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Review Article

Role of Ornamental Plants in Phytoremediation – An Overview

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Abstract

Harmful chemical compounds and pollutants are released into the atmosphere and causes serious health issues to human since industrial revolution. Bioremediation being the important operation that helps in remediating soil and water through plants. Phytoremediation, an emerging cost-effective, non-intrusive and aesthetically pleasing technology, that uses the remarkable ability of plants to concentrate elements and compounds from the environment and to metabolize them in their tissues, appears very promising for the removal of pollutants from the environment. In simple, Phytoremediation involves the use of plants to remove pollutants from the environment and renders them harmless. Ornamental plants have a greater impact on phytoremediation effect. For example, flowering plants such as African marigold, French marigold, Celosia, Tuberose, Chrysanthemum, etc., have a greater potential to accumulate heavy metals such as Cd, Cr and Pb. Industrial landscaping has gained importance in the recent times that helps in maintaining a clean and sustainable environment. Growing of plants becomes a tedious thing as most plants are susceptible to heavy metal toxicity. In order to overcome the constraint and to rectify the soil, use of several hyper-accumulator plants such as Marigold, Celosia. Tuberose, etc. and some trees like Neem and Willow can be grown. Advantage of employing flowering plants result in preventing heavy metals entering the food chain as they are non-edible and has viable potential for a source of income.

Keywords: Phytoremediation, Ornamental plants, Heavy metal accumulation

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Introduction

Phytoremediation is a bioremediation technique that employs diverse plant species to remove, transfer, stabilize, and/or eliminate pollutants in soil and groundwater [1]. It is derived from a greek word ‘phyto’ meaning plant and a latin word ‘remedium’ meaning remove an evil [2]. Phytoremediation applicability is in the remediation of metals, heavy metals, radionuclide, explosives, fuels, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs). This process can be applied in terrestrial and aquatic environment. Plants help to prevent pollutants from being transported away from the site by wind, rain, and groundwater flow. The uptake of contaminants in plants occurs primarily through the root system, where the principal mechanisms for preventing toxicity are found. The root system provides an enormous surface area that absorbs and accumulates water and nutrients essential for growth along with n~n-essential contaminants [3].

Plant roots alter the soil-root interface by releasing organic and inorganic exudates into the rhizosphere. The number and activity of microorganisms, the aggregation and stability of soil particles around the root, and the availability of pollutants are all affected by root exudates. Through changes in soil properties, the release of organic compounds, changes in chemical composition, and/or an increase in plant-assisted microbial activity, root exudates can enhance or reduce (immobilize) the availability of pollutants in the rootzone of plants. Plants facilitate in the removal of a wide range of pollutants, including metals, pesticides, explosives, and oil. However, they perform better in areas with low contamination levels since high concentrations potentially restrict plant growth and development and take too long to clean up. Phytoremediation mechanism are of different types namely, Rhizosphere biodegradation, Phyto-stabilization or Phyto-extraction, Rhizofiltration, Phyto-volatilization, Phyto-degradation and Hydraulic Control (**Figure 1**).

Mechanism of phytoremediation

Phyto-extraction removes metals or organics from soils by accumulating them in the biomass of plants. Phyto-degradation, or phyto-transformation is the use of plants to uptake, store and degrade organic pollutants; rhizofiltration involves the removal of pollutants from aqueous sources by plant roots. Phyto-stabilization reduces the bioavailability of pollutants by immobilizing or binding them to the soil matrix, and phyto-volatilization uses plants to take pollutants from the growth matrix, transform them and release them into the atmosphere [4]. In the process of rhizosphere biodegradation, plants release natural substances through roots by supplying nutrients to microorganisms in the soil. The microorganisms enhance biological degradation.

Figure 1 Phytoremediation mechanism (Source: phy2SUDOE)

Phyto-extraction

The utilization of plants to transport and accumulate metals from soil to the harvestable parts (leaves and aerial parts) is called as phyto-extraction. There are two forms of phyto-extraction namely, natural hyper-accumulation and induced (assisted) hyper-accumulation.

Natural hyper-accumulation

The plant uptake contaminants from the soil in an unassisted manner and the plants used are metallophytes that can tolerate and accumulate higher concentration of heavy and toxic metals.

Induced (assisted) hyper-accumulation

A conditioning fluid containing chelators are added to the soil which increases metal solubility or mobilize in the plants and absorbs them easily.

Phyto-degradation

This process involves the breakdown of contaminant taken up by plants through metabolic processes inside the plant or the breakdown of contaminants taken up by plants externally through the influence of substances synthesized by the plants. The complex organic molecules that are degraded into simpler molecule contaminants in soils, sediments, sludges, and groundwater medium [5]. As with phytoextraction and phytovolatilization, plant uptake generally occurs only when the contaminants' solubility and hydrophobicity fall into a certain acceptable range. Phytodegradation has been observed to remediate some organic contaminants, such as chlorinated solvents, herbicides, and munitions, and it can address contaminants in soil, sediment, or groundwater [6].

Phyto-volatilization

The ability of plants to absorb and subsequently volatilize the contaminant into atmosphere is called phyto-volatilization. Phytovolatilization can occur with contaminants present in soil, sediment, or water. Mercury is the primary metal contaminant that this process has been used for. It has also been found to occur with volatile organic compounds, including trichloroethene, as well as inorganic chemicals that have volatile forms, such as selenium, and arsenic [6]. It involves contaminants being taken up into the body of the plant, but then the contaminant, a volatile form thereof, or a volatile degradation product is transpired with water vapor from leaves [6]. Phytovolatilization may also entail the diffusion of contaminants from the stems or other plant parts that the contaminant travels through before reaching the leaves [7]. For example, the contaminant, mercuric ion, may be transformed into a less toxic substance (*i.e*., elemental Hg). On the other hand, mercury released into the atmosphere is likely to be recycled by precipitation and then redeposited back into lakes and oceans, repeating the production of methylmercury by anaerobic bacteria [8].

Phyto-stabilization

The root plants exudates to stabilize, demobilize and bind the contaminants in the soil matrix, thereby reducing their bioavailability. Certain plant species have used to immobilize contaminants in the soil and ground water through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone [5]. This technique can also be used to reestablish vegetation cover at sites where natural vegetation fails to survive due to high metals concentrations in surface soils or physical disturbances to surface materials. Metal-tolerant species is used to restore vegetation at contaminated sites, thereby decreasing the potential migration of pollutants through wind erosion and transport of exposed surface soils and leaching of soil contamination to ground water. It can occur through the sorption, precipitation, complexation, or metal valence reduction. It is useful for the treatment of lead (Pb) as well as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn).

Rhizo-filtration

Plants are used primarily to address contaminated ground water rather than soil. The plants to be used for clean-up are raised in greenhouses with their roots in water rather than in soil. To acclimatize the plants, once a large root system has been developed, contaminated water is collected from a waste site and brought to the plants where it is substituted for their water source. The plants are then planted in the contaminated area where the roots take up the water and the contaminants along with it. As the roots become saturated with contaminants, they are harvested. Sunflower, Indian mustard, tobacco, rye, spinach, and corn have been studied for their ability to remove lead from water, with sunflower having the greatest ability. In sunflower, lead concentration significantly reduced after only one hour of treatment [7]. It is the adsorption or precipitation onto plant roots or absorption of contaminants in the solution surrounding the root zone. Rhizofiltration is typically exploited in groundwater (either *in situ* or extracted), surface water, or wastewater for removal of metals or other inorganic compounds [6]. Rhizofiltration can be used for Pb, Cd, Cu, Ni, Zn, and Cr, which are primarily retained within the roots [8].

Rhizo-degradation

Rhizo-degradation process uses microorganisms to consume and digest organic substances for nutrition and energy. Natural substances released by the plant roots, sugars, alcohols, enzymes and amino acids, contain organic carbon that provides food for soil microorganisms and establish a dense root mass that takes up large quantities of water. This is also referred to as phytostimulation. The localized nature of rhizodegradation means that it is primarily useful in contaminated soil, and it has been investigated and found to have at least some successes in treating a wide variety of mostly organic chemicals, including petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), chlorinated solvents, pesticides, polychlorinated biphenyls (PCBs), benzene, toluene, ethylbenzene, and xylenes [6]. It can also be seen as plant-assisted bioremediation, the stimulation of microbial and fungal degradation by release of exudates/enzymes into the root zone (rhizosphere) [9].

Hydraulic control

It is referred to as the control of water table and the soil field capacity by plant canopies. It uses phreatophytic trees and plants that have the ability to transpire large volumes of water and thereby affect the existing water balance at the site. The increased transpiration reduces infiltration of precipitation (thereby reducing leaching of contaminants from the vadose zone) or increases transpiration of groundwater, thus reducing contaminant migration from the site in groundwater plumes. It also addresses a wide range of contaminants in soil, sediment, or groundwater [6]. It should be noted that hydraulic control is also a feasible phytoremediation mechanism for control of groundwater contamination in particular, because the characteristics of the contaminants are not as relevant to the success of the technique.

Use of ornamental plants in phytoremediation

Phytoremediation makes use of the harvestable parts of plants to remove pollutants, represents a green and environmentally friendly tool for cleaning metal polluted soils and waters, there is a danger of contamination of the food chain if edible crops are used for the purpose. A viable and remunerative alternative could be cultivation of non-edible crops, which will prevent the entry of heavy metals through food chain [10-12]. Among the non-edible crops, floriculture plants are important type of higher plants that can be used for remediation of contaminated soils.

Ornamental plants are plants that are grown for decorative purposes with a range of shapes, sizes and colors that are suitable to a broad array of climates, landscapes, and desired gardening characteristics (their flowers, leaves, scent, overall foliage texture, fruits, stems and bark, aesthetic form). The group broadly comprise various types of plants, from herbaceous to woody, lower- to higher-level, and aquatic to terrestrial plants [13, 14]. Distinguished from other types of reported remediation plants, some ornamental plants can beautify the environment while also remedying contaminated soils particularly in urban areas [15-20]. Optimistically, both economic and ecological benefits can be expected with the application of ornamental plants for the phytoremediation of contaminated soils. A contaminated area can be developed for ecotourism by growing ornamental plants to preserve the aesthetic beauty of the land. After artificial culturing, ornamental plants could also be sold as houseplants, which will result in economic benefits and save a large amount of the final disposal expenses [21]. Plant tourism is a worldwide industry worth billions of dollars annually, and as a tourism resource, ornamental plants have a huge market [22]. With the rising demand, the ornamental plant industry requires new plant varieties with excellent qualities such as improved anatomical attributes, stress tolerance and disease resistance, which also offer more options for phytoremediation [23]. There are abundant ornamental plant germplasm resources around the world, with the number of species amounting to approximately 30,000 [24], which is beneficial to selecting remediation plants from various ornamental plants, even from those in different climates zones. The heavy metal concentration in ornamental plants may not always meet the definition of a hyperaccumulator, but their high biomass indicates that ornamental plants could accumulate more heavy metals than hyperaccumulators. According to the literature herbaceous ornamental plants with aesthetic value are preferred for phytoremediation investigations [25, 26]. The short growth cycle of herbaceous ornamental plants enables the observation and recording of the plant responses to stress over an entire growing season in a greenhouse. This characteristic makes herbaceous ornamental plants a suitable vegetation type for screening heavy metal accumulator or hyperaccumulator species. The aboveground biomass of herbaceous ornamental plants applied for phytoextraction can be harvested as soon as the plants have flowered, usually no more than one year after planting.

Phytoremediation potential of ornamental plants

The tuberose varieties Prajwal, Mexican single and Shringar showed greater tolerance to Cadmium and exhibited strong ability to accumulate Cadmium and its partitioning from bulb to shoot. Therefore, the plant has greater potential to accumulate Cadmium contaminated soils [27]. Indian Marigold is a good Cadmium hyper-accumulator species screened out from various flowering plants [28]. Indian Marigold grown on contaminated soils of 50 and 500 mg kg^{-1} grapheme oxide promotes growth and 500 mg kg^{-1} of zero-valent iron nanoparticles is harmful to plants [29]. Among the ornamental plants studied for phytoremediation potential (*Jasminum sambac*, *J.grandiflorum*, *Polianthes tuberosa* and *Nerium oleander*), Jasminum sp. was found to be shown high degree of tolerance to Cr contaminated soils was found by [30]. Phytoremediation depends on the ability of the plants to concentrate heavy metals without showing signs of toxicity [31]. It was found that *T. erecta* was able to tolerate Cr concentrations up to 6 mg/kg without affecting plant growth. Further, it has high biomass, fast growing and easily harvestable phytoremediator. Among different types of hyper-accumulators, Indian Mustard (*Brassica juncea*) and Marigold (*Tagetes patula*) plants have been known to remove heavy metals from soil [32, 33]. Irrigation of flower crops with tannery effluent water resulted in considerable amount of Cr accumulation in *J.sambac*, *J.grandiflorum*, *P.tuberosa* and *N.oleander* was examined. French Marigold is a hyper-accumulator of Cd metal (45 to 66 mg kg^{-1} in shoots and 65 to113 mg kg^{-1} in roots) without showing any toxic symptoms in the pot experiment conducted by [34]. The growth response and phytoextracting ability of Marigold under lead stress conditions showed higher levels and viable candidate for lead accumulated soils and also has aesthetic sense of beauty [21]. *J.auriculatum* was found relatively tolerant to Cr at 1000 $\mu g\ g^{-1}$ in soils while *Crossandra infundibuliformis* and *J.sambac* were found to be sensitive at this concentration [35]. Greater accumulation of heavy metals was found in Nelumbo nucifera and poor content in *Echinochloa colonum* after studying the different aquatic macrophytes in comparison with biomonitors and abiotic monitors [36]. The amount of lead extracted from Marigold is at 60% for 200 mg kg^{-1} concentration and is reduced to 30% when the treatment is incorporated with vermicompost was studied by [37]. Marigold, Rose, Jasmine, Hibiscus showed bioaccumulation of Cd and Ni metals in aerial shoots and underground roots [38].

Ornamental plants with phytoremediation potential are initially assessed by their morphological characteristics. The root, stem and leaf morphologies play vital roles in the phytoremediation process [39]. Root length, density and surface area are important characteristics that can directly influence the uptake or degradation of contaminants, and root exudates can influence the growth and reproduction of microorganisms in the rhizosphere [40-42]. The essential part of ornamental plants is stem tissue that tolerates and accumulates contaminants and relates with height and diameter of the stem [43, 44]. The leaf area index increases biomass through its impact on photosynthesis and leaf being the major site for volatilization and excretion is primarily involved in detoxification mechanism for hazardous materials [45, 46]. *Mirabilis jalapa* may potentially be used for the phytoremediation of cadmium (Cd)-contaminated soils by accumulating the contaminants at above-ground parts [47].

The ornamental plants are screened and ideally selected by tolerance to biotic (disease and pest resistance) and abiotic (heat, drought and salt tolerance) stress [44]. The ability of plants to cope with or adapt to environmental stress, varies across and within species as well as cultivars. Such variation in the tolerance or adaptability to environmental stress has been subjected to natural selection as well as being selected artificially by breeders to improve agronomic traits [48]. Atmospheric pollutants absorbed on the surface of aerial plant parts can be taken up and metabolized by ornamental plants. Ornamental plants can eliminate atmospheric pollutants within a certain concentration range, but this ability is related to the type of ornamental plants and pollutant [13]. *Aloe vera* var. chinensis can absorb formaldehyde, *Crassula portulacea* can absorb benzene and Dianthus chinensis can absorb sulfur dioxide. Alternatively, *Dracaena sanderiana* and *Dendranthema morifolium* can simultaneously absorb and purify formaldehyde, benzene and carbon dioxide to a large extent. Heat stress may influence plant growth, causing a series of negative effects such as a reduced germination rate and abnormal seedlings [49].

Salt tolerance is necessary in ornamental plants for which low-quality water (recycled water or reclaimed water) may be used for irrigation. Salinity can inhibit growth and cause damage through physiological drought, nutrient deficiency and ion toxicity [50]. Some ornamental plants such as Plumbago auriculata and *Pavonia lasiopetala* have developed specialized salt glands on the surface of their leaves, through which excess toxic ions can be secreted onto the leaf surface to reduce the harmfulness to the plants [51]. Ornamental plants that are well adapted to high salinity can also be applied to phytoremediation of heavy metal-contaminated saline land.

Drought tolerance can enable the survival of ornamental plants in dry regions and save considerable amounts of water. The responses of six cultivars of *Gerbera jamesonii* to heat stress by analyzing the morphological, physiological and biochemical characteristics and observed yellowing, wilting, drying and death of their leaves to varying degrees. Among the six cultivars, Meihongheixin' was found to be a heat-resistant cultivar, whereas 'Beijixing' was found to be a heat-sensitive cultivar [52].

The most ornamental plants used for phytoremediating heavy metals such as (Cr, Ar, Cd, Cu, Pb, Hg, Mn, Mo, Ni and Zn) are annual and biennial herbs. Morphological and growth indicators including root length, shoot height and plant dry weight are the most common indicators to describe plant tolerance. Ecotoxicological indexes based on the inhibition rate of seed germination, root and shoot elongation, and biomass (fresh and dry weights), as well as the IC50 (heavy metal concentration at which 50% of the plants show inhibition) and tolerance (ratio of the maximum root length in an experimental group to that in a control group) indexes have also been determined [53]. Some ornamental plants such as *Chlorophytum comosum* have exhibited high tolerance to more than one type of pollutant. the dry weight and height of *Calendula officinalis* was found to increase to different extents with an increase in the soil Cd concentration. Similar results were also found in *Chlorophytum comosum*: the lengths of the roots and aboveground parts reached their maximal value at a Cd concentration of 5 mg/kg dry weight soil, and the dry weight of the roots reached its peak value at a Cd concentration of 20 mg/kg dry weight soil. Italian ryegrass (*Lolium multiflorum*) and white clover (*Trifolium repens*), two ornamental herb species, had better tolerance to Cd based on the median inhibition concentration values of seed germination and root and shoot elongation in hydroponics [25]. A field experiment on Pb-contaminated calcareous and acidic soils was conducted to explore the Pb tolerance of six scented *Pelargonium* cultivars. The plants were grown in natural agro-climatic conditions, with neither fertilization nor optimum irrigation, and no symptoms of morpho-phytotoxicity were observed in spite of high Pb concentration [54]. The effects of iron ore tailings on the growth and physiological activity of *Tagetes patula*, their results suggested an increase in growth, chlorophyll content and antioxidant activities with an increasing proportion of tailings in the soil [55].

Some of the ornamental plants that have been tested are rather sensitive to heavy metal stress, with symptoms of phytotoxicity occurring even in the presence of low heavy metal concentrations. According to a preliminary screening of 30 types of annual or biennial herbaceous ornamental plants, *Amaranthus hypochondriacus* and *Lupinus polyphyllus* showed extremely poor tolerance to Pb (1000 257 mg/kg dry weight soil) compared with the controls, and the shoot biomass of these 2 plants decreased by 49% and 88%, respectively [56]. *Antirrhinum majus* and *Quamoclit pennata* had poor tolerance to Pb. Pb contamination restricted plant growth, and the plant biomass of *A. majus* and *Q. pennata* in Pb-contaminated soil (1000 mg/kg dry weight) was significantly lower than that in the control [18]. *Impatiens balsamina* and *T.erecta* had poor tolerance to Cr compared with *M. jalapa* [57]. All the selected growth parameters such as root length, root biomass and shoot biomass decreased significantly as the Cr concentration increased, and dark brown spots even appeared on the roots and leaves of *I. balsamina*. Ecotoxicological effects of cadmium (Cd) on three ornamental plants *T.erecta*, *Salvia splendens* and *Abelmoschus manihot* were investigated [58]. Seeds of these plants were exposed to five Cd concentrations (0-50 mg/L), and the results showed that Cd had significant inhibitory effects on root elongation of the three plants and shoot elongation of *T.erecta*. Although some ornamental plants with poor tolerance to heavy metals are probably not suitable for phytoremediation applications, the results of these investigations are still valuable to phytoremediation research. Phytoextraction takes advantage of plants, especially hyperaccumulator plants, to extract or concentrate metals and organics into the harvestable biomass [59], whereas phytostabilization primarily makes use of plants ability to reduce the mobility and bioavailability of contaminants [60, 61]. Thus, in deciding whether an accumulator can be used for phytoextraction or phytostabilization purposes, the heavy metal accumulation in roots or aboveground shoots is a major factor. Both the bioaccumulation factor (BCF) and translocation factor (TLF) are important in selection and evaluation of plants for the phytoremediation of heavy metals [39, 62]. Ideal plants used for phytoextraction are expected to have heavy metal accumulation characteristics with BCF >100 and TLF >1. Screening potential hyperaccumulators is always a research hotspot in phytoremediation. Most of the identified hyperaccumulators can only hyperaccumulate Ni, with approximately 30 species accumulating either Cu, Co, Mn, or Zn and limited species accumulating Cd, Pb, and As [63, 64]. Some ornamental plants possess high tolerance and heavy metal accumulation characteristics, but most of the absorbed heavy metals are deposited in the roots of plants and cannot be transferred to the aboveground parts effectively. These types of ornamental plants have great potential for phytostabilization of heavy metal-contaminated soils. *T.patula* has potential utility in phytostabilization of soils contaminated with multiple heavy metals. *Iris lactea* var. chinensis can also be used for the phytostabilization of Pb-contaminated soils when exposed to 828 mg/L Pb, concentration in the roots and shoots of *I. lactea* var. Chinensis reached 2408 and 1109 mg/kg dry weight plant, respectively [65].

The subcellular distribution of Cr in *Iris pseudacorus* using TEM and X-ray microanalysis, and the highest Cr contents were found in the cell walls of the cortex in the roots and in the cytoplasm and the intercellular spaces of the rhizome [66]. Metal deposits generally distribute in the cell walls, vacuoles and cytoplasm plays a vital role in decreasing the free metal concentration. Heavy metals are absorbed through the root surface and transported to different plant tissues and detoxification of heavy metals occurs during this process to reduce the biotoxicity of heavy metals. As there is usually a large negative resting potential in the plasma membrane, most metal ions enter plant cells via specific or generic carriers. Once metal ions are taken up into the cell, constant chelation is required to accelerate the rate of metal translocation. The sequestration of metal ions in specific cell and organelle compartments, such as vacuoles or cell walls, has been proposed to be a detoxification mechanism. Chelators such as phytochelatins, metallothioneins and organic acids contribute to metal detoxification by buffering the free metal concentration. The isolation and functional characterization of a *Nelumbo nucifera* homologue of phytochelatin synthase (PCs) [40]. As a defense mechanism, SOD, peroxidase (POD) and CAT protect plants from the damage induced by heavy metals. SOD catalyzes the dismutation of superoxide radicals to O2 and H2O2, which can then be further detoxified by CAT and POD [67]. The activities of CAT and POD in *Chlorophytum comosum* increased significantly at lower Pb concentrations and reached their maximum at 1000 and 250 mg/kg dry weight soil, respectively [68].

Process of phytoremediation enhancement in contaminated soils

Increasing the metal bioavailability through adding chelators, fertilizers, inoculation of plant growth promoting rhizobacteria and using genetic engineering. A seed germination test with *Zinnia elegans* exposed to solutions containing Pb and four types of chelators including sodium ethylenediamine tetra-acetic acid (Na2EDTA), oxalic acid, tartaric acid and citric acid was conducted by [69]. The roots and shoots treated with equimolar amounts of the chelators and Pb were longer than those treated with half and two times of the molar Pb concentrations. Seedling growth was inhibited by the excess addition of chelators, and the toxicity of the complexes was less than that of the Pb and chelators. The application of EGTA in soil was shown to be safer than EDTA to enhance Cd uptake by *M. jalapa*. The available Cd that resulted from the application of the chelant EGTA to the contaminated soils was limited to the top 5 cm, while the EDTA applied to the contaminated soils is limited to the top 10 cm. [47]. The efficiency of tea saponin and EDTA in enhancing the Cd uptake by *Amaranthus caudatus* and found that tea saponin was more efficient at increasing the Cd concentration in the shoots and was more easily utilized [44]. The phosphate addition considerably increased the As uptake of *Pteris vittata* by 265% due to the replacement of P by As [70]. The effects of various soil Cd levels on the concentrations of N forms and the activity of key enzymes involved in N metabolism in leaves of *Solanum nigrum* [47]. The application of sulfur and vermicompost enhanced the photosynthetic pigments in *Chrysanthemum indicum*, and enhanced photosynthetic activities that protect plants against the hazardous effects induced by Pb [71]. Two heavy metal-resistant rhizobacteria were spiked with Pb- and Hg-contaminated soil to examine the effects of phytoremediation by *Scirpus mucronatus* [72], which was found to be feasible using a combined application of *S.mucronatus* and bacterial inoculums. [26] assessed the effects of PGPR strains on the growth of *Helianthus annuus* grown in Zn-Cd contaminated soil, and found inoculation with PGPR strains to be an effective way to promote the phytoremediation potential of *H.annuus*. A CAXcd (an Arabidopsis CAX1 mutant)-expressing petunia plant with significantly higher Cd tolerance and accumulation than the controls, with the transgenic plants accumulating up to 2.5 times more Cd than the controls [73]. In ornamental plants, PCs are thought to be involved in maintaining intracellular homeostasis with respect to essential metal ions. Isolation and functionally characterization of an *N.nucifera* homologue of PCs; the sequence, named *N. nucifera* phytochelatin synthase1 (NnPCS1) was dramatically expressed in response to Cd stress and may represent a useful target gene for phytoremediation of Cd contamination [40]. The identification and functional characterization of metal tolerance genes is highly relevant for improving the phytoremediation efficiency. 12 genes authentically related to Cu stress responses in *Paeonia ostii* and further validated the differentially expressed genes (DEGs) by quantitative real-time polymerase chain reaction (qRT-PCR) [74].

Table 1 Stress tolerant ornamental plants

S. No	Tolerance	Ornamental plants	References
1.	Salt tolerance	*Callistemon laevis, Malvaviscus arboreus* var. *drummondii, Plumbago auriculata, Pavonia lasiopetala, Caryopteris clandonensis, Anisacanthus quadrifidus* var. *wrightii*	[51,75,76]
2.	Drought tolerance	*Syzygium aromaticum, Caryopteris clandonensis, Gaillardia aristata, Echinacea purpurea, Dianthus plumarius, Rosa meillandina*	[77,78]

Table 2 Heavy metal accumulation and tolerance in ornamental plants

S. No	Ornamental plant	Heavy metal	Tolerance concentration	Accumulated concentration			Process of phytoremediation	Reference
				Soil	Shoot	Root		
1.	*Taraxacum mongolicum*	Cd	100	25	12	33	Phytoextraction	[79]
2.	*Althaea rosea*		100	100	136	100		[80]
3.	*Mirabilis jalapa*		100	100	68	141		[81]
4.	*Calendula officinalis*		100	100	1084	284	Phytostabilization	[80]
5.	*Chlorophytum comosum*		200	200	866	1522		[17]
6.	*Celosia cristata*	Pb	5000	1000	1022	360		[18]
7.	*Melastoma malabaricum*		200	200	13800	880		[19]
8.	*Chlorophytum comosum*		2000	1250	316	202		[70]
9.	*Melastoma malabaricum*	As	40	40	570	2800	Phytoextraction	[19]

Conclusion

Further investigations to yield valuable information on the molecular mechanisms underlying the heavy metal resistance of ornamental plants and lay a foundation for further genomics studies on related ornamental species for phytoremediation of heavy metal-contaminated soils. Understanding the transport pathway and regulatory mechanisms of heavy metals in ornamental plants will improve plant resistance to these heavy metals and also provides a theoretical basis for soil remediation by ornamental plants.

References

[1] W. R. Berti, S. D. Cunningham, "Phytostabilization of metals," in Phytoremediation of Toxic Metals: Using Plants to Clean-up the Environment. John Wiley & Sons, Inc. New York, 2000, p71-88.

[2] S. D. Cunningham, T. A. Anderson, P. A. Schwab, F. C. Hsu, Phytoremediation of soils contaminated with organic pollutants, Advances in Agronomy, 1996, 56: 55-114.

[3] Yin Ouyang, Phytoremediation modelling plant uptake and contaminant transport in the soil-plant-atmosphere continuum. J. Hydrology, 2002, 266: 1-2: 66-82.

[4] A. D. Peuke, H. Rennenberg, Phytoremediation with transgenic trees. Zeitschrift fur Naturforschung. C, Journal of biosciences, 2005, 60(3-4), 199-207.

[5] M. N. V. Prasad, H. M. De Oliveira Freitas, Metal hyperaccumulation in plants—biodiversity prospecting for phytoremediation technology. Electron J Biotechnol, 2003, 6(3), 110-146.

[6] EPA, A Citizen's Guide to Phytoremediation, Environmental Protection Agency, United States, 2000, p6.

[7] I. Raskin, B. D. Ensley, Recent developments for in situ treatment of metal contaminated soils. In: Phytoremediation of Toxic Metals: Using Plants to Clean Up the Environment. John Wiley & Sons Inc., New York, 2000.

[8] United States Environmental Protection Agency (USEPA), Introduction to Phytoremediation, 2000.

[9] P. Zhuang, Z. H. Ye, C. Y. Lan, Z. W. Xie, W. S. Hsu, Chemically assisted phytoextraction of heavy metal contaminated soils using three plant species. Plant Soil, 2005. 276: 153- 162.

[10] K. Lal, P. S. Minhas, R. K. Chaturvedi, R. K. Yadav, Cadmium uptake and tolerance of three aromatic grasses on Cd rich soil. Journal of the Indian Society of Soil Science, 2008, 56(3): 290–294.

[11] S. Ramana, A. K. Biswas, A. Subba Rao, Phytoextraction of lead by marigold and chrysanthemum. Indian Journal Plant Physiology, 2008, 13(3), 297–299.

[12] S. Ramana, A. K. Biswas, A. Subba Rao, Phytoextraction of cadmium by African marigold and chrysanthemum. National Academy Science Letters, 2009, 32(11&12), 333–336.

[13] J. N. Liu, Q. X. Zhou, T. Sun, X. F. Wang, Feasibility of applying ornamental plants in contaminated soil remediation. Chin. J. Appl. Ecol. 18(7): 1617–1623.

[14] M. S. Dobres, Prospects for commercialisation of transgenic ornamentals. In Transgenic horticultural crops challenges and opportunities, CRC Press, 2011, pp. 305-316.

[15] Y. L. Han, H. Y. Yuan, S. Z. Huang, Z. Guo, B. Xia, J. G. Gu, Cadmium tolerance and accumulation by two species of Iris. Ecotoxicology, 2007, 16(8): 557–563.

[16] R. Sun, Q. Zhou, S. Wei, Cadmium accumulation in relation to organic acids and nonprotein thiols in leaves of the recently found Cd hyperaccumulator Rorippa globosa and the Cd-accumulating plant Rorippa islandica. J. Plant Growth Regul, 2011, 30(1): 83–91.

[17] Y. Wang, A. Yan, J. Dai, N. Wang, D. Wu, Accumulation and tolerance characteristics of cadmium in Chlorophytum comosum: a popular ornamental plant and potential Cd hyperaccumulator. Environ. Monit. Assess, 2012, 184(2): 929–937.

[18] S. Cui, T. Zhang, S. Zhao, P. Li, Q. Zhou, Q. Zhang, Q. Han, Evaluation of three ornamental plants for phytoremediation of Pb-contamined soil. Int. J. Phytoremediation, 2013, 15(4): 299–306.

[19] S. N. Selamat, S. R. Abdullah, M. Idris, Phytoremediation of lead (Pb) and arsenic (As) by Melastoma malabathricum L. From contaminated soil in separate exposure. Int. J. Phytoremediation, 2014, 16(7–12): 694–703.

[20] S. Ramana, A. K. Biswas, A. B. Singh, N. K. Ahirwar, A. Subba Rao, Tolerance of ornamental succulent plant crown of thorns (Euphorbia milli) to chromium and its remediation. Int J Phytoremediation, 2015, 17(4): 363–368.

[21] J. N. Liu, Q. X. Zhou, X. F. Wang, Q. R. Zhang, T. Sun, Potential analysis of ornamental plant resources applied to contaminated soil remediation. Floriculture, 2006, 3: 245–252.

[22] Z. Tao, Q. Ge, H. Wang, J. Dai, Phenological basis of determining tourism seasons for ornamental plants in central and eastern China. J. Geogr. Sci., 2015, 25(11): 1343–1356.

[23] A. Noman, M. Aqeel, J. Deng, N. Khalid, T. Sanaullah, S. He, Biotechnological advancements for improving floral attributes in ornamental plants. Fronti. Plant Sci., 2017. p8.

[24] C. Y. Lu, X. Li, D. W. Wang, P. F. Zhao, Research status and developmental potential of flower remediation technology for polluted environment. Acta Agric. Jiangxi, 2015, 27(2): 49–53.

[25] Z. Liu, X. He, W. Chen, M. Zhao, Ecotoxicological responses of three ornamental herb species to cadmium. Environ. Toxicol. Chem., 2013. 32(8): 1746–1751.

[26] A. P. Marques, H. Moreira, A. R. Franco, A. O. Rangel, P. M. Castro, Inoculating Helianthus annuus (sunflower) grown in zinc and cadmium contaminated soils with plant growth promoting bacteria–effects on phytoremediation strategies. Chemosphere, 2013. 92(1): 74–83.

[27] S. Ramana, A. K. Biswas, A. B. Singh, N. K. Ahirwar, Phytoremediation of chromium by tuberose, 2012. National Academy Science Letters, 35(2), 71–73.

[28] W. Zhou, B. Qui, Effects of cadmium hyperaccumulation on physiological characteristics of Sedum alfredii Hance (Crassulaceae), 2015. Plant Science. 169:737-745.

[29] J. J. Du, Q. X. Zhou, Preliminary Study on Effects of Nanoscale Amendments on Hyperaccumulator Indian Marigold Grown on Co-Contaminated Soils, 2014. In Advanced Materials Research. 955:243-247.

[30] S. Mahimairaja, N. S. Bolan, D. C. Adriano, B. Robinson, Arsenic contamination and its risk management in complex environmental settings, 2005. Advances in Agronomy. 86:1-82.

[31] K. Chitraprabha, S. Sathyavathi, Phytoextraction of chromium from electroplating effluent by Tagetes erecta (L.), 2018. Sustainable Environment Research, 28(3), 128-134.
[32] S. C. McCutcheon, I. L. Schnoor, Phytoremediation: Transformation and Control of Contaminants, 2003. New Jersey: Wiley-Inter science, Inc.
[33] F. Haq, M. Mahoney, J. Koropatnick. Signaling events for metallothionein induction. 2003. Mutat Research 523:211–226.
[34] H. Y. Lai, K. W. Juang, Z. S. Chen, Large-area experiment on uptake of metals by twelve plant species growing in soil contaminated with multiple metals, 2010. International Journal of Phytoremediation 12, 454–467.
[35] K. Ramasamy, Tannery effluent related pollution on land and water ecosystems, 1997. Proceedings of Extended Abstracts from the International Conference on the Biogeochemistry of Trace Elements, California, USA, 771–772.
[36] J. N. Kumar, H. Soni, R. N. Kumar, I. Bhatt, Macrophytes in phytoremediation of heavy metal contaminated water and sediments in Pariyej Community Reserve, Gujarat, India, 2008. Turkish Journal of Fisheries and Aquatic Sciences, 8(2).
[37] K. Rajalakshmi, T. E. Haribabu, P. N. Sudha, Toxicokinetic studies of antioxidants of Amaranthus tricolour and marigold (Calendula officinalis L.) plants exposed to heavy metal lead, 2011. Int. J. Plant Animal Environ. Sci. 1: 101–109.
[38] S. Pal, H. B. Singh, A. Rakshit, Potential of different crop species for nickel and cadmium phytoremediation in peri-urban areas of Varanasi district (India) with more than twenty years of wastewater irrigation history, 2013. Italian Journal of Agronomy, 8(1).
[39] S. Wei, Q. Zhou, P. Koval, Flowering stage characteristics of cadmium hyperaccumulator Solanum nigrum L. and their significance to phytoremediation. 2006. Sci. Total Environ. 369(1–3): 441–446.
[40] Z. Liu, C. Gu, F. Chen, D. Yang, K. Wu, S. Chen, et al. Heterologous expression of a Nelumbo nucifera phytochelatin synthase gene enhances cadmium tolerance in Arabidopsis thaliana, 2012. Appl. Biochem. Biotechnol. 166(3): 722–734.
[41] Y. Sun, Q. Zhou, Uptake and translocation of benzo[a]pyrene (B[a]P) in two ornamental plants and dissipation in soil, 2016. Ecotox. Environ. Safe. 124: 74–81.
[42] L. Cheng, Y. Wang, Z. Cai, J. Liu, B. Yu, Q. Zhou, Phytoremediation of petroleum hydrocarbon-contaminated saline-alkali soil by wild ornamental Iridaceae species, 2016. Int. J. Phytoremediation, 19(3): 300–308.
[43] V. Campos, L. S. Souto, T. A. M. Medeiros, S. P. Toledo, I. J. Sayeg, R. L. Ramos, M. C. Shinzato, Assessment of the removal capacity, tolerance, and anatomical adaptation of different plant species to benzene contamination, 2014. Water Air Soil Poll. 225(8).
[44] S. Cay, Enhancement of cadmium uptake by Amaranthus caudatus, an ornamental plant, using tea saponin, 2016. Environ. Monit. Assess. 188(6): 320.
[45] R. Sun, C. Jin, Q. Zhou, Characteristics of cadmium accumulation and tolerance in Rorippa globosa (Turcz.) Thell., a species with some characteristics of cadmium hyperaccumulation, 2010.Plant Growth Regul. 61(1): 67–74.
[46] R. L. Sun, Q. X. Zhou, C. X. Jin, Cadmium accumulation in relation to organic acids in leaves of Solanum nigrum L. as a newly found cadmium hyperaccumulator, 2006. Plant Soil, 285(1–2): 125–134.
[47] S. Wang, J. Liu, The effectiveness and risk comparison of EDTA with EGTA in enhancing Cd phytoextraction by Mirabilis jalapa L., 2014. Environ. Monit. Assess. 186(2): 751–759.
[48] A. A. da Silva, J. A.de Oliveira, F. V. de Campos, C. Ribeiro, F. dos Santos Farnese, A. C. Costa, Phytoremediation potential of Salvinia molesta for arsenite contaminated water: role of antioxidant enzymes, 2018. Theoretical and Experimental Plant Physiology, 30(4), 275-286.
[49] H. Shen, B. Zhao, J. Xu, X. Zheng, W. Huang,. Effects of salicylic acid and calcium chloride on heat tolerance in rhododendron 'Fen Zhen Zhu', 2016 J. Am. Soc. Hortic. Sci. 141(4): 363–372.
[50] S. Álvarez, M. J. Gómez-Bellot, M. Castillo, S. Bañón, M. J. Sánchez-Blanco, Osmotic and saline effect on growth, water relations, and ion uptake and translocation in Phlomis purpurea plants, 2012. Environ. Exp.

Bot. 78: 138–145.

[51] S. Wu, Y. Sun, G. Niu, Morphological and physiological responses of nine ornamental species to saline irrigation water, 2016. Hort science 51(3): 285–290.

[52] W. Chen, X. Y. Zhu, W. Q. Han, Z. Wu, Q. X. Lai, Morphological, physiological and biochemical responses of Gerbera cultivars to heat stress, 2016. Korean J. Hortic. Sci. Technol. 34(1): 1–14.

[53] E. González-Valdez, A. Alarcón, R. Ferrera-Cerrato, H. R. Vega-Carrillo, M. Maldonado-Vega, M. Á. Salas-Luévano, Seed germination and seedling growth of five plant species for assessing potential strategies to stabilizing or recovering metals from mine tailings, 2016. Water Air Soil Poll. 227(1)

[54] M. Arshad, J. Silvestre, E. Pinelli, J. Kallerhoff, M. Kaemmerer, A. Tarigo, C. Dumat, A field study of lead phytoextraction by various scented Pelargonium cultivars, 2008. Chemosphere, 71(11), 2187-2192.

[55] N. Chaturvedi, M. J. Ahmed, N. K. Dhal, Effects of iron ore tailings on growth and physiological activities of Tagetes patula L, 2014. J. Soils Sediments, 14(4): 721–730.

[56] S. Cui, Identification, chelated strengthening and application of Pb hyperaccumulating flowers, 2007. Ph.D. thesis, Chinese Academy of Science.

[57] Q. Miao, J. Yan, Comparison of three ornamental plants for phytoextraction potential of chromium removal from tannery sludge, 2013. Journal of Material Cycles and Waste Management, 15(1), 98-105.

[58] X. Wang, Q. Zhou, Ecotoxicological effects of cadmium on three ornamental plants, 2005. Chemosphere, 60(1): 16–21.

[59] E. Pilon-Smits, Phytoremediation, 2005. Annu. Rev. Plant Biol., 56, 15-39.

[60] A. A. Erakhrumen, A. Agbontalor, Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries, 2007. Educational Research and Review, 2(7), 151-156.

[61] A. Karczewska, A. Mocek, P. Goliński, M. Mleczek, Phytoremediation of copper-contaminated soil. 2015. In Phytoremediation (pp. 143-170). Springer, Cham.

[62] M. Zacchini, F. Pietrini, G. Scarascia Mugnozza, V. L. Iori, Pietrosanti, A. Massacci, Metal tolerance, accumulation and translocation in poplar and willow clones treated with cadmium in hydroponics, 2009. Water Air Soil Pollut. 197(1–4): 23–34.

[63] M. Miransari, Hyperaccumulators, arbuscular mycorrhizal fungi and stress of heavy metals, 2011. Biotechnol. Adv. 29(6): 645–653.

[64] M. Gheju, I. Stelescu, Chelant-assisted phytoextraction and accumulation of Zn by Zea mays. 2013. J. Environ. Manage. 128: 631–636.

[65] Y. L. Han, S. Z. Huang, J. G. Gu, S. Qiu, J. M. Chen, Tolerance and accumulation of lead by species of Iris L., 2008. Ecotoxicology 17(8): 853–859.

[66] C. Caldelas, J. Bort, A. Febrero, Ultrastructure and subcellular distribution of Cr in Iris pseudacorus L. Using TEM and X-ray microanalysis, 2012. Cell Biol. Toxicol. 28(1): 57–68.

[67] H. Diwan, I. Khan, A. Ahmad, M. Iqbal, Induction of phytochelatins and antioxidant defence system in Brassica juncea and Vigna radiata in response to chromium treatments. 2010. Plant Growth Regul. 61(1): 97–107.

[68] Y. B. Wang, J. M. Tao, J. Dai, Lead tolerance and detoxification mechanism of Chlorophytum comosum, 2011. Afr. J. Biotechnol. 10: 14516–14521.

[69] S. Cui, Q. Zhou, S. H. Wei, W. Zhang, L. Cao, L. P. Ren, Effects of exogenous chelators on phytoavailability and toxicity of Pb in Zinnia elegans, 2007. Jacq. J. Hazard. Mater. 146(1–2): 341–346.

[70] X. Cao, L. Q. Ma, A. Shiralipour, Effects of compost and phosphate amendments on arsenic mobility in soils and arsenic uptake by the hyperaccumulator, Pteris vittata L. 2003. Environ. Pollut. 126(2): 157–167.

[71] D. Mani, C. Kumar, N. K. Patel, D. Sivakumar, Enhanced clean-up of lead-contaminated alluvial soil through Chrysanthemum indicum L., 2015. Int. J. Environ. Sci. Technol. 12(4): 1211–1222.

[72] A. Hamzah, S. B. Sarmani, N. I. Yatim, Phytoremediation of Pb and Hg by using Scirpus mucronatus with addition of bacterial inoculums, 2015. J. Radioanal. Nucl. Chem. 304(1): 151–155.

[73] Q. Wu, T. Shigaki, K. A. Williams, J. Han, C. K. Kim, K. D. Hirschi, S. Park, Expression of

an Arabidopsis Ca2+/H+ antiporter CAX1 variant in petunia enhances cadmium tolerance and accumulation. 2011. J. Plant Physiol. 168(2): 167–173.

[74] Y. J. Wang, C. L. Dong, Z. Y. Xue, Q. J. Jin, Y. C. Xu, De novo transcriptome sequencing and discovery of genes related to copper tolerance in Paeonia ostii. 2016. Gene 576: 126–135.

[75] S. Álvarez, M. J. Sánchez-Blanco, Comparison of individual and combined effects of salinity and deficit irrigation on physiological, nutritional and ornamental aspects of tolerance in Callistemon laevis plants, 2015. Journal of Plant Physiology, 185, 65-74.

[76] P. García-Caparrós, A. Llanderal, M. Pestana, P. J. Correia, M. T. Lao, Tolerance mechanisms of three potted ornamental plants grown under moderate salinity, 2016. Scientia Horticulturae, 201, 84-91.

[77] R. Liu, N. Xiao, S. Wei, L. Zhao, J. An, Rhizosphere effects of PAH-contaminated soil phytoremediation using a special plant named Fire Phoenix, 2014. Sci. Total. Environ. 473–474: 350–358.

[78] M. Paredes, M. J. Quiles, Stimulation of chlororespiration by drought under heat and high illumination in Rosa meillandina, 2013. Journal of plant physiology, 170(2), 165-171.

[79] S. Wei, Q. Zhou, S. Mathews, A newly found cadmium accumulator-Taraxacum mongolicum, 2008. J. Hazard. Mater. 159(2–3): 544–547.

[80] J. Liu, Q. Zhou, T. Sun, L. Ma, S. Wang, Growth responses of three ornamental plants to Cd and Cd-Pb stress and their metal accumulation characteristics, 2008. J. Hazard. Mater. 151(1): 261–267.

[81] Z. Yu, Q. Zhou, Growth responses and cadmium accumulation of Mirabilis jalapa L. Under interaction between cadmium and phosphorus, 2009. J. Hazard. Mater. 167(1–3): 38–43.

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