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Documentation of Chromium tolerant species for mitigation of mining pollution: A mini-review

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ABSTRACT

Extensive mining activities increased the chromium (Cr) contamination in the environment. Cr, a potentially toxic metal arising from various natural and anthropogenic activities such as the electroplating, steel and leather industries, is carcinogen to living organisms as well as a risk to ecology. Hence, the remediation of Chromium pollution has gained widespread attention. The toxic nature of Cr severely affects plant growth and development. Naturally Cr exists in various oxidation states, including Cr(III) and Cr(VI). The hexavalent Cr is the most toxic and persistent form in soil. Plants uptake Cr through various transporters such as sulfate and phosphate transporters. In recent years, Cr accumulating plants has been recognized as one of the promising Phytoremediation methods for the Cr contaminated region. This review summarized the Phytoremediation techniques of Cr and uptake mechanisms of different plants.

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1. Introduction

Environmental contamination of Chromium in soil arises from numerous natural and anthropogenic activities have gained substantial consideration worldwide due to its high level in the soil. (Ashraf *et al.*, 2017). Chromium accumulates in food crops from the contaminated soils and possesses severe health risks in humans via food chain (Ahmed *et al.*, 2016). Plant physiology (plant type, rate and type of root secretions, root surface area and transpiration) and soil conditions (texture, pH, cation exchange capacity) all influence Cr transport from the soil to the plant (Banks *et al.*, 2006; Zeng et al., 2011b; Santos and Rodriguez, 2012). Cr is translocated to aerial regions in the majority of plant species with slow process and mostly reserved in root tissues (Jaison and Muthukumar, 2016). Cr-hyperaccumulators like atlantic cord grass (*Spartina argentinensis*), jelutong (*Dyeracostulata*) and spleen amaranth (*Amaranthus dubius*), on the other hand, can ingest and translocate high Cr levels in shoot tissues (de Oliveira *et al.*, 2016).

Indian mineral sector is playing a vital role not only to generate employment opportunities with improved livelihoods but also responsible for environmental degradation. Moreover, the major impact of mining is depletion of natural resources, decrease in rainfall, loss of cultivable land and pollution in soil, water and air etc. As per NMI database based on UNFC system, the total reserves/ resources of chromite in the country as on 2020 has been estimated at 344 million tonnes with 102 million tonnes as “Reserves” (30%) and 241 million tonnes as “Remaining Resources” (70%). More than 96% resources of chromite are located in Odisha, mostly in Jajpur, Kendujhar and Dhenkanal districts. The Principal producers in Odisha are OMC Ltd., TATA (TISCO), Balasore Alloys Ltd. IMFA and Facor Ltd. Minor deposits are scattered over Manipur, Nagaland, Karnataka, Jharkhand, Maharashtra, Tamil Nadu, Telangana and Andhra Pradesh (Figure 1). The Sukinda valley in Odisha contains 96% of India’s chromite reserves. The pollution in and around the area made this place as Odisha’s Chernobyl and identified one of the world’s top 10 most polluted regions.

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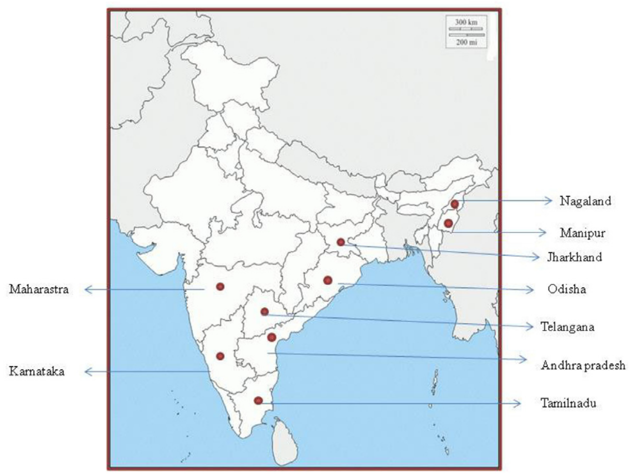

Source: India Minerals Year Book, 2018,57th edition, November 2019.

Figure 1- Distribution of Chromite deposits across different states of India.

According to the Orissa Voluntary Health Association (OVHA), chromium extraction is responsible for 84% of deaths in Sukinda's mining districts and 86% of deaths in neighboring industrial villages.

The Supreme Court of India has emphasized the need of Environmental Impact Assessments in light of the negative environmental and social effects of mining (Goa Foundation Case, April 2014). When "the macro effect of such wide-scale land and environmental degradation caused by the absence of remedial actions (including a rehabilitation plan)" is not taken into account, it has negative repercussions, according to the report (Karnataka mining case, Supreme Court of India, April 2013). The Supreme Court has also stated that mining operations must be conducted within the parameters of Article 21 of the Constitution, which includes the right to a clean environment and pollution-free air, the precautionary principle, and the principles of sustainable development and inter-generational equity. It makes financial sense to protect the environment. Natural resource degradation places a tremendous strain on the economy.

According to the World Bank, India's total yearly cost of environmental degradation is around Rs. 3.75 trillion (US$80 billion), or 5.7 percent of GDP in 2009, the base year for most damage estimates (World Bank, 2013). This is based on the total cost of air and water pollution, as well as the deterioration of cropland, pasture land, and forest area. Greenpeace's latest analysis (February 2020) backs this up, estimating that the yearly cost of air pollution in India is US$ 150 billion. After China and the United States, India has the third greatest cost of fossil fuel air pollution in the world, according to the analysis.

2. Environmental and chemical aspect of chromium

Chromium is naturally present in mineral form as crocoites and is usually a silvery hard metal with atomic number 24 and molecular weight 51.1u with density of 7.19 gram per cubic centimeter. It is the 7th most prevalent element in the earth's crust and the 21st most abundant metal. It is among 18 core hazardous air pollutants, 33 urban air toxicants and registered as 7th among top 20 dangerous substances by Agency for toxic compounds and disease registry (ASTDR). Chromium usually is found in the form of chemical compounds such as chromate and dichromate with high oxidizing potential, solubility and mobility across membranes in living organisms and the environment.

Different chemical speciation of chromium makes it unique among hazardous metals. Cr(VI) being the most toxic than Cr(III) has many toxic implications such as carcinogenic property. Similarly, both species differ significantly in terms of their absorption, bioavailability, and transport to the aerial parts (Choppala *et al.*, 2016). It can move to the animal system if a plant accumulated with chromium is ingested by the animals. Chromium toxicity has been shown to interfere with plant development, create ultrastructural changes in the cell membrane and chloroplast, cause chlorosis in leaves, harm root cells, diminish plant pigment content, disrupt water and mineral uptake as well as affect many enzymatic activities (Ali *et al.*, 2015; Farooq *et al.*, 2016; Reale *et al.*, 2016).

3. Phytoremediation of Cr by hyperaccumulating plants

Over the last few decades, Researchers have identified tolerant and hyperaccumulator plants in order to investigate their mechanisms and applications in the phytoremediation process. Nearly 500 plant species from more than 45 families have been recognised to date. The harmful metals were mostly converted into less toxic and immobile forms by the tolerant hyper-accumulator plants (Cervantes *et al.*, 2001). The function of high-affinity ligands like as amino acids, peptides, and organic acids, which chelates the metal ions and sequesters them within the vacuole, is central to the mechanism of Cr hyper-accumulators. Increased rhizospheric metal mobilisation by organic acids; absorption using different families of transporters and then translocating it into the shoot via xylem loading, finally detoxifying it via chelation and compartmentalization within the vacuoles are all important factors governing the hyper-accumulation of Cr and other heavy metals (Shahid *et al.*, 2013).

In mining areas, some naturally growing plant species can be found as these have high ability for uptake of contaminants as well as have innate mechanism to tolerate

Table-1

Accumulation of Cr at different parts of some hyperaccumulative Plants

Sl No.	Plant Name	Plant parts	Cr uptake (mg/Kg)
1.	*Alternanthera sessilis*	Roots Leaves	1,017201
2.	*Azolla caroliniana*	Whole plant	356
3.	*Brassica juncea*	Roots Shoots	1,6404,100
4.	*Callitriche cophocarpa*	shoots	1,000
5.	*Convolvulus arvensis*	leaves	2,800
6.	*Eichhorniacrassipes*	roots	3,951
7.	*Helianthus annuus*	Shoot root	1,356556
8.	*Leersia hexandra*	Leaves Stem Root	2,1643,4753,299
9.	*Leptospermum scoparium*	Foliage ash	20,000
10.	*Marsilea drummondii*	Roots	1,300
11.	*Nopalea cochenillifera*	Roots Shoots	25,263705
12.	*Nymphaea spontanea*	Plant	2,200
13.	*Polygonum hydropiperoides*	Roots	2,980
14.	*Pteris vittata*	Roots Shoots	5,7171,145
15.	*Thlaspi caerulescens*	Roots	3,400-3,500
16.	*Laguncularia racemosa*	Roots	560,000
17.	*Aerobryopsis longissima*	Moss ash	7,500
18.	*Rinorea niccolifera*	Leaves	30,000
19.	*Pearsonia metallifera*	Foliage ash	20,000
20.	*Typha angustifolia*	Roots	20,120
21.	*Prosopis juliflora*	Whole plant	372
22.	*Salix matsudana*	Roots	746
23.	*Salsola kali*	Roots Stems Leaves	2900790600
24.	*Salvinia natans*	Roots Leaves	52007400
25.	*Spartina argentinensis*	Whole plant	15,100
26.	*Vallisneria spiralis*	Roots Leaves	11271378
27.	*Lemna minor*	Plant tissue	2870
28.	*Marsilea drummondii*	Roots	1300
29.	*Phragmites australis*	Rhizome Shoot Leaves	4825883627

[Source: Singh *et. al.*, Environ Chem Lett (2013) 11:229-254]

their toxicity. These plants are called hyperaccumulator plants (Table 1) and with respect to this, plants with tendency to accumulate about 1000mg/kg (0.1 % of dry weight) have been categorized as chromium hyperaccumulators (Reeves and Baker 2000). Most of the chromium uptaken by the plant is retained inside the root and a little is translocated to the shoot. In fact, plants also show a great degree of difference in tolerance, uptake and accumulation of chromium (Shahandeh and Hossner 2000).

Hyperaccumulators are such plants which are capable of concentrating higher amount of heavy metal in their above-ground tissues which is far more than those present in the soil or in the nearby growing non-accumulating plants Memon *et al.*, 2001; Memon and Schröder, 2009). Two factors play important role while estimating the hyperaccumulation capacity of a specific plant. One is bioaccumulation factor and the other is translocation factor. Bioaccumulation factor

Table-2

Tolerance mechanism of Plants towards Chromium

Sl. No.	Plant	Family	Tolerance Mechanism
1	*Mesembryanthemum crystallinum* L.	*Aizoaceae*	Phyto-extraction
2	*Gomphrena celosoides* Mart.	*Amaranthaceae*	Increased proline and antioxidant enzyme activities
3	*Allium griffifithianum* Boiss.	*Amaryllidaceae*	Hyper-accumulation
4	*Calotropis procera* (Aiton) W.T. Aiton	*Apocynaceae*	Increased activities of superoxide dismutase (SOD), catalase (CAT), and glutathione reductase (GR)
5	*Colocasia esculenta* (L.) Schott	*Araceae*	High accumulation of Cr(VI)
6	*Lemna minor* L.	*Araceae*	Increased anti-oxidant activity, Phyto-extraction
7	*Lemna minuta* Kunth	*Araceae*	Increased anti-oxidant activity
8	*Pistia stratiotes* L.	*Araceae*	Anti-oxidant activity and hyper-accumulation
9	*Arundodonax* L.	*Poaceae*	Hyper-accumulation
10	*Brachiaria mutica* (Forssk.) Stapf	*Poaceae*	Phyto-stabilizer
11	*Chrysopogon zizanioides* (L.) Roberty	*Poaceae*	Hyper-accumulation
12	*Diectomis fastigiata* (Sw.) P. Beauv.	*Poaceae*	Hyper-accumulation
13	*Pennisetum americanus* L. *X*	*Poaceae*	Hyper-accumulation
14	*Pennisetum purpureum* (Schumach)	*Poaceae*	Hyper-accumulation
15	*Leersia hexandra* Sw.	*Poaceae*	Hyper-accumulation
16	*Miscanthus sinensis* Andersson	*Poaceae*	Hyper-accumulator
17	*Oryza sativa* L.	*Poaceae*	Hyper-accumulation
18	*Phragmites australis* (Cav.) Trin.	*Poaceae*	Phyto-reduction
19	*Phragmites communis* (Trin.)	*Poaceae*	Phyto-reduction
20	*Spartina argentinensis* (Trin.) Merr.	*Poaceae*	Hyper-accumulation
21	*Cymbopogon flexuosus*	*Poaceae*	Hyper-accumulation
22	*Eichhornia crassipes* Mart.	*Pontederiaceae*	Hyper-accumulation
23	*Pteris vittata* L.	*Pteridaceae*	Hyper-accumulation
24	*Genipa americana* L.	*Rubiaceae*	Hyper-accumulation
25	*Salvinia minima*	*Salviniaceae*	Increased anti-oxidant activity and hyper-accumulation
26	*Solanum viarum* Dunal	*Solanaceae*	Hyper-accumulation
27	*Origanum vulgare* L. Mediterranean,	*Lamiaceae*	Hyper-accumulation
28	*Salvia moorcroftiana* Wall. ex Benth.	*Lamiaceae*	Biosorptivedetoxifification
29	*Callitriche cophocarpa* Sendtn.	*Plantaginaceae*	Hyper-accumulation
30	*Euphorbia helioscopia* L. Desert	*Euphorbiaceae*	Hyper-accumulation
31	*Rumex dentatus* L.	*Euphorbiaceae*	Hyper-accumulation
32	*Arachis hypogea* L.	*Fabaceae*	Hyper-accumulation
33	*Cassia tora* L.	*Fabaceae*	Hyper-accumulation
34	*Medicago sativa* L.	*Fabaceae*	High proline and GST accumulation

35	*Medicago truncatula* Gaertn.	*Fabaceae*	Regulating the sulphur transport and metabolism
36	*Sesbania sesban* (L.) Merr.	*Fabaceae*	Phyto-stabilizer
37	*Vigna unguiculata* (L.) Walp.	*Fabaceae*	Hyper-accumulation
38	*Cirsium vulgare* (Savi) Ten.	*Asteraceae*	Hyper-accumulation
39	*Dicoma niccolifera*	*Asteraceae*	Hyper-accumulation
40	*Gynura pseudochina* (L.) DC.	*Asteraceae*	Cr (VI) reduction
41	*Helianthus annuus* L.	*Asteraceae*	Hyper-accumulation
42	*Parthenium hysterophorus* L.	*Asteraceae*	Hyper-accumulation
43	*Vernonia cinerea* (L.) Less.	*Asteraceae*	Hyper-accumulation
44	*Origanum vulgare* L. Mediterranean	*Lamiaceae*	Hyper-accumulation
45	*Salvia moorcroftiana* Wall. ex Benth.	*Lamiaceae*	Biosorptivedetoxifification
46	*Callitriche cophocarpa* Sendtn.	*Plantaginaceae*	Hyper-accumulation
47	*Phyllostachys pubescens*	*Poaceae*	Phyto-extraction

[Source: Srivastava *et. al.,* Sustainability, 2021, 13, 4629.]

is the concentration of metal accumulated in the aboveground part to that of concentration of metal in soil.

Some plants are having natural ability of hyperaccumulation for specific heavy metal and are known as natural hyperaccumulators. On the other hand, genetic modifications can also be performed to facilitate higher uptake capacity of plants for heavy metals and such plants are regarded as transgenic plants.

3.1 Techniques of phytoremediation

Phytoremediation in recent times has been exploited in several ways including phytoextraction, phytostabilisation, phytofilteration, phytvolatilisation, phytodegradation etc. (Table 2).

3.1.1 Phytoextraction

Also known as phytoaccumulation, phytoabsorption or phytosequestraction is the uptake of contaminants from soil or water by plant roots and their translocation to and accumulation in aboveground biomass (shoots). Metal translocation is crucial for effective phytoextraction and can be determined by using translocation factor i.e, concentration of metal in aboveground plant parts to that of soil concentration.

3.1.2 Phytofiltration

It is removal of pollutants from contaminated surface waters and waste waters by plants. It may be rhizofiltration as roots are used or blastofiltration if seedlings are used, when excised plant shoots are used it is regarded as caulofiltration. As the contaminants are absorbed or adsorbed, their movement to underground water is minimised.

3.1.3 Phytostabilisation

Use of certain plants for stabilisation of contaminants in polluted soils, mostly used to reduce the mobility and bioavailability of pollutants in the environment. Plants can immobilise the heavy metals in soils through absorption by roots, precipitation, complexation, or metal valence reduction in rhizosphere. In turn, the metals vary in toxicity owing to their special redox mechanisms; these are converted into less toxic forms thus decreasing the deleterious effects. For this purpose, the reduction of Cr^{6+} to Cr^{3+} is widely studied, as the latter is comparatively less toxic and less mobile.

3.1.4 Phytovolatilisation

It is the uptake of pollutants from soil by plants, thus facilitating their conversion to volatile form and subsequently release into the atmosphere. This technique is usually applied for organic pollutants and some heavy metals like Hg and Se. However, it is limited by the fact that it doesn't actually remove the pollutant completely rather transfers it from soil to the atmosphere from where it can be re-deposited.

3.1.5 Phytodegradation

This involves degradation of organic pollutants by plants with the help of enzymes such as dehalogenase and oxygenase and not dependent on rhizospheric microorganisms. Plants have the ability to accumulate organic pollutants from the soil and detoxify them through their metabolic activities. Recently, major focus is being given to synthetic herbicide and insecticides, and their degradation using efficient plant species.

3.1.6 Rhizodegradation

It refers to breakdown of organic pollutants in the soils by microorganisms in the rhizosphere, which extends about 1mm around the root and is under the influence of the plant. The higher metabolic activities of the microbes in this zone are responsible for enhanced degradation of pollutants. In turn plants can stimulate microbial activity by 10-100 times higher by secreting exudates containing carbohydrates, amino acids, flavonoids. These provide carbon and nitrogen sources to the soil microbes and creates a nutrient rich environment in which microbial activity is stimulated (Kuiper et al., 2004; Yadav et al., 2010).

4. Conclusion and Future Prospective

Mining of Chromium affects various life forms by altering the physiological and metabolic pathways. With the exposure to Cr, plant remodulates its genetic and transcriptional regulation for better adaptation. However, bioremediation techniques still have some disadvantages because they are time consuming, limited to moderately contaminated sites and readily disturbed by the external environment. Thus, in order to fully exploit bioremediation for Cr contamination, we must first understand the complete Cr remediation processes and mechanisms for biologically-derived materials, living organisms, and their coupled effects because there is still some uncertainty about the processes and mechanisms involved. Thus, great efforts and practices are required to study the processes and mechanisms of Cr(VI) remediation, and to promote efficient field applications of bioremediation techniques for site-specific Cr(VI) pollution.

Therefore, we suggest the following areas for future remediation research.

- Specific research is required to evaluate various transporters involved in chromium uptake and associated metabolic pathways.
- Tolerant and native hyperaccumulative plants need to be screened/evaluated for the better adaptation and can bioremediate Cr from the Cr-contaminated regions.
- The mechanisms related to the remediation with microbes need to be elucidated in order to identify more Cr-resistant microbial strains and applications of microbial strains in the contaminated area should be taken care especially protecting the surrounding water in an ecological environment.
- Molecular biology and genetic engineering techniques should be employed to develop transgenic plants with hyperaccumulating capability with rapid reproduction and growth, high resistance to Cr.
- Further studies are required of the complex functions of plant roots, microbial strains and carrier molecules, including the characteristics of different plant species and rhizosphere microbes.

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