasing Zn and Cd Concentrations in Soil. American Journal of Plant Sciences. 6: 2906-2923.

82. Sani A, Nagam V, Netala VR, Tartte V (2017) Screening and identification of heavy metal- tolerant endophytic fungi Lasiodiplodia theobromae from Boswellia ovalifoliolata an endemic plant of Tirumala hills. Asian J Pharm Clin Res 10(3): 488-491.

83. Hussain A, Shah M, Hamayun M, Qadir M, Iqbal A (2022) Heavy metal tolerant endophytic fungi Aspergillus welwitschiae improves growth, ceasing metal uptake and strengthening antioxidant system in Glycine max L. Environ Sci Pollut Res Int 29(11): 15501-15515.

84. Su Z, Zeng Y, Li X, Perumal AB, Zhu J, et al. (2021) The endophytic fungus Piriformospora indica-assisted alleviation of cadmium in tobacco. J Fungi 7(8): 675.

85. Ignatova L, Kistaubayeva A, Brazhnikova Y, Omirbekova A, Mukasheva T, et al. (2021) Characterization of cadmium- tolerant endophytic fungi isolated from soybean (Glycine max) and barley (Hordeum vulgare). Heliyon 7(11): e08240.

86. Li X, Li W, Chu L, White Jr JF, et al. (2016) Diversity and heavy metal tolerance of endophytic fungi from Dysphania ambrosioides, a hyperaccumulator from Pb–Zn contaminated soils. Journal of Plant Interactions 11(1): 186-92.

87. Salazar-Ramírez G, Flores-Vallejo RD, Rivera-Leyva JC, Tovar-Sánchez E, Sánchez- Reyes A, et al. (2020) Characterization of fungal endophytes isolated from the metal hyperaccumulator plant Vachellia farnesiana growing in mine tailings. Microorganisms 8(2): 226.

88. Pietro-Souza W, de Campos Pereira F, Mello IS, Stachack FF, Terezo AJ, et al. (2020) Mercury resistance and bioremediation mediated by endophytic fungi. Chemosphere 240: 124874.

89. Strobel G, Daisy B (2003) Bioprospecting for Microbial Endophytes and Their Natural Products Bioprospecting for Microbial Endophytesand Their Natural Products. Microbiol Mol Biol Rev 67: 491-502.

90. Schulz BJE. Mutualistic interactions with fungal root endophytes. Microbial Root Endophytes 9: 261-279.

91. AlyAH, Debbab A, Proksch P (2011) Fungal endophytes: Unique plant inhabitants with great promises. Appl Microbiol Biotechnol 90: 1829-1845.

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