Eco. Env. & Cons. 30 (February Suppl. Issue) : 2024; pp. (S202-S205)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2024.v30i02s.041

Heavy Metal Resistant Bacteria in Rhizospheric Soil: A Review

Indrani Gogoi[1]* and Kalyan Das[2]

[1]Department of Life Sciences, Dibrugarh University, Dibrugarh 786 004, Assam, India
[2]Department of Botany, J.B. College (Autonomous), Jorhat 785 001, Assam, India

(Received 22 July, 2023; Accepted 7 September, 2023)

ABSTRACT

Concern over heavy metal contamination is a common issue related to soil health. Soil is an excellent habitat for various microbes. Microbial activities in soil are negatively impacted by high concentrations of heavy metals. The physico-chemical changes of soil microorganisms are recognized as a sensitive indicator to assess soil quality. Some plants can absorb metals, and eventually, through food chains, humans and other animals are exposed to them. As a result of ongoing exposure to heavy metals, the rhizospheric bacteria of metal accumulator plants develop intrinsic or extrinsic resistance mechanisms. Through their critical contribution to metal detoxification, these resistance mechanisms either directly or indirectly support plant growth and development. Therefore, it is crucial to look into the correct mechanisms of plant-rhizospheric microbe interaction in metal-contaminated soils. The current review sought to highlight the metal-resistant bacterial communities in rhizospheric soils and their part in plant health management.

Key words*: Metal contamination, Rhizosphere, Nodulation, Resistance mechanisms, Soil*

Introduction

Heavy metals are widely distributed in the environment and are considered significant contaminants of soil pollution. Even while all metals are toxic, many of them are advantageous in trace amounts. Metals having a density above 5 g/cm^3 are heavy metals (Nies, 1999). The key characteristics that set heavy metals apart from other harmful contaminants are their inability to degrade through biodegradation and their tendency to accumulate in living things. The unrestricted use of agrochemicals, prolonged application of urban sewage, disposal of industrial waste products, and vehicle exhausts are the primary sources of heavy metals in soils. High levels of heavy metals in the soil cause plants to absorb and accumulate them, and eventually, through the food chain, these metals reach animals and humans (Zhuang *et al.,* 2014). Such accumulation causes serious abiotic stress that impairs human and animal health as well as soil biodiversity and lowers plant productivity. Due to heavy metal stress, there is an increase in reactive oxygen species, hydroxyl, superoxide radical and hydrogen peroxide production which are very harmful to plants (Eltahawy *et al*., 2022; Li *et al.*, 2022).

Soil bacteria are an integral part of the ecosystems and by participating in mineral cycles and decomposing organic matter, they play a crucial role in the environment. The presence of heavy metals in excessive amounts also affects the growth and survival of soil bacterial populations (Bååth, 1989). Heavy metals inhibit enzymatic cellular activities inside bacterial cells by disrupting membrane functions and

([2]Associate Professor)

damaging DNA (Matyar, 2012). Although, for many cellular functions of bacteria, low quantities of specific transition metals like cobalt, copper, nickel, and zinc are crucial. But, heavy metals, such as lead, cadmium, mercury, silver, and chromium, are harmful even at low doses and have no recognized benefits for bacterial cells) (Abou-Shanab *et al.*, 2007). Therefore, many researchers marked soil microbial activities as an important indicator to determine soil degradation by heavy metals.

Soil bacteria adapt various types of resistance mechanisms in response to continuous exposure to heavy metals. Those mechanisms may be intrinsic or extrinsic. Usually, the heavy metal resistance encoding genes are located on the plasmid, but some are reported from the chromosomes of the bacteria also. Such resistance genes carrying bacteria are common in contaminated soils and rhizospheres of roadside plants and play an important role in the enhancement of plant health. There are several bacteria isolated from polluted areas which are found to be very efficient plant growth promoters that could produce siderophores, indole acetic acid and solubilize the phosphate (Tirry *et al.*, 2018). Thus, the importance of the rhizosphere bacterial ecology of roadside plants and their role in heavy metal resistance will be emphasized in the current review.

Rhizosphere bacterial communities

With so many advantages to plant growth and development, the rhizosphere of plants offers a great microhabitat to a wide variety of bacterial species. Through active mineral cycling, the deposition of organic matter, and mineral weathering, rhizosphere bacteria work as the primary nutrition reserve for plants. Rhizosphere refers to the portion of soil that is exposed to root activity. Rhizosphere includes the rhizosphere microbiome which is <3–5 mm from the root, the rhizoplane microbiome at root–soil interface, and the interior root microbiome (Coats and Rumpho, 2014). A variety of microorganisms that make up the rhizosphere, affect plant health and adaptation, either directly or indirectly (Dlamini *et al.*, 2022). Several studies have demonstrated that the major part of the plant root surface is devoid of bacteria. Scanning electron microscopy (SEM) investigations showed that bacteria only occupied a small percentage of the root surface in the roots of several plants, such as wheat, clover, and rye. Microorganisms generally follow a definite pattern of colonization and therefore they are not randomly distributed on roots.

The roots of plants secret different organic compounds which enhances the bacterial population in the rhizosphere zone. The secretion of enzymes, oxygen, ions, mucilage, a variety of carbon-containing compounds, and secondary metabolites including sterols are all included in root exudation. The root exudate's composition varies from plant to plant, so the host plant creates selection pressure on the growth rhizosphere microbiome by favouring and attracting a particular plant microbiota. Investigations revealed that as a result of substrate availability through root extrudes, the rhizosphere soils contain higher bacterial biomass compared to rootless (bulk) soil (Odelade and Babalola, 2019). Some common genera reported to be isolated in rhizosphere soils are *Bacillus, Microbacterium, Azospirillum, Serratia, Pseudomonas, Burkholderia, Erwinia, Acinetobacter, Enterobacter, Mesorhizobium* and *Acetobacter* (Mohamed and Abo-Amer, 2012). Traditionally, the common culture-based method for isolating and characterizing microorganisms was used to identify bacterial isolates in the rhizosphere.Using this conventional method, one can only identify a small number of genera. As a result, high throughput sequencing has recently been recommended by researchers for the accurate identification of rhizosphere bacterial populations.

Bacterial heavy metal resistance

Bacteria have been examined to develop different efficient mechanisms of heavy metals tolerance. When bacteria become exposed to heavy metal ions, they usually adopt two types of metal uptake systems to combat this problem. The first one is constitutively expressed in the bacterial cells and forms a chemiosmotic gradient across the cell cytoplasm. In the second type of uptake system, ATP is hydrolysed to get energy during the process (Nies, 1999). Moreover, bacterial cells acquire a large number of plasmids-mediated heavy metal resistance genes via vertical and horizontal gene transfer. In a study, these resistance genes were found in *Acinetobacter* spp. (Argudín *et al.*, 2019). Later on, *Staphylococcus aureus, Bacillus subtilis, Bacillus cereus, Pseudomonas* sp. and *Bordetella* sp. isolated from Egyptian soils were also found to exhibit metal resistance genes. *mer, chr, czc, ncc,cadA, cadB, cuoO, cuoP, golT* etc. are some examples of bacterial genes responsible for metal resistance (Eltahawy *et al.*, 2022).

Table 1. Some important metal-resistant bacteria isolated from different rhizosphere soils

Heavy metal	Metal resistant bacteria	Host plants	References
Cr, Zn, Cu	*Cellulosimicrobium* sp	-	(Tirry *et al*., 2018)
Hg, Zn, Cr, Ni	*Microbacteriumarabinogalactanolyticum*	*Alyssum murale*	(Abou-Shanab *et al*., 2007)
Zn, Cd	*Agromyces*	*Salix caprea*	(Kuffner *et al*., 2008)
Pb, Zn	*Acinetobacter*	*Boehmeria nivea*	(Ziang *et al*., 2017)
Pb, Zn, Cd, Cu	*Alcaligenes faecalis, Bacillus cereus*	*Sorghum vulgare*	(Abou-Aly *et al*., 2021)
Cd	*Enterobacter bugandensis*	lettuce	(Han *et al*., 2020)
Cd, Zn, Ni	*Pseudomonas*, *Azotobacter*, *Shewanella*	*Avicennia marina*	(Balakrishnan *et al*., 2017)
V	*Pseudomonas*, *Microbacterium*	*Brassica juncea*	(Wang *et al*., 2020)
Ni	*Cupriavidus*, *Pseudomonas*, *Bacillus*	*Rinorea bengalensis*	(Pal *et al*., 2007)

Exposure of heavy metals to rhizosphere bacteria

Soils are the major sink for metal contamination where the concentration of metals can range from 1 to 1000000 mg/kg in a typical contaminated soil. In contaminated soils, soil microorganisms, particularly those in the rhizosphere, play a crucial role in heavy metal detoxification. 'Rhizoremediation' is the term used to describe this input of the rhizosphere microbial population (Bååth, 1989). Firmicutes, Proteobacteria, Actinobacteria and some selected genera such as *Bacillus, Pseudomonas, Arthrobacter* are abundantly found bacteria in heavy metal-contaminated soils (Pires *et al.,* 2017). Heavy metal stress limits the nodulation and nitrogenase activities, however, in some nodulated plants heavy metal tolerant rhizosphere bacteria were also found to be reported carrying out symbiotic nitrogen fixation. Heavy metal-microbe interactions in the rhizosphere are extremely complex phenomena and somehow depend on the physicochemical makeup of the soil, the concentration of metal species, and microbial diversity. Root exudates play a significant role in the activity of rhizosphere microbes by modification of pH and redox potential and increasing or decreasing metal bioavailabilityin heavy metal-deposited soils. The presence of heavy metals in soils changes the concentration of root exudates which is a developing biomarker of soil contamination. A recent study based on gas chromatography-mass spectrometry and metabolomics revealed that Pb stress can change the root exudates concentration of *Sedum alfredii,* which established it as a potential biomarker of Pb-contaminated soil (Luo *et al*., 2017).

Heavy metal-resistant bacteria isolated from rhizosphere zones of different plants

Molecular identification and next-generation sequencing of heavy metal-resistant bacteria isolated from rhizosphere zones have opened up great potential for environmental management. Researchers investigated a wide range of important rhizosphere bacteria that can enhance the phytoextraction of heavy metals from contaminated soils.

Conclusion

Heavy metal-contaminated soil effectively increases the stress tolerance of plants in the presence of rhizosphere bacteria. However, more field research is needed to better understand soil metal contamination and stress tolerance output of microbial communities. In this regard, a better comprehension of root-microbe interactions and precise identification of metal-resistant bacterial genes involved in stress responses would be useful for future applications in the treatment of contaminated soils and phytoremediation.

Conflict of Interest

The authors declare no competing interests that are relevant to the content of this article.

References

Abou-Aly, H.E., Youssef, A.M., Tewfike, T.A., El-Alkshar, E.A. and El-Meihy, R.M. 2021. Reduction of heavy metals bioaccumulation in sorghum and its rhizosphere by heavy metals-tolerant bacterial consortium. *Biocatal. Agric. Biotechnol.* 31: 101911.

Abou-Shanab, R.A.I., van Berkum, P. and Angle, J.S. 2007. Heavy metal resistance and genotypic analysis of metal resistance genes in gram-positive and gram-negative bacteria present in Ni-rich serpentine soil and in the rhizosphere of Alyssum murale. *Chemosphere.* 68: 360–367.

Argudín, M.A., Hoefer, A. and Butaye, P. 2019. Heavy metal resistance in bacteria from animals. *Res. Vet. Sci*. 122: 132–147.

Bååth, E. 1989. Effects of heavy metals in soil on microbial processes and populations (a review). *Water. Air. Soil*

Pollut. 47: 335–379.

Balakrishnan, B., Sahu, B.K., Kothilmozhian Ranishree, J., Lourduraj, A.V., Nithyanandam, M., Packiriswamy, N. and Panchatcharam, P. 2017. Assessment of heavy metal concentrations and associated resistant bacterial communities in bulk and rhizosphere soil of *Avicennia marina* of *Pichavaram mangrove*, India. *Environ. Earth Sci*. 76: 1–10.

Coats, V.C. and Rumpho, M.E. 2014. The rhizosphere microbiota of plant invaders: An overview of recent advances in the microbiomics of invasive plants. *Front. Microbiol.* 5: 368.

Dlamini, S.P., Akanmu, A.O. and Babalola, O.O. 2022. Rhizospheric microorganisms: The gateway to a sustainable plant health. *Front. Sustain. Food Syst.* 6:925802.

Eltahawy, A.M.A.E., Awad, E.S.A.M., Ibrahim, A.H., Merwad, A.R.M.A. and Desoky, E.S.M. 2022. Integrative application of heavy metal–resistant bacteria, moringa extracts, and nano-silicon improves spinach yield and declines its contaminant contents on a heavy metal–contaminated soil. *Front. Plant Sci*. 13: 1–18.

Gupta, R., Singh, A., Srivastava, M., Shanker, K. and Pandey, R. 2019. Plant-microbe interactions endorse growth by uplifting microbial community structure of Bacopa monnieri rhizosphere under nematode stress. *Microbiol. Res.* 218: 87-96.

Han, H., Wu, X., Yao, L. and Chen, Z. 2020. Heavy metal-immobilizing bacteria combined with calcium polypeptides reduced the uptake of Cd in wheat and shifted the rhizosphere bacterial communities. *Environ. Pollut*. 267: 115432.

Kuffner, M., Puschenreiter, M., Wieshammer, G., Gorfer, M. and Sessitsch, A. 2008. Rhizosphere bacteria affect growth and metal uptake of heavy metal accumulating willows. *Plant Soil.* 304: 35–44.

Li, X., Zhou, T., Li, Z., Wang, W., Zhou, J., Hu, P., Luo, Y., Christie, P. and Wu, L. 2022. Legacy of contamination with metal(loid)s and their potential mobilization in soils at a carbonate-hosted lead-zinc mine area. *Chemosphere.* 308: 136589.

Luo, Q., Wang, S., Sun, L.N. and Wang, H. 2017. Metabolic profiling of root exudates from two ecotypes of Sedum alfredii treated with Pb based on GC-MS. *Sci. Rep*. 7: 1–9.

Matyar, F. 2012. Antibiotic and heavy metal resistance in bacteria isolated from the Eastern Mediterranean Sea coast. *Bull. Environ. Contam. Toxicol*. 89: 551–556.

Mohamed, R.M. and Abo-Amer, A.E. 2012. Isolation and characterization of heavy-metal resistant microbes from roadside soil and phylloplane. *J. Basic Microbiol.* 52: 53–65.

Nies, D.H. 1999. Microbial heavy-metal resistance. *Appl. Microbiol. Biotechnol*. 51: 730–750.

Odelade, K.A. and Babalola, O.O. 2019. Bacteria, fungi and archaea domains in rhizospheric soil and their ef^fects in enhancing agricultural productivity. *Int. J. Environ. Res. Public Health.* 16(20): 3873.

Pal, A., Wauters, G. and Paul, A.K. 2007. Nickel tolerance and accumulation by bacteria from rhizosphere of nickel hyperaccumulators in serpentine soil ecosystem of Andaman, India. *Plant Soil.* 293: 37–48.

Pires, C., Franco, A. R., Pereira, S. I., Henriques, I., Correia, A., Magan, N. and Castro, P. M. 2017. Metal (loid)-contaminated soils as a source of culturable heterotrophic aerobic bacteria for remediation applications. *Geomicrobiol. J.* 34(9): 760-768.

Tirry, N., Tahri Joutey, N., Sayel, H., Kouchou, A., Bahafid, W., Asri, M. and El Ghachtouli, N. 2018. Screening of plant growth promoting traits in heavy metals resistant bacteria: Prospects in phytoremediation. *J. Genet. Eng. Biotechnol*. 16: 613–619.

Wang, L., Lin, H., Dong, Y., Li, B. and He, Y. 2020. Effects of endophytes inoculation on rhizosphere and endosphere microecology of Indian mustard (*Brassica juncea*) grown in vanadium-contaminated soil and its enhancement on phytoremediation. *Chemosphere* 240: 124891.

Zhuang, P., Lu, H., Li, Z., Zou, B. and McBride, M.B. 2014. Multiple exposure and effects assessment of heavy metals in the population near mining area in South China. *PLoS One.* 9: 1–11.