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Phytoremedial Potential of Some Terrestrial Ornamental Plants Against Chromium: A Review

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ABSTRACT

Purpose: *Adding unwanted toxic substances to water and soil degrades the quality of food and nutrients. The main cause of pollution on land and water surfaces is industrial discharge. Heavy metals found in industrial effluents include aluminum (Al), zinc (Zn), lead (Pb), chromium (Cr), arsenic (As), mercury (Hg), and cadmium (Cd). Chromium is considered one of the most perilous, poisonous, and carcinogenic heavy metals among them. The continuous use of these metals causes harm to the agro-biological system. Though the physical and chemical approaches are extremely expensive, ineffective and unsuitable for our environment but still are in use for getting rid of heavy metals.*

Research Method: *The current analysis focuses on existing knowledge in the form of research papers available on google scholar and Scopus, issues associated with chromium pollution, such as its environmental, plant development, and human health toxicity as well as its prompt eradication through ornamental plants with high accumulation potential and contamination acceptance.*

Findings: *There is a necessity for green and cost-effective technology for polluted soil and industrial wastewater. Phytoremediation has been considered the most encouraging and suitable green technique to remove contaminants in recent decades due to its low cost and environmental friendliness.*

Originality/ Value: *Ornamental plants appear to be more viable options than edible crops and therapeutic plants as they provide several benefits, including heavy metal pollution removal, environmental embellishment with revenue generation and rare connection in the food chain.*

Keywords: *Chromium, Heavy metals, Ornamental plants, Phytoremediation, Pollution.*

INTRODUCTION

The majority of regions of the Earth have become badly polluted via heavy metals and suffering significantly as an outcome of numerous anthropogenic activities and over-exploitation of natural resources, proportionately many toxic heavy metals that cause destructive impacts to biota have been incorporated in water and soil, including zinc (Zn), lead (Pb), chromium (Cr), arsenic (As), mercury (Hg) and cadmium (Cd), (Fu *et al*., 2017; Bali *et al*., 2020). Some heavy metals are required to run life at a relatively low-level quantity, but at large concentrations, they induce toxicity, carcinogenicity and allergenicity and can change the activity of sensitive enzymes (Koropatnick and Leibbrandt, 1995). These metals are to blame for decreased profitability as well as damage to agro-biological systems., and inflicting harm on humans in direct or indirect ways. They enforce stress on plants and have an antagonistic effect on their physiology. Among these metals, Chromium is also considered very hazardous to the environment.Textiles, tanneries, electroplating, metallurgy, aircraft production, electronics, nuclear reactor vessels, paper industries, negative-film making, cement-producing plants, pyrotechnics, wood preservation, glassware, ceramic ware, and dye synthesis are all major sources of chromium waste (Lu *et al*., 2013).

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The most plentiful mineral Chromium is found in the Earth and is present in the form of chromite (FeCr2O4) ore. Nicolas Louis Vauquelin discovered chromium in 1798. Cr is a transitional metal that has a 24 atomic number and has a relative atomic mass of 51.996, its melting and boiling points are 1890^{o}C and 2482^{o}C respectively. The oxidation states of Chromium range from -2 to +6. The trivalent and hexavalent forms of Chromium (Cr) are often stable. Cr in its 0 oxidation, having a pure metal state is biologically inert, has no negative effects, and does not occur naturally on the Earth's surface, whereas Chromium (III) and Chromium (VI) which are derived from industries effluents, are biologically active and causes destructive effects on living beings. Trivalent chromium is not as hazardous as hexavalent chromium.

According to the Indian standard maximum tolerance for total chromium in the water supply is 0.05 mg/L. The stability and low biodegradability of chromium allow it to persist for extended periods in the atmosphere, soil, and water, where it can have numerous detrimental impacts. (Li *et al*, 2020). Table 1 shows the destructive effect of chromium on soil, plants,, and human beings.

Chromium in the environment

Cr is a hazardous contaminant that poses a severe environmental risk. It enters the environment through the burning of fossil fuels, airborne emissions from chemical plants, incineration facilities, electroplating, effluents from chemical plants, cement dust, catalysts, chromium steel, fertilizers, contaminated landfills, oil drilling sites, and metal tanneries. High Chromium (VI) content present in the soil causes soil degradation, and microbe damage and reduces plant productivity (Wani *et al.*, 2019; Peng and Guo, 2020). The chromium hexavalent form is sensitive to the redox potential value of the soil, when its value is low, the reduction process stops, while when the redox potential is high, the oxidation process takes over (Rinklebe and Shaheen, 2014). The soil's reductive property leads Chromium (VI) to be changed into chromium (III), and Chromium (III) to get immobilized as a precipitated form (Shahid *et al.*, 2017).

Effects of chromium on human health

Chromium and its derivatives are absorbed into the human body via oral, dermal, and inhalation routes. Cr (III) trivalent chromium- when administered orally, 99% of the dose is recovered in the feces, while 94% is retrieved by duodenal administration. Only 0.5% was eliminated through urine in both cases, indicating low Cr (III) absorption. Human inhalation raises Cr content in urine, indicating respiratory absorption, and substantial research indicates that Chromium (III) has less absorption and toxicity is mostly due to the Cr(VI) form (Dayan and Paine, 2001). Cr (VI) is the second most constant type of Cr and a powerful oxidizer. Cr (VI) interacts with oxygen to generate chromate and dichromate. Chromium(VI) can pass cell membranes via anion channels, react with nucleic acids and proteins, delayed contact sensitizer, has the kidney as its primary target organ, and is categorized as a group-I human carcinogen (Mancuso, 1997). According to fecal testing, 10% of the dosage is absorbed the in gastrointestinal tract. Hexavalent Chromium enters the bloodstream, where it is taken up by RBC, reduced, and bound to hemoglobin. Because of the high oxidizability of Chromium (VI), it has been linked to asthma, allergic reactions, cardiovascular and neurological illnesses, cancer, and organ failure (Gupta and Kumar, 2012). Granular Chromium (VI) is a known carcinogen in the lungs of humans (Browning and Wise, 2017).

A chromosomal instability, breakage, or deletion has been linked to Hexavalent chromium-triggered malignancies and generates an early warning role in these processes (Ventura *et al.*, 2021). The mitochondrial genome particularly is susceptible to a variety of environmental toxic substances and prone to damage due to the special structure of DNA and the absence of a repair system (Fontana and Gahlon, 2020).

Chromium toxicity and plants

Heavy metals, depending on their valence states, can be exceedingly reactive, producing plant cell abnormalities from a variety of angles, Cr (III) is a trace element for healthy mammals as it is involved in the absorption and breakdown of carbohydrates, proteins, lipids and enhance the action of insulin hormone but not for plants (Shahid *et al.*, 2017). Symptoms of Cr (VI) toxicity create noxious disorders in plants including a decrease in plant biomass, leaf deformation, chlorosis, necrosis, inhibited enzyme activity, protein deformation, blocked mineral absorption and transportation, low grain production, reduced photosynthesis, cell membrane damage, chromosome aberration and ultimate death of the plant. Excess Cr was found to impair critical mineral intake by obscuring sorption sites and creating insoluble complexes. Under excessive Cr exposure, paddy plants (*Oryza sativa* L.) showed a steady decline in the absorption of micronutrients such as copper (Cu), zinc (Zn), manganese (Mn) iron (Fe), and macronutrients such as potassium (K), phosphorus (P) and nitrogen (N) (Sundaramoorthy *et al.*, 2010)

Table 1: Heavy metals with their effects on soil, humans, and plants.

S. No.	Heavy metals	Atomic no.	Hazardous effects on soil	Effects on humans	Effects on Plants	References
1.	Al	13	Restricts the uptake of essential nutrients and nitrogen fixation	Forgetfulness, anemia, depression, inability to concentrate	Suppression of cell division, cell expansion, and transportation.	Pietraszewska, 2001; Crisponi et al. 2013.
2.	Cr	24	Causes nutrient imbalance, root injury, and inhibiting enzyme activity	Cytoplasmic protein and DNA damage, allergic and eczematous skin reactions, gastrointestinal hemorrhage.	leaf deformation, chlorosis, and necrosis, reduced biomass decreased enzyme activity, and low grain production.	Baruthio,1992; Mahurpawar, 2015; Gupta and Kumar, 2017.
3.	Ni	28	Soil pH imbalance, inhibits seed germination, plant growth	Bronchitis, sickness cardiovascular damage,	reduces seed germination, root and shoot growth, and chlorosis.	Lone et al., 2008; Bhalerao et al., 2015.
4.	Cu	29	Higher concentration in soil affects seed germination, root development, and plant vigor.	Liver damage, Wilson disease, insomnia	metabolic disturbances, growth inhibition, blocking of photosynthetic electron transport	Fernandes and Henriques, 1991; Gupta and Kumar, 2017
5.	As	33	Higher concentrations in the soil can damage the plasma membrane of living beings.	Causes respiratory ailments, skin diseases, gastrointestinal complications, and carcinogenic.	Cell membrane damage, reduction in leaf and fruit formation	Signes-Pastor et al., 2008; Mahurpawar, 2015; Gupta and Kumar, 2017.
6.	Cd	48	An increasing percentage of Cd in soil becomes nutrient-deficient	Kidney damage, degeneration of bones, carcinogenic.	cell structure destruction, antioxidant system damage, and metabolic obstruction.	Koeppe 1977; Gupta and Kumar, 2017.
7.	Hg	80	Suppress plant growth and even kill them	Kidney damage, mental retardation, deafness, digestive problems, and adverse neuro disorders.	growth retardation, reducing seed viability, and denaturing of proteins.	Mahurpawar, 2015; Gupta and Kumar, 2017
8.	Pb	82	Creates rapid inhibition of plant root growth, and inhibits cell division.	Renal and nervous system disorders, Mental retardation,	reduction in the growth of the roots, decreases enzyme activities, ATPase inhibition.	Mahurpawar, 2015; Gupta and Kumar, 2017.

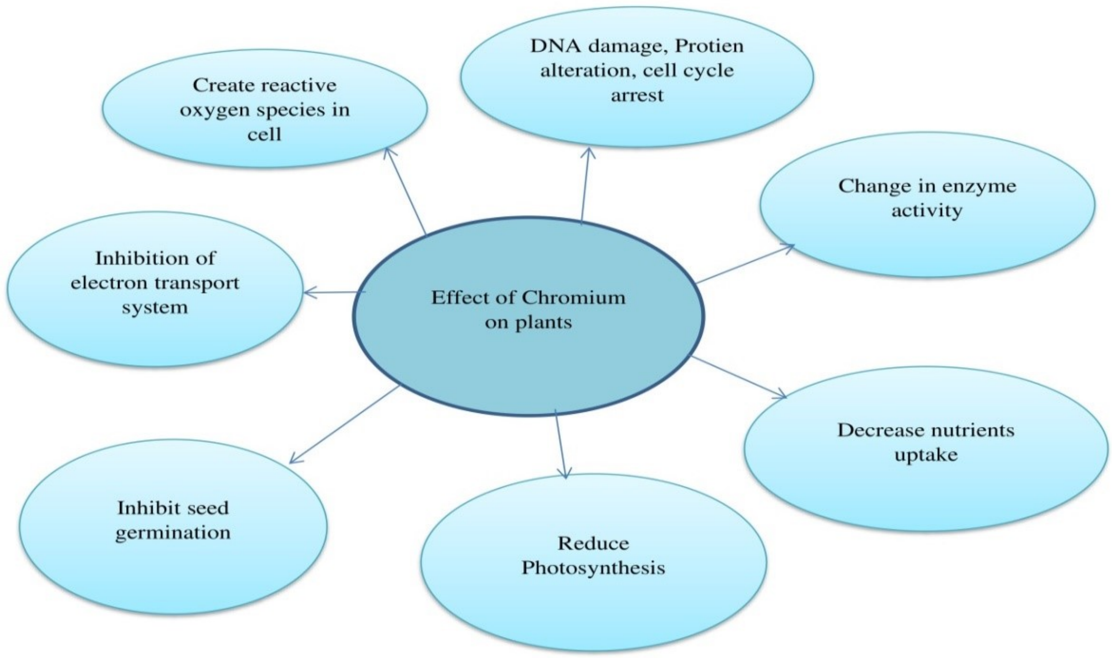

Figure 1: Toxic effect of Chromium on plant

Plants may be capable to survive in severely polluted surroundings and tolerate high quantities of hazardous chemicals in their tissues. In phytoremediation, numerous plants from the representative families Solanaceae, Asteraceae, Rosaceae, Betaceae, Poaceae, and Caryophyllaceae are utilized to absorb, breakdown, digest, metabolize, evaporate, and detoxify heavy metal pollutants (Gawronski and Gawronska, 2007). Phytoremediation of chromium (Cr) from contaminated soil is a cost-effective green approach that includes the provision of income generation, environment beautification, cut-flowers, and other by-product benefits (Nakbanpote *et al*., 2016).

This strategy employs a diversity of plant varieties including ornamental plants. Ornamental plants are produced to decorate and beautify indoor and outdoor spaces like parks, roadsides, shopping areas, workplaces, landscapes, etc. They give visual effects, and foraging opportunities for pollinators, boost positive energy, and make people feel relaxed. Ornamental plants, as proven by the current COVID-19 outbreak, are not just pleasures, but also human necessities.

Heavy metal phytoremediation plant selection and preference

The selection of suitable plant species is critical to the effectiveness of phytoremediation; they should have a high tolerance and accumulation of heavy metals, rapid development, should have a deep root system, capable of absorbing heavy metals although they are present in very low concentration, be able to generate a high amount of biomass, should be well adapted to their current environment and be repulsive to herbivores to limit the danger of heavy metal biomagnification entering the food chain (Butt *et al*., 2018). The morphologies of the root, stem, and leaf are critical in the phytoremediation process (Wei *et al*., 2005). The majority of attractive plants have high concentrations of heavy metals in their roots. The root is the main absorption organ in plants; root dimension, surface area, and density can affect heavy metal absorption while microorganism growth and reproduction in the rhizosphere can be influenced by root exudes. (Cheng *et al*., 2016). The leaf area influences biomass development by influencing photosynthesis and the leaf surface is also an important site for volatilization and perspiration, which is another method of detoxification for harmful chemicals (Sun *et al*., 2011). Ornamental plants require developed stem tissue, and pollution tolerance and accumulation are proportional to stem height as well as diameter

Table 2: Chromium (Cr) tolerance in Ornamental plants

S. No	Ornamental plant name	Cultivation site	Initial Chromium concentration	Remediation rate	Incubation time (in Days)	*references*
1	Zinnia elegans	Pot Experiments	25, 50, 75ppm	NA	30, 45 and 60 days	Panda et al., 2020.
2	*Cordase rose*	Pot Experiments	0, 50, 100, 500, 1000 mg/kg	NA	NA	*Akay and Omar, 2022.*
3	*Tagetes erecta*	Growing media	*0, 100, and 500 mg/L*	NA	NA	Intansari et al., 2022.
4	*Calendula officinalis L.*	Pot experiments	5.20–6.40 mg kg–1	NA	NA	Sahu et al. , 2022.
5	*Tagetes erecta*	Pot experiments	30mg kg1	NA	NA	Biswal et al. , 2022.
6	*Convolvulus arvensis L*	A non-cultivated lot of the experiment station	80 mg/L	NA	16 days	Gardea-Torresdey et al., 2004.
7	*Tagetes erecta (L.)*	Red sandy –clay–loam soil	2 mg/L	94%	35 days	*Chitraprabha and Sathyavathi, 2018.*
8	Indian marigold	spiked by landfill leachate	NA	NA	NA	Bhagwat et al. , 2023.
9	*Silphium perfoliatum L.*	Pot Experiments	186.5 mg kg^{1}	15.25%	NA	Nescu et al. , 2022.
10	*Nephrolepis exaltata*	Pot experiments	250, 500, 750 mg/kg	475 to 2136 µg ^{1}	30, 60 days	Sehrawat et al. , 2021.
11	*Helianthus annuus*	Greenhouses	0, 100, 500, 1000, 5000, and 10,000 g/L	16.78 g/g dry	3 months	Stoikou et al. , 2017.
12	*Tagetes erecta L*	Pot experiments	20–100 mg K2Cr2O7 kg^{1}	NA	60 days	Pradhan et al. , 2023.
13	*Catharanthus roseus (Vinca rosea)*	Pot Experiments	10, 20, 30, 40, 50, and 60 ppm.	NA	NA	Ehsan et al. , 2016.
14	*Mirabilis jalapa*	Pot experiments	20.50 × 10^{3} mg kg^{1} , 51.25 × 103 mg kg^{1} , 102.50 × 10^{3} mgkg^{1}	408.97, 124.97, 630.16 and 57.30 mg kg1	NA	*Miao and Yan , 2013.*
15	*Euphorbia milli*	Pot experiments	50 mg/kg	80%	NA	Ramana et al. , 2014.
16	*Impatiens walleriana*	direct injection tests	164.23 mg kg^{1}	NA	10 days	Campos et al. , 2017.
17	*Miscanthus sinensis*	Pot experiments	200 mg/L	1976.81 mg/ kg	0, 1, 3, 5 and 7 days,	*Nie et al. , 2021.*
18	*Iris pseudacorus L.*	Pot experiments	0, 10, 50, 100, and 200 g ml1	59.97 mg	5 weeks	Caldelas et al. , 2012.
19	*Melissa officinalis*	Pot experiments	(0–2000 mg Cr kg^{1} soil).	NA	NA	Rendina et al. , 2015.
20	*Helianthus annuus*	Pot experiments	20, 40, and 60 mg/kg	NA	NA	Fozia et al. , 2008.

(Cay, 2016). The toxic metal absorption of ornamental plants does not necessarily meet the characteristics of a hyperaccumulator, but their faster growth and high biomass allow for higher heavy metal accumulation than hyperaccumulators (Marques *et al*., 2009).

The physiology behind heavy metal absorption and transportation in plants

Toxic metal absorption, root captivation, root-to-shoot transportation, cellular compartmentation, and sequestration are some of the processes associated with the accumulation and mobilization of heavy metals in plants. Toxic metals mainly penetrate roots via two different paths; symplastic (active diffusion) and apoplastic (passive diffusion). Metal ion carriers facilitate heavy metal uptake via the symplastic (active transport) pathway, which is an energy-driven process (Peer *et al*., 2005). Specific transporters (channel or carrier proteins) mediate the heavy metal ion uptake by the plasma membrane of plant cells and facilitate metal transfer from roots to shoots by mediating influx-efflux (Dalcorso *et al*., 2019).

Benefits of Ornamental plants as phytoremediators

Decorative plants are grown for their appealing qualities such as flowers, leaves, scent, and general texture of foliage. They are grown for landscape attractiveness, ecotourism, and cut flowers in pots, gardens, and landscape design projects (Nakbanpote *et al*., 2016). Exposure to plants boosts human pleasure hormone-like endorphin that improves our health and stress recovery, provides a sense of calm, change people's mental states, and psychological and physiological relaxation (Liu *et al*., 2017). Decorative plants are grown not just for their beauty, but also to help clean up the environment and generate income for landlords, farmers, and for government through their by-products. Most ornamental plants are non-edible so the heavy metals accumulated by them do not enter into the food chain. According to the findings, Tegetis erecta shows 95% and Euphorbia millii shows an 80% of phytoremediation rate (Table:02) which is quite high so they will be a good resource for cleaning the environment.

Limitation and futuristic approach

Phytoremediation is a time-consuming process. Harvesting of these plants yields highly polluted bio-waste, which, if not treated properly, can easily become a secondary pollution source in other words shifting the problem from one place to another (Gong *et al.*, 2018). After the phytoremediation of toxic metals, disposal procedures include hydrothermal reactions, incineration, pyrolysis, and gasification (Liu *et al.*, 2017; Gong *et al.*, 2018) Acording to results obtained by pyrolysis on 500oC of plant residues attained after phytoremediation, could be reutilised for dye adsorbtion (Gong *et al.*, 2018). According to Wan *et al.*, 2016 in a two year phytoremediation project conducted at Huanjiang Maonan autonomous county, China and estimated expenditure study showed the cost of phytoremediation is lower than the other conventional techniques used for the removal of heavy metals from polluted sites. Thus Phytoremediation is an effective technique can be recommened for eradication of soil pollutants due to its less expensive nature, more cost effective, easier for use, environmental friendly as compared to other conventional physical and chemical cleanup techniques.

There are around 295,383 blooming plants scattered across the world, yet there are extremely few instances of decorative plant species retaining phytoremediation capabilities (Table:2). There is a need to attract researchers' attitudes towards the green cleaning of the environment by using ornamental plants so that more accumulator plant species could be identified. Future research and information required to investigate the best dispose technique after phytoremediation and suitable plant for site rehabilitation.

CONCLUSION

This review focused on the harmful effects of the heavy metal chromium on the three main ecosystem components—soil, plants and humans. Hexavalent chromium is the most dangerous type of the metal. Soil containing chromium has the ability to change its pH and reduce microbial activity in the rhizosphere of the cultivated sites used for growing economically important plants which are major component of Food chain and Food Web in an ecosystem. After being absorbed and building up in plant cells, the hexavalent form of chromium damages DNA, breaks down proteins, inhibits photosynthesis, and can have a negative impact on other physiological functions.

The absorbed and accumulated increased amount of heavy metals in plant parts such as stem, leaves and roots are consume by other organisms, in this way heavy metals enters into food chain and create many health hazards. Although numerous techniques are in use to remediate heavy metals from agricultural soil but they are quite expensive, less efficient and particularly not successful.

Phytoremediation is the cost effective environmental restoration technology in which plants are used to remediate the heavy metals from the soil, water and air. Phytoremediation through ornamental plants is more profitable because many of them are not edible so there is very less risk to enter the heavy metals in food chain. In addition to improve the appearance of growth zone, ornamental plants also help to purify the surrounding area by removal of toxic metals from the soil, water and air. Decorative plants pose an impact on people's psychology and mental wellness. People who are around plants tend to think more positively. An individual can increase their income and expand their career and self-employment prospects by selling cut flowers in open market and by perfume production. This review emphasises the phytoremediation activity & role of reported ornamental plants for cleaning of Chromium accumulated polluted sites in a eco-friendly sustainable manner. More screening of Ornamental plants for the identification of metal tolerant plant species with a Phytoabsorbent quality towards heavy metals is needed and expected for future research work.

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REFERENCES

Akay, A., and Omar, M.Y. (2022). The effect of leonardite on chromium toxicity and growth of cordes rose. *Turkish Journal of Agriculture-Food Science and Technology*, 10(10), 1845-1853. https://doi.org/10.24925/turjaf.v10i10.1845-1853.5200

Bali, A.S., Sidhu, G.P.S., and Kumar, V. (2020). Root exudates ameliorate cadmium tolerance in plants: a review. *Environmental Chemistry Letters*, 18(4), 1243-1275. https://doi.org/10.1007/s10311-020-01012-x

Baruthio, F. (1992). Toxic effects of chromium and its compounds. *Biological Trace Element Research*, 32, 145-153. https://doi.org/10.1007/BF02784599

Bhagwat, A., Ojha, C.S.P., Pant, A., and Kumar, R. (2023). Interaction among heavy metals in landfill leachate and their effect on the phytoremediation process of Indian Marigold. *Journal of Hazardous, Toxic, and Radioactive Waste*, 27(1). DOI: 10.1061/(ASCE)HZ.2153-5515.0000731

Bhalerao, S.A., Sharma, A.S., and Poojari, A.C. (2015). Toxicity of nickel in plants. *International Journal of Pure and Applied Bioscience*, 3(2), 345-355.

Biswal, B., Singh, S.K., Patra, A., and Mohapatra, K.K. (2022). Evaluation of phytoremediation capability of French marigold (Tagetes patula) and African marigold (Tagetes erecta) under heavy metals contaminated soils. *International Journal of Phytoremediation*, 24(9). DOI: 10.1080/15226514.2021.1985960

Browning, C.L., and Wise, Sr. J.P. (2017). Prolonged exposure to particulate chromate inhibits RAD51 nuclear import mediator proteins. *Toxicology and Applied Pharmacology*, 331, 101-107. https://doi.org/10.1016/j.taap.2017.05.030

Butt, A., Rehman, K., Khan, M. X., and Hesselberg, T. (2018). Bioaccumulation of cadmium, lead, and zinc in agriculture-based insect food chains. *Environmental Monitoring and Assessment*, 190, 1-12. https://doi.org/10.1007/s10661-018-7051-2

Caldelas, C., Araus, J.L., Febrero, A., and Bort, J. (2012). Accumulation and toxic effects of chromium and zinc in Iris pseudacorus L. *Acta Physiologiae Plantarum*, 34, 1217-1228. https://doi.org/10.1007/s11738-012-0956-4

Campos, V., Lessa, S.S., Ramos, R.L., Shinzato, M.C., and Medeiros, T.A.M. (2017). Disturbance response indicators of Impatiens walleriana exposed to benzene and chromium. *International Journal of Phytoremediation*, 19(8), 709-717. https://doi.org/10.1080/15226514.2017.1284745

Cay, S. (2016). Enhancement of cadmium uptake by Amaranthus caudatus, an ornamental plant, using tea saponin. *Environmental Monitoring and Assessment*, 188(6), 320.

Cheng, L., Wang, Y., Cai, Z., Liu, J., Yu, B., and Zhou, Q. (2017). Phytoremediation of petroleum hydrocarbon-contaminated saline-alkali soil by wild ornamental Iridaceae species. *International Journal of Phytoremediation*, 19(3), 300-308. DOI: 10.1080/15226514.2016.1225282

Chitraprabha, K., and Sathyavathi, S. (2018). Phytoextraction of chromium from electroplating effluent by Tagetes erecta (L.). *Sustainable Environment Research*, 28, 128-134. https://doi.org/10.1016/j.serj.2018.01.002

Crisponi, G., Fanni, D., Gerosa, C., Nemolato, S., Nurchi, V.M., Crespo-Alonso, M., Lachowicz, J.I., and Faa, G. (2013). The meaning of aluminium exposure on human health and aluminium-related diseases. *Biomolecular Concepts*, 4(1), 77-87. DOI: 10.1515/bmc-2012-0045.

DalCorso, G., Fasani, E., Manara, A., Visioli, G., and Furini, A. (2019). Heavy metal pollutions: state of the art and innovation in phytoremediation. *International Journal of Molecular Science*, 20(14), 3412. https: //doi.org/10.3390/ijms20143412

Dayan, A.D., and Payne, A.J. (2001). Mechanisms of chromium toxicity, carcinogenicity and allergenicity: review of the literature from 1985 to 2000. *Human and Experimental Toxicology*, 20, 439-45. DOI: https://doi.org/ 10.1191/096032701682693062

Ehsan, N., Nawaz, R., Ahmad, S., Khan, M.M. and Hayat, J. (2016). Phytoremediation of Chromium-Contaminated Soil by an Ornamental Plant, Vinca (Vinca rosea L.). *Journal of Environmental and Agricultural Sciences*. 7, 29-34. (ISSN) 2313-8629

Fernandes, J.C. and Henriques, F.S. (1991). Biochemical, physiological, and structural effects of excess copper in plants. *The Botanical Review*. 57, 246-273. DOI: https://doi.org/10.1007/BF02858564

Fontana, G.A. and Gahlon, H.L. (2020). Mechanism of replication and repair in mitochondrial DNA deletion formation. *Nucleic Acids Research*. 48(20), 11244-11258. DOI: https://doi.org/10.1093/nar/gkaa804

Fozia A., Muhammad A. Z., Muhammad A. and Zafar, M. K. (2008). Effect of chromium on growth attributes in sunflower (Helianthus annuus L.). *Journal of Environmental Sciences*. 20, 1475-1480. DOI: https://doi.org/ 10.1016/S1001-0742(08)62552-8

Fu, J.W., Liu, X., Han, Y.H., Mei, H.Y., Cao, Y., De Oliveira, L.M., Liu, Y.G., Rathinasabapathi, B., Chen, Y.S. and Ma, L.Q. (2017). Arsenic-hyperaccumulator Pteris vittata efficiently solubilized phosphate rock to sustain plant growth and As uptake. *Journal of Hazardous Materials*. 330, 68-75. DOI: https://doi.org/10.1016/j. jhazmat.2017.01.049

Gardea-Torresdey, J.L., Peralta-Videa, J.R., Montes, M., De la Rosa, G. and Corral-Diaz, B. (2004). Bioaccumulation of cadmium, chromium and copper by Convolvulus arvensis L.: impact on plant growth and uptake of nutritional elements. *Bioresource Technology*. 92(3), 229-235. DOI: https://doi.org/10.1016/j. biortech.2003.10.002

Gawronski, S.W. and Gawronska, H. (2007). Plant taxonomy for phytoremediation. In: Marmiroli, N., Samotokin, B., Marmiroli, M. (eds) Advanced Science and Technology for Biological Decontamination of Sites Affected by Chemical and Radiological Nuclear Agents. *NATO Science Series: IV: Earth and Environmental Sciences, vol 75. Springer, Dordrecht*. 79-88. DOI: https://doi.org/10.1007/978-1-4020-5520-1_5

Gong X.M., Huang D.L., Liu Y.G., Zeng G.M., Wang R.Z., Wei J.J., Huang C., Xu P., Wan J. and Zhang C. (2018). Pyrolysis and reutilization of plant residues after phytoremediation of heavy metals contaminated sediments: for heavy metals stabilization and dye adsorption. *Bioresource Technology*. 253, 64-71. DOI: https://doi.org/10.1016/j.biortech.2018.01.018

Gupta, N. and Kumar, V. (2012). Identification and isolation of heavy metal (copper) resistant bacteria. *Archives of Applied Science Research*. 4, 577-583. https://api.semanticscholar.org/corpusaID:46614056

Gupta, P. and Kumar, V. (2017). Value added phytoremediation of metal stressed soils using phosphate solubilizing microbial consortium. *World Journal of Microbiology and Biotechnology*. 33, 1-15. DOI: https://doi.org/10. 1007/s11274-016-2176-3

Intansari, P., Kasmiyati, S. and Sucahyo, (2022). The application of Fe and Cr(III) in growing media and its effect on plant growth and Cr(III) oxidation on Tagetes erecta. *Jurnal Bioteknologi and Biosains Indonesia*. 9(1), 30-45. DOI: https://doi.org/10.29122/jbbi.v9i1.4865

Koeppe, D.E. (1977). The uptake, distribution, and effect of cadmium and lead in plants. *Science of the Total Environment*. 7, 197-206. DOI: https://doi.org/10.1016/0048-9697(77)90043-2

et al.,

Koropatnick, J. and Leibbrandt, M.E.I. (1995). Effects of Metal on Gene Expression. In: Handbook of Experimental Pharmacology, Toxicology of Metals. (R.A. Goyer and M.G Cherian, Eds.). Biochemical Aspects, Springer. 115, 93-120.

Li, X., Zhang, J., Ma, J., Liu, Q., Shi, T., Gong, Y., Yang, S. and Wu, Y. (2020). Status of chromium accumulation in agricultural soils across China (1989-2016). *Chemosphere*. 256, 127036. DOI: https://doi.org/10.1016/j.chemosphere.2020.127036

Liu, J., Xin, X. and Zhou, Q. (2017). Phytoremediation of contaminated soils using ornamental plants. *Environmental Reviews*. 26(1), 43-54. DOI: https://doi.org/10.1139/er-2017-0022

Lone, M.I., He, Z.L., Stoffella, P.J. and Yang, X.E. (2008). Phytoremediation of heavy metal polluted soils and water: progresses and perspectives. *Journal of Zhejiang University Science B*. 9(3), 210-220. https://doi.org/10.1631/jzus.B0710633

Lu, L., Han, X., Li, J., Hua, J. and Ouyang, M. (2013). A review on the key issues for lithium-ion battery management in electric vehicles. *Journal of Power Sources*. 226, 272-288. DOI: https://doi.org/10.1016/j.jpowsour.2012.10.060

Mahurpawar, M. (2015). Effects of heavy metals on human health. *International Journal of Research-Granthaalayah*. 3(9SE), 1-7. DOI: https://doi.org/10.29121/granthaalayah.v3.i9SE.2015.3282

Mancuso, T.F. (1997). Chromium as an industrial carcinogen: part II. Chromium in human tissues. *American Journal of Industrial Medicine*. 31, 40-147. DOI: https://doi.org/10.1002/(SICI)1097-0274(19970204)31:23.0.CO;2-3

Marques, A.P.G.C., Rangel, A.O.S.S. and Castro, P.M.L. (2009). Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology. *Critical Reviews in Environmental Science and Technology*. 39(8), 622-654. DOI: http://dx.doi.org/10.1080/10643380701798272

Miao, Q. and Yan, J. (2013). Comparison of three ornamental plants for phytoextraction potential of chromium removal from tannery sludge. *Journal of Materials Cycles and Waste Management*. 15, 98-105. DOI: https: //doi.org/10.1007/s10163-012-0095-4

Nakbanpote, W., Meesungnoen, O. and Prasad, M.N.V. (2016). Potential of ornamental plants for phytoremediation of heavy metals and income generation. In: *Bioremediation and Bioeconomy* (Prasad, M.N.V. Eds). Elsevier. 177-217. DOI: 10.1016/B978-0-12-802830-8.00009-5

Nescu, V., Ciulca, S., Sumalan, R.M., Berbecea, A., Velicevici, G., Negrea, P., Gaspar, S. and Sumalan, R.L. (2022). Physiological Aspects of Absorption, Translocation, and Accumulation of Heavy Metals in Silphium perfoliatum L. Plants Grown in a Mining-Contaminated Soil. *Minerals*. 12, 334. DOI: https://doi.org/10.3390/min12030334

Nie, P.G., Zhong, M., Cai, J., Yang, X., Zhou, J., Appiah, C., Tang, M., Wang, X., Feng, G., Huang, L. and Zhang, X. (2021). Transcriptome characterization of candidate genes related to chromium uptake. transport and accumulation in Miscanthus sinensis. *Ecotoxicology and Environmental Safety*. 221(4), 112445. DOI: https://doi.org/10.1016/j.ecoenv.2021.112445

Panda, A., Patra, D.K., Acharya, S., Pradhan, C. and Patra, H.K. (2020). Assessment of the phytoremediation potential of Zinnia elegans L. plant species for hexavalent chromium through pot experiment. *Environmental Technology and Innovation*. 20, 101042. DOI: https://doi.org/10.1016/j.eti.2020.101042

Peer, W.A., Baxter, I.R., Richards, E.L., Freeman, J.L. and Murphy, A.S. (2005). Phytoremediation and hyperaccumulator plants. In: *Molecular Biology of Metal Homeostasis and Detoxification*. (Tamas, M.J. and Martinoia, E. Eds). Berlin: Springer. 299-340. DOI: 10.1007/4735_100

Peng, H. and Guo, J. (2020). Removal of Chromium From Wastewater by Membrane Filtration, Chemical Precipitation, Ion Exchange, Adsorption Electrocoagulation, Electrochemical Reduction, Electrodialysis, Electrodeionization, Photocatalysis and Nanotechnology: a Review. *Environmental Chemistry Letters*. 18(6), 2055-2068. DOI: https://doi.org/10.1007/s10311-020-01058-x

Pietraszewska, T.M. (2001). Effect of aluminium on plant growth and metabolism. *Acta Biochimica Poinica*. 48(3), 673-686. https://pubmed.ncbi.nlm.nih.gov/11833776/

Pradhan, B., Chand, P.K. and Das, A.B. (2023). Hexavalent chromium bioaccumulation mediated enhancement of pyrethrin production in African marigold (Tagetes erecta L.): a promising plant for phytoremediation. *Acta Physiologiae Plantarum*. 45, 80. DOI: https://doi.org/10.1007/s11738-023-03564-1

Ramana, S., Biswas, A.K., Singh, A.B., Ajay, Ahirwar, N.K. and Rao, A.S. (2014). Tolerance of Ornamental Succulent Plant Crown of Thorns (Euphorbia milli) to Chromium and its Remediation. *International Journal of Phytoremediation*. 17, 363-368. DOI: https://doi.org/10.1080/15226514.2013.862203

Rendina, A., Barros, M.J. and De Iorio, A.F. (2011). Changes in the speciation, partitioning and phytoavailability of chromium induced by organic soil amendments. *Chemical Speciation and Bioavailability*. 23, 53-60. DOI: https://doi.org/10.3184/095422911X12971977268431

Rinklebe, J. and Shaheen, S.M. (2014). Assessing the mobilization of cadmium, lead, and nickel using a seven-step sequential extraction technique in contaminated floodplain soil profiles along the central Elbe River, Germany. *Water, Air, and Soil Pollution*. 225, 1-20. DOI: https://doi.org/10.1007/s11270-014-2039-1

Sahu, V., Mani, D., Kanaoujiya, R. and Singh, B. (2022). Accumulation of Cd, Cr, and Pb and Sustainable Detoxification in Sewage-Irrigated Soils. *Russian Agricultural Science*. 48, 383-391. DOI: https://doi.org/10.3103/S1068367422050111

Sehrawat, G., Singh, R. and Kaushik, A. (2021). Tolerance of Three Ornamental Plant Species to Chromium contamination in Soil and their Potential for Phytoextraction and Phytostabilization of the Toxic Metal. *Current World Environment*. 16, 386-398. DOI: http://dx.doi.org/10.12944/CWE.16.2.06

Shahid, M., Shamshad, S., Rafiq, M., Khalid, S., Bibi, I., Niazi, N.K., Dumat, C. and Rashid, M.I. (2017). Chromium speciation, bioavailability, uptake, toxicity and detoxification in soil-plant system: a review. *Chemosphere*. 178, 513-533. DOI: https://doi.org/10.1016/j.chemosphere.2017.03.074

Signes-Pastor, A.J., Mitra, K., Sarkhel, S., Hobbes, M., Burló, F., De Groot, W.T. and Carbonell-Barrachina, A.A. (2008). Arsenic speciation in food and estimation of the dietary intake of inorganic arsenic in a rural village of West Bengal, India. *Journal of Agricultural and Food Chemistry*. 56(20), 9469-9474. DOI: https://doi.org/10.1021/jf801600j

Stoikou, V., Andrianos, V., Stasinos, S., Kostakis, M.G., Attiti, S., Thomaidis, N.S. and Zabetakis, I. (2017). etal Uptake by Sunflower (Helianthus annuus) Irrigated with Water Polluted with Chromium and Nickel. *Foods*. 6(7), 51. DOI: https://doi.org/10.3390/foods6070051

Sun, Y. and Zhou, Q. (2016). Uptake and translocation of benzo[a]pyrene (B[a]P) in two ornamental plants and dissipation in soil. *Ecotoxicology and Environmental Safety*. 124, 74-81. DOI: https://doi.org/10.1016/j.ecoenv.2015.09.037

Sundaramoorthy, P., Chidambaram, A., Ganesh, K.S., Unnikannan, P. and Baskaran, L. (2010). Chromium stress in paddy: (i) nutrient status of paddy under chromium stress; (ii) phytoremediation of chromium by aquatic and terrestrial weeds. *Comptes Rendus Biologies*. 333(8), 597-607. DOI: https://doi.org/10.1016/j.crvi.2010.03.002

Ventura, C., Gomes, B.C., Oberemm, A., Louro, H., Huuskonen, P., Mustieles, V., Fernández, M.F., Ndaw, S., Mengelers, M., Luijten, M., Gundacker, C. and Silva, M.J. (2021). Biomarkers of effect as determined in human biomonitoring studies on hexavalent chromium and cadmium in the period 2008-2020. *Environmental Research*. 197, 110998. DOI: https://doi.org/10.1016/j.envres.2021.110998

Wan, X., Lei, M. and Chen, T. (2016). Cost-benefit calculation of phytoremediation technology for heavy-metal-contaminated soil. *Science of the Total Environment*. 563-564, 796-802. DOI: https://doi.org/10.1016/j.scitotenv.2015.12.080

Wani, P.A., Garba, S.H., Wahid, S., Hussaini, N.A. and Mashood, K.A. (2019). Prevention of oxidative damage and phytoremediation of Cr (VI) by chromium (VI) reducing Bacillus subtilus PAW3 in cowpea plants. *Bulletin of Environmental Contamination and Toxicology*. 103, 476-483. DOI: https://doi.org/10.1007/s00128-019-02683-1

Wei, S.H., Zhou, Q.X. and Wang, X. (2005). Cadmium-hyperaccumulator Solanum nigrum L. and its accumulating characteristics. *Journal of Environmental Sciences-China*. 26(3), 167-171.