Potential of plant growth promoting bacteria to alleviate chromium pollution.

Shovana Pal[1], Keshab Ghosh[1], Ayan Ghorui[1], Subhajit pal[1], Monalisa Mallick[1], Sudip Sengupta[2], Aritri Laha[1*]

[1]Depertment of Microbiology, School of Life Sciences, Swami Vivekananda University Barrackpore, 700121, West Bengal, India
[2]School of Agriculture, Swami Vivekananda University, Barrackpore, 700121, West Bengal, India
[*]Corresponding Author. E-mail: *lahaaritri@gmail.com*

Abstract: -Heavy metals (chromium, lead, cadmium, mercury, arsenic) is a threat to environment. The chromium (Cr) is one of the lethal heavy metals which affects biological activities of living systems. The two most important form of Cr, Cr (III) and Cr (VI) are more stable in environment. The plant growth also effected by the high concentration of Cr (VI). The biological remediation is a eco-friendly and low cost remediation options of heavy metals. A bunch of plant growth promoting bacteria (PGPB) can resist the toxic Cr and also able to carry their PGPB attributes. Recent studies have discussed the use of heavy metal resistant-PGPBs (*Bacillus sp., Azospirillum sp.*) to increase agricultural output without metal build-up in plant tissues. This review describes the mechanisms of Cr tolerant-PGPBs (which alleviate metal stress to plants) and its application in agriculture.
Keywords: Cr, Cr (III),Cr (VI), Bacteria, PGPB, Bioremediation

Introduction: - As the main drivers of a nation's development, urbanization is the economic actions to support the country's economy. However, there are some negative side effects that are concurrently impeding the development process as a whole. Despite the fact that some industrial goods might be harmful to people, simple by promptly giving consumers the items they need. To meet the needs of modern life in both the economic and social spheres, more industrialization is imperative. But these expanding sectors are seriously harming the environment and, eventually, people's health (Yadav and Pathak, 2013).

Heavy metal pollution is one of the major environmental problems, and the rise in the number of environmentally destructive businesses is mostly to blame. The chemical industries disrupt natural processes and pollute the air, water, and soil, among other things. Heavy metals from industrial sources eventually find their way into the food chain and pass through membranes, disrupting the process of photosynthesis (Mushtaq et al., 2021). The most crucial characteristic of heavy metals is that they cannot biodegrade, remain into the body and only can be changed into less hazardous forms (Shanker et al., 2005).
Freshwater, minerals, and rocks all contain chromium, a geochemical element that is extensively distributed. There are various oxidation states in which chromium can exist, but its two most stable forms are hexavalent (Cr-VI) and trivalent chromium (Cr-III) (Prasad et al., 2021). Hexavalent chromium is a carcinogen and mutagen to biological organisms due to its potent oxidising properties. Chromium has been designated as a priority contaminant by a number of organisations, including the United States Environmental Protection Agency (USEPA) (Mushtaq et al., 2021). The main cause of chromium toxicity is the metal's ease of passage through the intercellular barrier, which causes more

hazardous intracellular Reactive Oxygen Species (ROS). Cr (VI) is 1000 times more dangerous and 100 times more mutagenic than Cr (III). Trivalent chromium, on the other hand, is considered to be a metal that is advantageous to humans due to its function in management of cholesterol, triglycerides, and glucose. (Zhitkovich et al., 2001).

Chromium and its Occurrence

After arsenic, Cr is the second-most significant pollutant in soil, sediments, and basement water (Kar et al., 2008). The transition metal Cr has an atomic weight of 52.9, a density of 7.16 g/cm3 at 293 K, and an atomic volume that ranges from 7.23 to 7.56 cm^3mol. Various geographical areas have different levels of chromium. The chromium (III), which is less hazardous since it is immobile and is necessary for human metabolism of glucose and fat at low concentrations. When the levels of chromium (VI) are 1.86 ppm at a depth of 0–45 cm and 194.67 ppm for Cr(III), the soil is contaminated (Gustafsson et al., 2014).

The Cr is most frequently used in industries and also is primarily used in a variety of processing methods, such as Catalytic and electroplating production. Finally result is that metal pollution causes the ecosystem to become more contaminated every day. This contamination with metal increases the accessibility of chromium in both soil and water, as like as its bioavailability and biomobility. Industries are primarily to blame the leather sector is the largest source of this metal contamination and also have a significant role in poisoning the environment, particularly with chromium. Around 12,000 tonnes of chromium were reportedly discharged into water bodies per year (Fishbein, 1981).

Cr and its derivatives are used in numerous businesses, including those that produce drilling mud, electroplating cleaning products, refractory steel, and catalytic manufacturers. As a result, the addition of chromium is continuously damaging the environment in one way or another. The yearly global production of chromate has topped 10 million tonnes (Laurenti et al., 2017).

Chromium Effect in Plants

Chromium significantly slows down plant growth and development. Plants that are exposed to chromium suffer from reduced root length, plant biomass, and plant height. Moreover, Cr(VI) toxicity in plants shows a significant impact on the dry matter and yield of the plant. For the vast nearly all plants listed by Suwalsky et al. (2008), the permissible amount which is dangerous is believed to be higher than 0.05 mg/L.

Plants are subjected to lipid peroxidation due to oxidative damage caused by chromium, which severely damages cell membranes. Chemicals related to photosynthetic processes start to decay when a plant is under oxidative stress, which slows down overall plant development.

As the Cr concentration increases the chloroplast structure is initially altered by concentrations exceeding the permitted limit. Chromium affects how plants react to antioxidants in a similar way. Chromium also has an impact on the catalytic activity of such antioxidant enzymes as CAT, POX, and SOD. Cr (III) is less dangerous than chromium (VI) because it is less mobile, which serves as an oxidising agent and cannot cross the plasma membrane. Cr is incredibly dangerous because it generates reactive oxygen species including superoxide radicals and hydrogen. Because of their capacity to oxidize nucleic acid, lipids, and protein. So the agronomic and physiological parameters of the plants are disturbed, nitrogen and sulphur metabolism are both lowered, and when plants are grown in soil that has been contaminated with Cr, it also affects the plant's nutritional state. (Panda and Choudhury, 2005).

Chromium toxic effects in Human

In comparison between Cr (III) and Cr (VI), Cr(VI) is primarily responsible for all carcinogenic activities. Asthmatic reactions can occasionally be very noticeable with respiratory exposures despite all the negative effects of Cr. It contributes to dermatitis allergies, nasal septum perforations, and a few cases of lung cancer. Heavy metal exposure can cause serious diseases affecting humans, including cancer, neurological conditions, renal pathology, and respiratory problems. For example, chromium is a carcinogen and has been linked to respiratory issues as well as skin blemishes. The International Agency for Research on Cancer (IARC) has classified the chemical chromium (VI) as a Group-I human carcinogen because it significantly affects a person's biological system. A living thing has a good likelihood of dying if the amount of chromium is above a certain threshold. Chromium is to blame for a variety of human illnesses, including birth abnormalities, early birth, and brain damage. There must be some acceptable techniques that can be used to combat this metal pollution if we are to prevent such a serious health risk brought on by it. We need to keep an eye out for metal contamination as this trend continues (Mushtaq et al.,2022).

The three primary stable forms of chromium that are known to exist in nature are metallic chromium, trivalent chromium, and hexavalent chromium. Its level of toxicity is influenced by its potency and exposure route. Trivalent chromium, which can be found in a variety of forms in nature, is an important dietary trace element for human health. It also improves the function of insulin and is used to treat all forms of diabetes. On the other hand, consuming hexavalent chromium is harmful to human health (Pellerin & Booker 2000; Liang et al. 2021). Hexavalent chromium, according to international research, may play a key role in the body's digestive, gastrointestinal, urinary, reproductive, respiratory, and immunological systems.

Removal of Cr

Numerous papers have looked at how to effectively use PGPR to minimise Cr (VI) bioavailability and plant Cr absorption. The basic principles behind how the two Cr (VI) bioremediation methods—biotransformation, which converts highly flammable and mobile Cr (VI) into the harmless form Cr (III), and biosorption, which solubilizes Cr (VI) by bacteria and biologically derived materials—work are the same. Through a process known as "bio-assisted phytoremediation," the interaction between plants and rhizosphere bacteria significantly improves the efficiency of phytoremediation.

PGPR resistant to heavy metals may be able to lessen heavy metal stress by fostering plant development. Through techniques of biocontrol and growth promotion (VI), the PGPR can also enhance plant growth and resistance to Cr. Its components include bacterial release of extracellular polymeric substances (EPS), formation of antioxidant enzymes to scavenge ROS, activation of phytohormones, reduction of stress-induced ethylene synthesis by the enzyme ACC (1-aminocyclopropane-1-carboxylate) deaminase, synthesis of ammonia, HCN, and siderophores, phosphate solubilization, nitrogen fixation, and release of ammonia, HCN, and siderophores.

Such PGPR may be crucial for phytoextraction and plant growth due to its various Cr resistance properties paired with plant growth stimulation. In order to better understand how particular Cr (VI)-resistant PGPR interact with M. sativa species to reduce Cr stress and increase Cr (VI) bioremediation, marijuana experiments were conducted (Mushtaq et al., 2022).

Microbial Aproaches of Cr (VI) contamination

Many bacteria have been discovered that can colonizes and adapt to habitats that are contaminated with metal. Chromium-reducing bacterial strains must be isolated and purified before being used in bioremediation. Heavy metals and microbes are currently the subject of a lot of discussion. Microbial remediation is a process that swiftly reduces hazardous environmental pollutants in soil, water, and sludge to a level that is safe. It makes use of metal-tolerant bacteria.

In order to fight chromium toxicity, microorganism research is of vital relevance to the biotechnology industry. Microorganisms use biosorption, bioaccumulation, and oxidation-reduction reactions to detoxify substances. One of these essential microbial strategies, according to some experts, is the biological reduction of extremely carcinogenic, mobile, and poisonous Cr (VI). The second school of thought, on the other hand, maintained that Due to its reusability and inexpensive initial outlay, biosorption is a realistic and promising option.

The three techniques to microbial chromium reduction that are most effective and promising are (a) Biosorption, (b) Biotransformation and (c) Bioabsorption (Mushtaq et al.,2022).

Cr (Vl) Biosorption

A biological substance (bio-sorbent) interacts with a metal species (sorbate) in a physical-chemical process known as biosorption. Whether a bacterium is active or dormant has no bearing on this slow process. The use of dead biomass has a number of benefits over the use of living cells, including the elimination of the need for supplemental nutrition, resistance to poisoning or unfavourable working conditions, facilitated recovery of metal by processes which enable biomass regeneration, and greater availability of the biomass. Yet, live cells display a variety of metal accumulating processes, such as movement, creation of extracellular complexes, and precipitation. These procedures, which could also involve physicochemical and metabolic absorption mechanisms, are not mutually exclusive.

Numerous fungi and bacteria have been found to bioaccumulate Cr. From decreased Cr (VI), *Alishewanella sp.* WH16-1 creates Cr (III) nanoparticles. Cr (VI) is absorbed by CHR-1 and accumulates in the Neurospora crassa vacuolar system, increasing Cr (VI) resistance. Microorganisms are advantageous as biosorbents because to their high surface-to-volume ratio and cheap production of biomass. Along with fungus, yeasts, and bacteria, algae, microalgae, and cyanobacteria all have been employed when heavy metals are removed. The ability to remove Cr has been established for each biosorption approach (VI). In murky aquatic environments, it's also critical to include macrophytes, plant, fruit, and vegetable wastes, and inorganic substances (Saba et al.,2019).

Cr (VI) to Cr (III) transformation

Cr (VI) breaks down DNA by inducing oxidative stress within the cells, but Cr (III) is more toxic and more difficult to reach the cells. Therefore, changing Cr (VI) to Cr (III) is a crucial tactic for dealing with Cr. Numerous microorganisms, including bacteria, yeasts, actinomycetes, fungi, and algae, have the capacity to lower Cr(VI). Enzymatic and nonenzymatic microbial Cr (VI) reduction are the two types. Several reducing agents, including GSH, vitamin C, cysteine, H2S, and mercapto groups, cause nonenzymatic reduction. The enzymatic reduction process is influenced by the ambient oxygen level.

It has been established that the majority of aerobic Cr (VI) reductases are intracellular. NfsA, NfsB, NemA, ChrR, YieF, and FerB are a few of the soluble reductases found in the internal membranes of bacteria. Others include Cr (VI) most frequently, AzoR, Frp, YcnD, NfoR, and CsrF. There are several familiesuctases, including ChrR, OYE, NemA, YieF, NfoR, and NfsA. Cofactors NAD(P)H and Flavin serve as an electron donor for these enzymes. Despite having identical co-factors and electron donors, they use different electron transport routes. A two-step electron transfer mechanism, for instance, is used by the ChrR to transport electrons (Mushtaq et al., 2021).

Cr (VI) uptake and efflux

Since their chemical compositions are similar, Cr (VI) can enter cells through SO42 transporters. Many microorganisms, such as S. oneidensis MR-1, P. putida F1, and Cupriavidus metallidurans CH34, exhibit elevated sulphate transporter-related genes when Cr (VI) is present. Crescent-shaped Caulobacter CB15 N. However, during Cr (VI) stress, the SO42 transporter is downregulated. Through efflux (VI), microbes can also withstand Cr. Numerous Cr (VI) resistant bacteria include the efflux protein ChrA. ChrA is an efflux mechanism in Pseudomonas aeruginosa PAO1 with a Km of 0.12 mM Cr (VI) and a Vmax of 0.5 nmol Cr (VI)/min per mg of protein.

Many Cr-resistant bacteria have ChrA on their chromosomes or plasmids. In addition to the chrB, chrC, chrE, chrF, chrI, chrL, and chrK genes, these bacteria also have the chrA gene. ChrC is engaged in cellular oxidative stress mitigation, whereas ChrB is a chromate-sensing regulator. ChrE may contribute to the breakdown of particular chromium-glutathione complexes. Cr (VI) resistance is significantly influenced by efflux proteins. Therefore, one approach to getting past the restriction may involve employing Cr (VI) efflux proteins in these bacteria (Mushtaq et al., 2022).

Plant growth promoting rhizobacteria (PGPR)

The soil bacteria in the rhizosphere are some of the most crucial for plant growth. The term “plant growth promoting rhizobacteria” refers to this diverse group of microbes, and the majority of these strains come from the genera *Bacillus, Azospirillum, Burkholderia, Pseudomonas, Rhizobium, Acinetobacter, Erwinia, Serratia, Alcaligenes, Enterobacter, Arthrobacter, and Flavobacterium.*Since it threatens public health and can affect all living things, including microbes, exposure to metals over a predetermined threshold is a major environmental problem worldwide. Some bacteria have defence systems to metabolise and alter heavy metals in order to survive in such harsh environments.

Species from *Erwinia*, *Agrbacterium, Arthrobacter, Chromobacterium, Pseudomans, Serratia, Azospirillum, Bacillus, and Burkholderia* are some of the most significant examples of these helpful bacteria. These bacteria helped plants grow and develop more quickly, and they also produce soil polluted with metal. less harmful to plants. Species. They can endure stressful situations. Not all bacterial isolates have the ability to produce bio-fertilizer, and they do not actively contribute to fostering plant development. These isolates maintain/regulate the pathogenic of several pathogens (Mushtaq et al., 2022).

Mechanisms for promoting plant growth

Plant growth regulators support the development of plants both directly and indirectly. They are able to control plant growth by producing plant hormones, improving nutrient availability, lessening the impacts of metallic substances on plant growth, and inhibiting the effects of particular diseases. Rhizosphere bacteria, also known as rhizobacteria (PGPR), can stimulate plant growth in a variety of ways. Some of these mechanisms include phosphate solubilization, siderophores production, biological nitrogen fixation, rhizosphere engineering, 1-aminocyclopropane-1-carboxylate deaminase production, interference with the quorum sensing (QS) signal, prevention of biofilm formation, and phytohormone production.

Plant growth regulator substances: When tryptophan is present, a large number of PGPR release hormones that control plant development in crop plant rhizospheres or rhizoplanes, such as indole acetic acid. A plant's defence system against phyto-pathogenic microorganisms is also started by acetic acid. Cellular elongation, differentiation, and development are all impacted by indole acetic acid. Additionally improving growth, indole acetic acid boosts seed and tuber germination rates. The rhizosphere bacteria's release of indole acetic acid causes plants to lose their cell walls and increases root exudation, which produces extra cellular nutrients for the growth of rhizosphere microorganisms. The many organic complex chemicals that are found in the soil are also broken down by indole acetic acid. The *Aeromonas veronii, E. cloacae*, *Agrobacterium sp.*, *Alcaligenes piechaudii*, and *Comamonas acidovorans* are a only few rhizosphere bacteria produce IAA. Bacillus species generate the hormone gibberellin, which has an impact on plant growth. In a lab culture, ethylene is released by Enterobacter species, which affects plant development. Stresses including dryness, salt, bright light, radiation, heavy metals, insect assault, and pathogenic attack caused the level of ethylene in plants to rise, and plants began defoliating to cope with the stress. Ethylene has the effect of inoculating the bacteria that produce ACC deaminase. Numerous studies revealed that rhizosphere bacteria can produce plant growth hormones as well. These bacteria can associate with plants to promote their growth as well as release ethylene in lab cultures, which has an impact on plant growth. Numerous investigations revealed that rhizosphere bacteria also create plant growth hormones, which can bind to plants and promote the growth of their hosts (Karami et al.,2010)..

Scale up Approches: The employment of microorganisms in Cr (VI) removal processes has been investigated using a number of techniques, including batch, feed batch, and continuous processes. The right bioreactor must take into account all of the operational factors required to remove Cr (VI), including hydrodynamics, mass transfer, and growth conditions. This strategy offers a numerous applications due to the possibility for microbial development and adaptation brought on by contemporary biotechnology. A bioreactor system is frequently more effective (greater bio elimination rate), controllable, predictable, and easier to adjust to the constrained environment than in situ or solid phase systems (Mushtaq et al., 2021).

Microbial assisted remediation of contaminated

The most modern and effective method for removing polluted soils that contain heavy metals and water is phytoremediationThe use of metal tolerant growth boosting rhizobacteria that promotes hyperaccumulator plant development under metal stress conditions may be inoculated to plant seeds or roots is an alternative approach to increase the efficacy of phytoremediation. These bacteria can reduce the amount of ethylene in plants and give them growth regulators, which could ultimately increase the effectiveness of phytoremediation through hyperaccumulation. Microbial activity is also decreased in stressful situations, however plants may aid bacteria providing exudates. Consequently, plant-microbe interaction may increase the effectiveness of phytoremediation. Thus, the interaction between plants and microorganisms may enhance the effectiveness of phytoremediation. The removal or degradation of pollutants/contaminants by utilising a combination of plants and microbes in the rhizosphere is known as phytoremediation assisted by soil rhizobacteria (also known as phytodegradation, rhizoremediation, enhanced rhizosphere biodegradation, or microbe-assisted phytoremediation). Some rhizobacteria have the ability to emit organic acids to aid in these several bacteria, mostly PGPR, have been identified as phytoextraction helpers, including Bacillus spp., Pseudomonas spp., Microbacterium spp., Mesorhizobium spp., Variovorax spp., Rhizobium spp., Psychrobacter spp., Sinorhizobium spp. including Rhodococcus sp., Achromo sp.Organic acid synthesis, siderophore synthesis, and phosphate solubilization are three mechanisms employed by microbes to mobilise heavy metals (Mushtaq et al., 2021).

Conclusion and future scope

The use of bacteria and other microscopic organisms for remediation is cost-effective approach that might promote plant development. Some heavy metals are easily accumulated by or reduced by many microorganisms. Because microbes have a significant surface area to volume ratio, they offer a huge surface area for interacting and reacting with the metals in their environment. If these microorganisms simultaneously work to enhance other areas of the environment that are of importance, such as improving plant development, the environment will be improved even more. In order to address the concerns of soil toxicity and food crops. A new and promising remedy is heavy metal-resistant plant growth-promoting bacteria.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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