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Influence of Heavy Metal Toxicity on Plant Growth, Metabolism and Its Alleviation by Phytoremediation - A Promising Technology

Farha Ashfaque[1*], Akhtar Inam[1], Seema Sahay[1] and Saba Iqbal[1]

[1]*Department of Botany, Environmental and Plant Physiology Section, Aligarh Muslim University, Aligarh, (U.P.), 202002, India.*

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Heavy metals (HMs) contamination of soil and water is a serious problem in recent time and cause hazardous effects on humans and animals which ultimately results in destruction of environment. HMs such as Cd, Cr, Pb, As, Co, Cu, Ni, Zn, Mn, etc. are considered as environmental pollutants due to their toxic effects. These metals alter the plant growth, physiology, and development, it involves the production of reactive oxygen species (ROS) which leads to subsequent cell death, eventually results in the reduction of crop growth and yield. To sustain the agricultural environment, it is necessary to alleviate the toxicity of HMs from the environment. There are number of technologies evolved but, phytoremediation is an emerging technology that uses plants to clean up pollutants from the environment. It is a promising technology for the remediation of contaminated soil because of its low cost, non-intrusiveness, and sustainable features. Hyperaccumulator plants absorb, accumulate and decontaminate high concentration of metals in their above-ground tissues from natural contaminated sites such as mining, smelting, compost, sewage sludge, wastewater, and flyash producing areas.

**Corresponding author: E-mail: farhaashfaque15@gmail.com;*

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1. INTRODUCTION

It has been predicted that increased abiotic stress of arable land is expected to have disturbing global effects resulting in 30% land loss within the next 25 years, and up to 50% by 2050 [1]. Stressful environment are now being recognised as a potential agricultural threat for the sustainable agriculture. Plants often face the challenges of severe environmental conditions that may adversely affect many physiological and metabolic processes, finally diminishing growth, development and productivity. These external factors may be abiotic and biotic arising either from an excess or from the deficit in the physical and chemical environment. Abiotic stress is the primary cause of crop loss worldwide, reducing average yield for most of the major crop plant by more than 50% [2].

The contamination of soil and water over the years by toxic HMs has become a major concern to the soil, air and water. Their contamination by human activities, such as mining and industrial activities is a serious threat for all over the world and has brought hazards to the growing population as well as the environment [3]. In recent years, as the development of global economy increased, both type and content of HMs in the soil has increased due to anthropogenic activities, resulting in the destruction of the environment [4-7].

2. HEAVY METALS AND ITS ENVIRONMENTAL CONSEQUENCES

Most of the toxic metals are endorsed to transition metals with atomic masses over 20 and having a specific gravity of above 5 g cm^{-3} or more. Biologically, “heavy” refers to a series of metals and metalloids that can be toxic to both plants and animals even at very low concentration [8]. Though HMs is thought to be synonymous with toxic metals, on the other hand, lighter metals such as Al also have toxic effects. Not all HMs are toxic, some are essential such as Fe, Cu, Zn, Mo, and Ni for the growth and metabolism of organisms at low concentration but at higher concentration these essential metals also become toxic. Metals concentration in soil typically range from less than 1 mg kg^{-1} to as high as 100,000 mg kg^{-1}.

Because of rising environmental pollution in industrial areas, toxicity of various HMs has become a matter of health and productivity concern. HMs such as As, Cd, Cr, Cu, Pb, Hg, Ni, Se, and Zn are considered as environmental pollutants due to their toxic effect in plants, human and food particularly in highly anthropogenically disturbed areas [9,10]. The source of metals in soil and water may arise as a consequence of a range of activities, such as mining, metal industries, road traffic, power stations, burning of fossil fuels, crop production, animal rearing, use of wastewater as a source of irrigation, use of agrochemicals, waste disposal and so on [11]. Contamination of soil with metals lead to losses in agricultural yield and are threat to the health of wildlife and human [12,13].

3. ADVERSE EFFECTS OF HEAVY METALS ON PLANTS

3.1 Responses of Heavy Metals on Growth, Physiology and Metabolism of Plants

HMs have adverse effects on physiological and biochemical function of plants, most obvious effects are the inhibition of growth rate, chlorosis, necrosis, leaf rolling, altered stomatal action, decreased water potential, efflux of cations, alterations in membrane functions, inhibition of photosynthesis, respiration, altered metabolism, (Fig. 1) and activities of several key enzymes [11,12,14]. Some of the HMs affects growth, physiology, metabolism and yield attributes on plants as given in Table 1. Water responses found to be regulated by an impairment of aquaporin, which is one of the earliest response to HMs in plants. [15] observed excess Cr decreased the water potential and transpiration rate with increasing diffusive resistance and relative water content in cauliflower. Similarly excess Cu, Zn, and Mg inhibits the seed germination and early growth of barley, rice and wheat [16] while, the excessive use of Fe, Pb and Cu causes drastic decline in seed germination of tomato seedlings [17].

HMs are highly toxic, once the cytosolic concentration in plant turns out of control, phytotoxicity occur which inhibits photosynthesis, cell respiration and also nitrogen metabolism while, induce oxidative stress, which collectively affect the plant growth and development [18-20]. HMs affects the function of PSI and PSII, changes stomatal function that results in reduction of photosynthesis [21-23]. Main targets of the influence of HMs are two key enzymes of CO_2 fixation, ribulose 1, 5-bisphosphate carboxylase (RuBisCO) and phosphoenol pyruvate carboxylase (PEPC). Cd^{2+} ions lowers the activity of RuBPC and damage its structure by substituting for Mg^{2+} ions, which are important cofactors of carboxylation reactions, and may also shift RuBisCO activity towards oxygenation reactions [24-26]. High concentration of Cr can disturb the chloroplast structure thereby disturbing the photosynthetic process [27]. A time and dose-dependent HMs like Cu, Ni, Pb, and Zn decreases photosynthesis in *Zea mays* [28].

At toxic concentration of HMs, respiration is usually inhibited [29], however, at very low concentration, respiration increases in some plant species [23]. Respiration is found to sensitive to Cr in *Pisum sativum* [30]. Additionally, nitrogen assimilation enzymes, nitrate reductase, nitrite reductase, and glutamine synthetase activities decreased in rice seedlings in response to As and Al [11,31,32].

3.2 Reactive Oxygen Species Production in Plant Cell by Heavy Metals

HMs disturb redox homeostasis by stimulating the formation of excessive ROS, such as superoxide (O_2^-), hydroxyl radical ($OH^{\cdot}$), singlet oxygen ($^1O_2$), and hydrogen peroxide (H_2O_2) [11,14,33]. The production of ROS is high when plants are associated with various environmental stress such as drought, chilling, nutrient deficiency and salinity [34-36]. It causes membrane lipid peroxidation, protein oxidation, enzyme inhibition, and damage to nucleic acids and subsequent cell death [33,37,38]. Chloroplasts are the major plant organelles producing ROS during photosynthesis [36]. HMs stress enhanced peroxisomal mobility correlated with an increase in ROS [39-41] like induction of H_2O_2 in leaf peroxisomes in response to Cd stress [42]. Plasma membrane-bound NADPH oxidases as well as cell wall associated peroxidases are the main sources of $O_2^{\cdot-}$ and H_2O_2 producing apoplastic enzymes [43]. NADPH oxidase dependent ROS induction has been reported in wheat in response to Ni stress [44], *Pisum sativum* in response to Cd stress [45], *Vicia faba* in response to Pb stress [46], and *Arabidopsis* in response to Cd and Cu [47]. The undesirable result of ROS overproduction is the oxidative stress, which can cause extensive cellular damage [48].

However, plants have evolved specific strategies to overcome and repair the damages caused by ROS, it can be scavenged by antioxidant enzymes. Plants cope with oxidative stress by using ROS scavenging enzymes such as, superoxide dismutase (SOD), ascorbate peroxidase (APX), mono dehydro ascorbate reductase (MDHAR), dehydro ascorbate reductase (DHAR), glutathione reductase (GR), catalase (CAT), glutathione peroxidase (GPX) [49,50], as well as by non-enzymatic compounds viz. cysteine (Cys), reduced glutathione (GSH), carotenoids, ascorbate (ASC), α-tochopherol, etc. [51-53].

4. PHYTOREMEDIATION: CONTROL MEASURE FOR ADVERSE EFFECT OF HEAVY METALS

Due to the increasing trends of HMs contamination in the environment and their negative impact on plants and other organisms, it is important to mitigate the toxicity of HMs from the environment which has become a burning issue. Hence, it is crucial to develop effective and environmentally safe technologies for soil remediation. There are many methods to control HMs contamination of soil by physical, chemical and biological methods. Other methods include washing and compounding, heat treatment, physical solidification, chemical improvers, chemical curing lamp remediation, etc. Many traditional technologies are enormously costly and time consuming; other methods for cleaning up environment require the use of chemicals that may always not be benevolent with respect to the various compartments. An alternative to conventional technologies, biologically based remediation strategy including phytoremediation i.e. the use of plants to remove toxic metals from contaminated site, is a promising technology for the remediation of contaminated soil [54]. The term phytoremediation consist of the Greek prefix *phyto* (plant), attached to the Latin root *remedian* (to correct or remove an evil) [55].

Phytoremediation has been reported to be a cost effective, non-intrusive, aesthetically pleasing, socially accepted technology to remediate polluted soils [56-58]. Brassicaceae family represents a differential range of tolerance to two important abiotic stresses viz. salinity and trace metals. Regarding the concept of hyperaccumulation, plants tolerating and accumulating high concentration of metals in their above-ground tissues are called hyperaccumulators [59-61]. In the context of metal-hyperaccumulation, four species of brassicaceae such as *Alyssym* sp., *Thlaspi caerulescens*, *Thlaspi rotundifolium* and *Arabidopsis halleri* have been studied extensively for their ability to hyperaccumulate several trace metals, including Zn, Cd and Ni [62-64]. [65] revealed that all mustard including Indian mustard (*B. juncea*), black mustard (*B. nigra* Koch), rape (*B. napus* L.) and kale (*B. Oleracea* L.) showed a strong ability to accumulate and translocate Cu, Cr, Cd, Ni, Pb, and Zn to the shoots. However, the ability to accumulate HMs both qualitatively and quantitatively varies significantly between species and between cultivars within a species as shown in Tables 2 and Table 3.

Hyperaccumulators have the ability partially or substantially to remediate contaminants in contaminated soil, sludge, sediment, ground water, surface water, waste water, smelt area, tannery sludge, and fly ash producing area, caused by natural as well as some of the anthropogenic activities. A number of plants have been selected for the remediation from natural contaminants as described in Table 4.

5. MECHANISM OF PHYTOREMEDIATION TECHNOLOGY

Plants have a range of mechanisms at cellular level to mitigate the toxicity of HMs by avoiding the build-up of toxic concentration within the cell, preventing the damaging effects [164]. One way of avoiding metal accumulation can be the restriction of its movement to roots with the help of mycorrhizal fungi [165], while other can be the stimulation of efflux of metals into the apoplast [166]. Phytoremediation technologies are emerging innovative technologies that use plants for effective treatment of a wide variety of contaminants. Phytotechnologies may potentially clean up moderate to low levels of selected elemental and organic contaminants over large areas, and offer a more active form of monitored natural diminution [113,167]. The mechanism of phytotechnology include phytovoatilization, phytodegradation, phytoextraction, phyto-stabilization, rhizodegradation and phytosequestration by which plant can affect contaminant mass in soil, sediments and water [168].

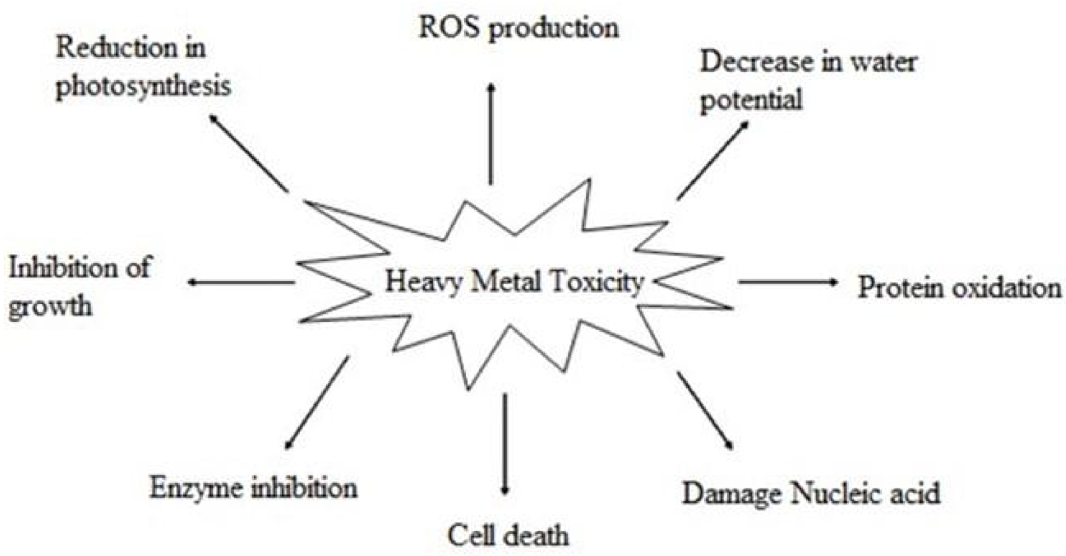

Fig. 1. Adverse effects of heavy metals on plants

Table 1. Effects of heavy metals on growth, physiology, metabolism and yield attributes of plants

Metals	Doses	Plants	Physiological effects, metabolism and yield	References
Cd	10 and 15 μM $CdCl_2$	*Nicotiana tabacum*	DNA damage, increase in lipid peroxidation	[66]
Cd	15 and 30 mg $CdCl_2$ kg^{-1} soil	*Triticum aestivum*	Reduction in plant biomass , nitrogen and phosphorus content	[67]
Cd	200 mg $CdCl_2$ kg $^{-1}$soil	*Brassica juncea*	Decrease in net photosynthetic rate, RuBisCO activity, enhancement in lipid peroxidation and H_2O_2 content	[68]
Cd	25,50,and 100 mg $CdCl_2$ kg^{-1} soil	*Vigna radiata*	Decrease in dry weight, leaf area, net photosynthetic rate and chlorophyll content	[69]
Cd	25, 50, 100 and 150 mg $CdCl_2$ kg^{-1} soil	*Brassica juncea*	Decrease in dry weight, leaf area, net photosynthetic rate, chlorophyll content and seed yield	[37]
Cd	100 and 200 mg $CdCl_2$ kg $^{-1}$ soil	*Raphanus sativus*	Decrease in length , fresh and dry weight, leaf number,chlorophyll, soluble proteins, and total amino acid content	[70]
Cd	25 and 50 μM L^{-1} $CdCl_2$	*Brassica juncea*	Reduction in photosynthesis, growth, chlorophyll fluorescence, leaf area, and dry mass and increase in antioxidant enzyme activity	[71]
Cd	25, 50 and 100 mg $CdCl_2$ kg^{-1} soil	*Vigna mungo*	Reduction in chlorophyll content, net photosynthetic rate, stomatal conductance and water use efficiency	[72]
Cd	50 μM $CdCl_2$	*Pisum sativum*	Inhibition of growth, reduction in the transpiration, photosynthetic rate, and chlorophyll content	[73]
Pb	Pb $(CH_3COO)_2$100 and 300 mg kg^{-1} soil	*Helianthus annuus*	Inhibition in seed germination, fresh and dry biomass, leaf area, chlorophyll and growth	[74]
Pb	0.05-1.0 g L^{-1} $Pb(NO_3)_2$	*Triticum aestivum*	Reduction in seed germination and biomass	[75]
Pb	150-1500 μM of Pb $(C_2H_3O_2)_2$	*Brassica juncea*	Decline in growth, chlorophyll, carotenoids and proline content	[76]
Pb	0.5 mM Pb $(NO_3)_2$	*Raphanus sativus*	Increased proline content	[77]
Pb	0.025-2.5 μM of Pb	*Vigna unguiculata*	Decrease in plant growth, root hair	[78]
As	5-50 μM Na_2AsO_4	*Brassica juncea*	Decrease in seed germination and inhibition in plant growth	[79]
As	5–100 mg L^{-1} $Na_2HAsO_4.7H_2O$	*Vigna radiata*	Inhibition of germination, root growth, and cell division	[80]
As	25 μM Na_3AsO_4	*Brassica juncea*	Reduction in root and shoot growth	[81]
Cu	5-50 μM $CuSO_4{\cdot}5H_2O$	*Brassica juncea*	Decrease in seed germination, repressive impression in plant growth and reduction in root and shoot length	[82]

Metals	Doses	Plants	Physiological effects, metabolism and yield	References
Cu	0.5–2.0 mM $CuSO_4.7H_2O$	*Arabidopsis thaliana*	Inhibition of germination and prolonged time required for germination	[83]
Zn	400 and 600 µM $ZnSO_4$	*Zea mays*	Increase in lipid peroxidation	[84]
Zn	2 mM Zn	*Oryza sativa*	Decrease in root and shoot growth and biomass reduction	[85]
Zn	35-700 µM $ZnSO_4$	*Pisum sativum*	Chlorosis, reduction in root, stem and leaf growth	[86]
Zn	0.1-2.5 ppm $ZnSO_4$	*Lycopersicon esculentum*	Leaf chlorosis	[87]
Ni	200 mg $NiSO_4$ kg^{-1} soil	*Brassica juncea*	Reduction in net photosynthesis, chlorophyll content, stomatal conductance, nitrogen content and enzymy activities such as RuBisCO and nitrate reductase	[88]
Ni	1 and 10 ppm $NiSO_4$	*Pistia stratiotes*	Decrease in leaf chlorophyll content	[89]
Ni	125-1000 µM $NiCl_2$	*Brassica napus*	Chlorosis, suppression in root hypocotyl, chlorophyll content and enhancement in lipid peroxidation	[90]
Ni	0.5 mM $NiCl_2{\cdot}6H_2O$	*Brassica napus*	Chlorosis and necrosis, decreased biomass and chlorophyll content	[91]
Ni	40 and 80 mg $NiCl_2$ kg^{-1} soil	*Brassica juncea*	Decrease in plant yield	[92]
Ni	50-200 µM $NiCl_2$	*Glycine max*	Decrease in fresh and dry mass of root and shoot	[93]
Cr	0.5- 4.0 mg $K_2Cr_2O_7kg^{-1}$ soil	*Cyamopsis tetragonobola*	Decrease in enzyme activity such as nitrate reductase, nitrogenase etc.	[94]
Cr	0.5-100 mg $K_2Cr_2O_7$ kg^1 soil	*Hibiscus esculentus*	Reduction in germination, plant height, fresh and dry weight and chlorophyll content	[95]
Cr	20-100 ppm $K_2Cr_2O_7$	*Prosopis juliflora*	Reduction in growth, germination and dry biomass	[96]
Mn	0.5 and 100 µM Mn	*Cucumis sativus*	Chlorosis, necrosis, inhibition of growth	[97]
Mn	40-160 mM $MnSO_4$	*Vicia faba*	Decrease in chlorophyll content and increase proline content	[98]
Mn	5-100 mg L^{-1} $MnSO_4.H_2O$	*Vigna radiata*	Reduction in germination, growth and chromosome length	[80]
Al	100–2000 µM $Al_2(SO_4)_3$	*Cucumis sativus*	Decrease in electrolyte leakage and chlorophyll content	[99]
Al	10–60 µM Al^{3+}	*Zea mays*	Decrease in relative root growth, fresh and dry weight	[100]
Al	50-1500 µM Al	*Gleditsia triacanthos*	decrease in growth, leaf number	[101]

Table 2. List of some plants and their accumulating metals

Plants	Metals	Accumulation quality	References
Arundo donax	Cd	-	[102]
Noccaea caerulescens	Cd and Zn	Hyperaccumulator	[8,103,104]
Chrysopogon nemoralis	Cd, Zn and Pb	-	[105]
Rorippa globosa	Cd	-	[106]
Vetiveria zizanioides	Cd and Pb	-	[107]
Brassica napus	Cd	Accumulator	[108,109]
Thalspi caerulescens	Cd	Hyperaccumulator	[110,111]
Solanum nigrum	Cd	Hyperaccumulator	[112]
Bacopa monnieri	Cd, Cu, Cr, Hg and Pb	Hyperaccumulator and Accumulator	[113]
Brassica juncea	Cd, Cr, Cu, Ni, Pb, Zn and U	Hyperaccumulator and Accumulator	[114]
Medicago sativa	Cd	-	[115]
Arabidopsis halleri	Zn	Hyperaccumulator	[116]
Silene vulgaris	Cd	Accumulator	[117]
Brassica juncea	Cd	Accumulator	[118]
Thalspi caerulescens	Cd, Cu, Cr, Al, As, Co, Pb, Ni, and Zn	Hyperaccumulator	[119,120]
Pistia stratiotes	Cr and Co	Hyperaccumulator	[121]
Salvinia natans	Cr and Cu	Accumulator	[122]
Dicoma niccolifera	Cr	-	[113]
Brassica juncea	Cr	-	[123]
Medicago sativa	Cr	-	[124]
Ceratophyllum demersum	Ni	-	[125]
Brassica juncea	Ni	-	[126]
Azolla filiculoides	Ni, Pb, Mn, and Cu	Hyperaccumulator and Accumulator	[113]
Sebertia acuminata	Ni	Accumulator	[127]
Alyssum bertolonii	Ni	Hyperaccumulator	[128]
Berkheya coddii	Ni	Hyperaccumulator	[129]
Thalspi goesingense	Ni	Hyperaccumulator	[130]
Vetiveria zizanioides	Pb and Cr	-	[131]
Glycine max	Pb	-	[132]
Vetiveria zizanioides	Pb, and Cd	-	[107]
Brassica juncea	Pb	Accumulator	[133]
Fagopyrum esculentum	Pb	Hyperaccumulator	[134]
Cynadon dactylon	Pb, and Zn	-	[135]

Plants	Metals	Accumulation quality	References
Brassica juncea	Pb	Accumulator	[136]
Pisum sativum	Pb	-	[137]
Brassica juncea	Cu	-	[138]
Sorghum sudanense	Cu	-	[139]
Littorella uniflora	Cu, and Pb	-	[113]
Ipomea alpina	Cu	-	[119]
Ocimum centraliafricanum	Cu, and Ni	Tolerant	[140]
Sedum alfredii	Zn	Hyperaccumulator	[62]
Thalspi caerulescens	Zn	Hyperaccumulator	[141]
Arabidopsis halleri	Zn	Hyperaccumulator	[142]
Lupinus albus	As	Accumulator	[143]
Agrostis capillaris	As, Al, Mn, Pb, and Zn	Accumulator	[113]
Pteris vittata	As	Accumulator	[144]
Sarcosphaera corornaria	As	Hyperaccumulator	[145]
Macademia neurophylla	Mn	-	[119]
Maytenus pancheriana	Mn	-	[120]
Brassica juncea	Al	Hyperaccumulator	[146]
Hordeum vulgare	Al	-	[113]
Vicia faba	Al	-	[113]
Liquidamar styraciflua	Cs, U, and Pt	Hyperaccumulator and Accumulator	[147]
Brassica juncea	Se	Tolerant	[148]
Astragalus racemosus	Se	-	[149]

Table 3. List of some plants with their bioaccumulation quantity

Plants	Metals	Accumulation quantity	References
Oryza sativa	Mn	14.4-21.9 µg g^{-1}	[150]
Sagittaria japonica	Cd	1.62 µg g^{-1}DW	[131]
Lycopersicon esculentum	Fe	4342-8819 mg kg^{-1}	[151]
Arundo donax	Cd	262.8 µg g^{-1}	[102]
Lycopersicon esculentum	Ni	109 mg kg^{-1}	[151]
Lycopersicon esculentum	Cr	206 mg kg^{-1}	[151]
Brassica juncea	Hg	1 mg g^{-1}DW	[152]
Imperata cylinderica	Zn	731.92 mg kg^{-1}	[153]
Cenchrus pennisetiformis	Cu	416.9 mg kg^{-1}	[154]
Brassica juncea	Zn	14429 mg kg^{-1}	[155]
Amaranthus viridis	Pb	43 mg kg^{-1}	[154]
Elusime indica	Zn	117.9 mg kg^{-1}	[154]
Rorippa globosa	Cd	218.9 µg g^{-1}DW	[106]
Thalspi praecox	Cd	> 1,000 µg g^{-1}DW	[156]
Chenopodium botrys	Mn	1288 µg g^{-1}	[157]
Scariola orientalis	Zn	1208.3 µg g^{-1}	[157]
Atriplex halimus	Cd	606.51 µg g^{-1}DW	[158]
Brassica juncea	Ni	3916 mg kg^{-1}DW	[126]
Phytolacca americana	Mn	32,000 µg g^{-1}	[159]
Arabis paniculata	Cd	1127 mg kg^{-1}	[160]
Thalspi caerulescens	Zn	19410 mg kg^{-1}	[110]
Thalspi caerulescens	Cd	80 mg kg^{-1}	[110]
Sorghum sudanense	Cu	5330 mg kg^{-1}	[139]
Brassica juncea	Cd	4725 ± 583µg g^{-1}DW	[161]
Brassica napus	Cd	4626 ± 690µg g^{-1}DW	[161]
Vetiveria zizanioides	Cr	10,000 mg kg^{-1}	[123]
Phyla nodiflora	Pb	1183 mg kg^{-1}	[162]
Pteris vittata	As	23,000 µg g^{-1}	[163]
Brassica juncea	Ni	34.02 mg kg^{-1}DW	[92]
Berkheya coddii	Ni	5500 mg kg^{-1}	[129]
Ipomea alpine	Cu	12,300 mg kg^{-1}	[119]

Phytoextraction is the uptake or absorption and translocation of contaminants by plant roots into the above ground portions of the plants (Fig. 2). Discovery of metal hyperaccumulator species demonstrates that plants have the potential to remove metals from contaminated soil [169]. Phytovolatilization, a process in which plants have ability to absorb and subsequently volatilize the contaminant into the atmosphere (Fig. 2). Phytovolatilization may also entail the diffusion of contaminants from the stems or other plant parts that the contaminant travels through before reaching the leaves [169]. Phytodegradation process is the breakdown of contaminants taken up by plants through metabolic processes within the plant (Fig. 2) or the breakdown of contaminants externally to the plant through the effect of compounds produced by the plants [55,170]. Phytostabilization is the use of certain plant species to immobilize contaminants into the soil, sediments, and groundwater through the absorption and accumulation in the roots, adsorption onto the roots, or precipitation within the root zone (Fig. 2) [55]. Rhizodegradation is the breakdown of contaminants in soil through microbial activity (Fig. 2) and is a much slower process than the phytodegradation. Microorganisms (yeast, fungi, or bacteria) consume and digest organic substance for nutrition and energy [185]. Phytosequestration is one of the environmental friendly technologies that use plants to clean up soil from trace element contamination in which certain contaminants sequestrates into the plant through transport protein and cellular process (Fig. 2). The uptake and accumulation of pollutants vary from plant to plant and also from species to species within a genus [168].

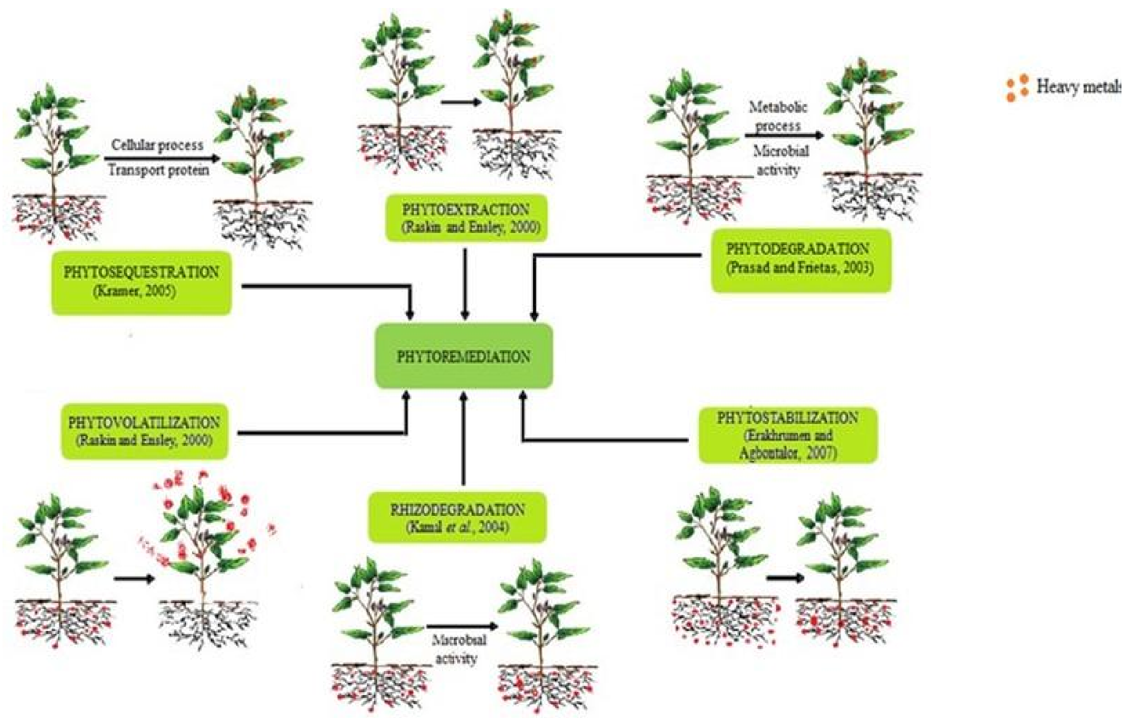

Fig. 2. Mechanism of phytoremediation technology

Table 4. Phytoremediation from natural contaminants

Plants	Contaminants	Metals uptake	References
Viteveria zizanioides	Synthetic waste water	Pb and Cr	[131]
Deschampsia cespitosa	Smelt area	Cu, Fe, Mg, Ni, Zn	[171]
Brachiaria decumbens	Mining waste	Cu	[172]
Euphorbia prostrata	Waste water	Cd, Cr, Pb	[173]
Typha domingensis	Municipal waste water	Fe, Mn, Zn, Ni, Cd	[174]
Brassica oleracea	Mining waste water	Cu, Pb, Fe Mn, Zn, Cd	[175]
Scirpus littoralis	Fly ash	Mn, Ni, Cu, Zn, Pb	[176]
Sorghum bicolor	Vermicompost	Cr	[177]
Allium cepa	Fly ash	Mn, Ni, Co, Zn, Cu, Pb, Cr, Cd	[178]
Brassica campestris	Tanney sludge	Cu, Pb, Cr, Cd, Ni	[179]
Datura stramonium	Fly ash	Cr, Mn, Pb, Cu, Fe, Ni, Zn, Cd	[180]
Triticum aestivum	Municipal solid waste	Pb, Cu, Zn, Cd, Cr, Ni	[181]
Brassica campestris	Fly ash	Cr, Mn, Pb, Cu, Fe, Ni, Zn, Cd	[180]
Zea mays	Fly ash	Se, As, Pb	[182]
Arachis hypogea	Fly ash	Se, As, Pb	[182]
Phaseolus vulgaris	Fly ash	Fe, Mn, Zn, Cu, Ni, Co, Pb, Cd	[183]
Brassica juncea	Fly ash	Ni	[184]

6. CONCLUSION AND FUTURE PERSPECTIVES

Nowadays, HMs contamination in soil have been recognised as a potential threat to plants due to industrial activities and other anthropogenic factors which ultimately result in losses in agricultural yield, leading us to unsecure sustainable environment for future including food insecurity, biodiversity loss and soil infertility. In recent times, phytoremediation is a promising technology for the remediation of contaminated soil because of its low cost and unique features. A number of hyperaccumulators have been identified which accumulates large number of toxic HMs from soil, indicated that plants have some genetic potential to remove contaminants from soil and water. Exploitation of a number of transgenic plants with extensively augmented remediation potentials must be necessary to improve the potentiality of phytoremediation technologies. Future research work would also involve genetic engineering to further improve phytoremediating characteristics by identifying and manipulating the responsible genes for metal accumulation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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