Chapter

Phytoremediation Strategies of Some Plants under Heavy Metal Stress

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Abstract

Environments are polluted with heavy metals across the world because of increase in industrial garbage and sewage. Plants which are grow in polluted areas shows a reduction in growth, performance, productivity. Heavy metals affect physiological and biological process of plants. Heavy metals show metallic properties which are very harmful to the plants. Accumulation of heavy metals in plants through root are caused root malformation reduction in biomass and seed production, decrease in chlorophyll-aand carotenoid content. Phytoremediation is a natural biological process through which plants remove, detoxify or immobilise environmental heavy metals in a growth matrix.

Keywords: phytoremediation, heavymetal, pollution, sewage and detoxify

1. Introduction

Heavy metals are those elements which have density greater than 5 g cm^{-3} [1]. Some heavy metals namely, cobalt (Co), copper (Cu), molybdenum (Mo), manganese (Mn), nickel (Ni) iron (Fe), and zinc (Zn) are considered to be essential for plants. These heavy metal elements directly impact on plant growth, development, senescence and energy producing processes and other physiological process due to their high reactivity. The concentration of heavy metals in soil after the admissible limits is toxic to plants either provoke oxidative stress through free radicals or crumbling up the functions of enzymes by replacing metals and nutrients which are essential [2, 3]. Cell metabolism changes by the affect of heavy metals at first reduce the plant growth. However, toxicity of metals depends on various stage of their growth stage [4]. Maksymiec and Baszynski [5] reported that dicotyledonous plants like various beans and *Medicago sativa* were more resistant to heavy metals at the early growth stage [6]. So, the heavy metals toxicity on the plant physiology and metabolism are much more noticeable. Among the heavy metals, chromium and cadmium are of special concern due to their potential toxicity on plants even at low concentrations [7–9]. The various types of chromium toxicity in plant had described by [10], and the inhibition of enzymatic activity by vaeious types mutagenesis had also be described. The visible symptoms are reduction in growth, leaf chlorosis, stunting, and yield reduction [7, 11]. [12] has explain that Cadmium (Cd) is particularly is one of the most dangerous pollutant due to its high level of toxicity and much solubility in water. [13, 14], have reported that in some plant species Cd interacts with the absorption of metal nutrients such as Fe, Zn, Cu and

Mn, in addition to inducing a process named as peroxidation and breakdown of chlorophyll in plants, resulting in an enhanced production of reactive oxygen species (ROS) [15]. According to [16], Cadmium also inhibits the uptake of elements such as K, Ca, Mg, Fe because it uses the same transmembrane carriers. Cadmium acquisition in plants may also cause serious health hazard to human beings through food chain; however, it causes an extra risk to the children by direct ingestion of Cd-contaminated soil [17].

2. Origin and occurrence

Heavy metals remain in environment in various forms like colloidal, ionic, particulate and dissolved phases. The soluble forms of heavy metal elements are remain in environment as ionised or unionized organometallic chelates. According to [18], the metal concentrations of soil ranges from low to 100,000 mg kg^{-1} which depends on the location, area and the types of metals. [19], studied that among chemical elements, Cr is considered to be the seventh most abundant elements on earth and constitutes 0.1 to 0.3 mg kg − 1 of the crystal rocks. According to McGrath [20], In alloys and 15 percent in chemical industrial processes, mainly leather tanning, pigments, electroplating and wood preservation, about 60–70 percent of the total world production of Cr is used. Chromium has many oxidation states ranging from Cr^{2-} to Cr^{6+}; however, in a number of compounds, valences of I, II, IV and V have been shown to exist [21]. Cr (VI) is, however, considered the most toxic form of chromium and is also generally associated with oxygen as chromate (CrO_4^{2-}) or dichromate (CrO_4^{2-}) and dichromate ($Cr_2O_7^{2-}$) oxyanions. [22], observed that Cr (III) is less mobile and less toxic and is mainly bound to organic matter in soil and aquatic environments. According to [23], Cr present mostly in the form of Cr (III) in soil, and mineral environment. [24], has described that Cr and Fe $(OH)_3$ is a solid phase of Cr(III) having even lower solubility than $Cr(OH)_3$. Consequently, within the soil add up to solvent Cr(III) remains inside the allowable limits for drinking water for a wide extend of pH (4–12) due to precipitation of $Cr(OH)_3$, $Fe(OH)_3$[25, 26], moreover, major source of Cd is the parental fabric. Anthropogenic exercises have too been improved the sum of Cd in soil [27]. Overwhelming metals are regularly show at exceptionally moo concentrations in freshwaters [28], but the release of fluid squander from a wide assortment of businesses such as electroplating, metal wrapping up, calfskin tanning, chrome planning, generation of batteries, phosphate fertilizers, shades, stabilizers, and amalgams has solid impact in sea-going situations [29–31]. Cadmium pollution is also happened from rubber when car tires run over streets, and after a rain, the Cd is washed into sewage disposal systems and collected in the slush.

3. Mobility of heavy metals

Heavy metals are enter in environment are transported by water and air, also deposited in soil and sediments where they could be immobilized [32]. However, the bonding process of metals may take considerably long time. At the starting of the official handle the bio accessible division of metal components in soil is tall, but diminishes continuously in due course of time [33]. Metal dissolvability and bioavailability to plant is basically affected by the chemical properties of soil such as, soil pH, stacking rate, cation trade capacity, soil surface, redox potential, clay substance and natural matter [34–36]. For the most part, higher the slime or natural matter and soil pH, the metals will be relentlessly bound to soil with longer time and will be less organically accessible to the plants. Soil temperature is additionally an vital calculate for varieties in metal amassing by crops [37]. The bioavailability of metals is make greater in soil through several means, the secretion of phytosiderophores into the rhizosphere to chelate and solubilise metals that are soil bound [38]. Acidification of the rhizosphere and exudation of carboxylates are deliberated potential means to enhancing metal consumption.

4. Uptake of heavy metals

Heavy metals are taken through root cells of the vegetation after their mobilization inside the soil, and their improvement inside the soil relies upon in the main upon: (i) dissemination of steel additives alongside the attention attitude which has formed because of take-up of factors and ultimately inanition of the aspect inside the root region; (ii) interferences through roots, in which soil extent is uprooted through root extent after developing (iii) move of steel additives from enormous soil association down the water capacity slope [39]. Cell divider acts as a particle exchanger of relatively moo partiality and moo selectivity in which metals are first of all bound. From the mobileular divider, the shipping frameworks and intracellular high-affinity authoritative locations intercede and power the take-up of those metals over the plasma layer. A stable using power for the take-up of steel additives thru auxiliary transporters is made because of the layer capacity, that is bad at the indoors of the plasma movie and can exceed −200 mV in root epiderm. This is examined both in soil culture and in solution culture for Cd which might probably be due to low concentration of heavy metals per unit of absorption area [40, 41]. Both non-essential and essential metals are also preoccupied through leaves. Within the shape of gases, they input via thestomata withinside the leaves, while in ionic shape metals specifically input via theleaf cuticle [39, 42]. Hg in gaseous shape istaken up through stomata [43] and its uptake is recommended to bebetter in C3 than C4 flora [44]. The uptake of metals takes place viaectodesmata, non-plasmatic "channels" at a excessive level whichare much less dense elements of the cuticular layer which are located fundamental withinside theepidermal mobileular wall or cuticular membrane machine among shield cells andsubsidiary cells. Furthermore, the cuticle overlaying shield cells are oftenspecific to it overlaying everyday epidermal mobileular [39]. Most of the metallic factors are insoluble that won't capin an edge toflow freely withinside the vascular machine of flora and, as a result typically shapesulphate, phosphate or carbonate precipitates immobilizing them inextracellular booths i.e. apoplastic and intracellular compartment i.e. symplastic [45]. In the apoplastic pathway solute and also the water debris diffuse via mobileular membrane, consequently the pathway stays unregulated. The mobileularwall of the endodermal mobileular layer acts as an impediment for apoplastic diffusioninto the vascular machine. Generally, prior to the access of metallic ions withinside thexylem, solutes must be haunted through root symplasm [46]. Ifmetals are obsessed through the premise symplasm, their similarly motion from root tothe xylem is specifically ruled through 3 processes, including: (i) metallicsequestration arise into the premise symplasm, (ii) symplastic shipping ariseinto the stele, and (iii) launch of metals arise into the xylem. The ionshipping into the xylem is often occured through membrane shipping proteins. Metal factors which are not wished through the flora successfully compete thecritical heavy metals for his or her shipping the usage of the equal transmembranecarriers. Cr(III) uptake through the plant is specifically a passive process, whilst Cr(VI) shipping is mediated through sulphate carrier [47]. Inhibitors like, sodium azide and di nitrophenol inhibits the uptake of Cr(VI) through barley seedlings however this is not happened just in case of Cr(III) [47]. In keeping with [48], Group VI anions like SO_4^{-2} additionally inhibit the uptake of chromateswhile Ca^{2+} stimulates its shipping. This inhibition of chromate shipping is passed thanks to the aggressive inhibitiondue to the chemical similarity, whilst inspired shipping of Cr(VI) because of Ca is attributed to its critical position in flora for the receive and shipping of metallic factors [26, 49].

5. Accumulation of heavy metals

According to Kumar et al. [50], many plants species show an unusual capability to absorbe heavy metals through root system and accumulate of these heavy metals in their parts. Zayed and Terry [26] said that it seems a common tendency of all plant species to maintain Cr in their roots, but with quantitative differences. It is found that for the translocation of Cr to the plant tip, leafy vegetables such as spinach, turnip leaves that tend to acquire Fe appear to be the most effective [51]. While those leafy vegetables such as lettuce were considerably less effective for translocating Cr to their leaves, cabbage which accumulated relatively low Fe levels in their leaves. Zayed and Terry [26] have reported that some plant species attain substantially higher root or shoot concentration ratio than other species. However, a 'Soil–Plant Barrier' well protects the food chain from heavy metal toxicity, implying that, due to one or more of the following processes, heavy metal levels in edible plant tissues are reduced to safe levels for animals and humans: (i) prevention of metal element uptake due to soil insolubility, (ii) prevention of metal element translocation by making them immobile in roots, or (iii) prevention of metal element translocation for animals and humans to the permissible level [52]. Within plant tissues, some elements such as B, Mo, Cd, Mn, Se, and Zn are readily absorbed and translocated, while others such as Al, Ag, Cr, Fe, Hg, and Pb are less mobile because of their strong binding to soil components or root cell walls. However, at certain concentrations, all of these elements are mobilised, even against a concentration gradient, within the transport system of the plant. Kinetic data show, for instance, that essential Cu^{2+}, Ni^{2+} and Zn^{2+} and non-essential Cd^{2+} compete for their transport with the same transmembrane carrier [53]. As is the case of phytosiderophore such as Fe-transport in graminaceous species, metal chelate complexes can be transported by plasma membrane [54]. Among the most important parameter the most influencing factor of heavy metal accumulation in plants is soil pH [55–58]. At higher soil pH, metal elements in soil solution decrease their bioavailability, and at lower soil pH metalelements in soil solution increase their bioavailability to plants [59].

6. Effect on growth and development

Heavy metals mitigate the growth and development of the plant [60, 61]. The plant parts which are associated with the heavy metals polluted soils normally the roots express rapid and sensorial changes in their growth and development [62]. It is well observed that the very significant effects of a number of metals (Cd, Al, Cu, Fe, Ni, Pb, Hg, Cr, Zn,) on the growth of above ground plant parts vary [63]. Through the formation of free radicals and reactive oxygen species (ROS), heavy metals mainly affect plant growth, which causes constant oxidative damage by decreasing important cellular components. [64, 65]. For example, rice seedlings irradiated to Cd or Ni [66] and runner bean plants treated with Cd and Cu have shown an increase in carbohydrate content and a decrease in photosynthesis process, resulting in growth inhibition [67]. Similarly, in cucumber plants, Cu limits K uptake by leaf and inhibits the photosynthesis via sugar acquisition resulting into the inhibition of cell expansion [68]. Limped leaves, growth inhibition, progressive chlorosis in certain leaves and leaf sheaths and browned root systems, especially the root tips, are the symptoms of Cd toxicity in rice plants [7, 69]. Moreover, plant growth has also been retarded in maize (*Zea mays*) Cd [70, 71]. Some phenotypic abnormalities such as stunted growth, less branching and less fruiting are also shown by tomato plants irrigated with polluted water. However, acquisition of heavy metals is much more appears in stems, roots, and leaves as compared to fruits [72].

6.1 Germination

Seed germination is the breaking of seed dormancy which is inhibited by heavy metals. Germination of seeds and growth of seedling may sensitive towards environmental conditions [59]. So as per [73], the performance of germination, breaking of seed dormancy and seedlings growth rates are therefore often used to assess the abilities of plant tolerance to metal elementsIn comparison to control, higher concentrations such as 1 μM, 5 μM and 10 μM of heavy metals such as Cu, Zn, Mg and Na significantly inhibit seed germination and early growth of rice, barley, wheat and maize seedlings [74]. The ability of a seed to germinate in a moderate containing any metal element like Cr would be a direct indication of its level of tolerance to this metal, but seed germination is the first physiological process affected by toxic elements [73]. At 200 μM of Cr treatment, the seed germination of *Echinochloa colona*is decreased to 25 percent [75], and high levels (500 ppm) of Cr (VI) in soil decreased *Phaseolus vulgaris* germination by up to 48 percent [76]. Jain et al. [77] observed reductions in sugarcane bud germination of up to 35 per cent and 60 per cent at 20 and 80 ppm Cr application, respectively. In another study by Peralta et al. [73], at 40 ppm Cr (VI) treatment, *Medicago sativa*cv germination was reduced to 23 percent.

6.2 Root

Among the plant parts, roots are firstly come into contact with toxic elements and they usually absorbed more metals by root hair through absorbption process but shoots are not that [78–80]. The inhibition or retard of root elongation appears to be the first visible effect of metal toxicity. Elongations of root are reduced by the inhibition of cell division, the decrease of cell expansion, decrease of cell size in the elongation zone [81]. So the first visible effect of metal toxicity is the inhibition of root elongation, the root length can be used as most important tolerance index [82–85]. *Medicago sativa* plants grown in solid media watered with 20 mg L^{-1} of Cr (VI) in another [73] study, the ratio of Cr in shoots to Cr in roots was approximately 43 percent. This is an indication that in the roots, 50 percent of the absorbed Cr is held. The response of roots to heavy metals in both herbaceous plant species and trees has been extensively studied. [86–89]. After the work of numerous researchers [86, 87, 89, 90]. The main morphological and structural effects of metal root toxicity can be summarised as: (i) decrease in root elongation, (ii) decrease in biomass, (iii) decrease in vessel diameter, (iv) damage to tip, (v) collapse of root hair or decrease in number of roots, (vi) increase or decrease in lateral root formation, (vii) enhancement of suberification, (viii) enhancement of lignifications, (ix) translocation process become hampered. The research work of [91], revealed that Cr affects the root length than the other parts of plant as compared to other heavy metals. Mokgalaka-Matlala et al. [92], have observed that when increasing concentrations of As (V) and As (III) in *Prosopis juliflora,* the root elongation decreased significantly. It is reported that when Cr has applied on *Salix viminalisis* then the root length is affected more than by Cd and Pb [91]. In fact, the inhibition effect of Cr on the growth of the *Salix alba* root is similar to that of Hg and stronger than that of Cd and Pb, whereas the root length of Ni decreased less than Cr [93, 94]. In Salix viminalisis, the order of metal toxicity to the new root rimordial was reported to be Cd > Cr > Pb [91].

6.3 Stem

The heavy metal elements highly affect the plant height as well as shoot growth [95]. Cr transport to the various part of the plant have a direct impact on cellular metabolism as a result shoots contributing affected so plant height ultimately reduces [61]. It is observed that reduction of 11, 22 and 41% respectively compared to control in oat plants at 2, 10 and 25 ppm of Cr content in nutrient solutions in sand cultures [96]. Joseph et al. [97] observed a similar reduction in the height of Curcumas sativus, *Lactuca sativa* and *Panicum miliaceum* due to Cr (VI). Shoot growth in *Medicago sativa* is inhibited by Cr (III) [98]. In a glasshouse experiment after 32 and 96 days, Sharma and Sharma [99] noted a significant decrease in the height of *Triticum aestivum* when sown in sand with 0.5 μM sodium dichromate. A significant reduction in height of *Sinapsis albaat* a level of 200 or 400 mg kg^{-1} of Cr in soil along with N, P, K and S fertilizers was reported by Hanus and Tomas [100]. Very recently, it is found that a reduction in stem height at various concentrations (10, 20, 40 and 80 ppm) of Cd and Cr have been reported in *Dalbergia sisso* seedlings compared to the control [101].

6.4 Leaf

The heavy metal elements severely affect the leaf height as well as leaf growth. Metal elements like Cd induce morphological changes such as drying of older leaves, wilt, and chlorosis and necrosis of younger leaves. *Datura innoxia, D. metel,* plants grown in a contaminated environment with Cr(VI) exhibited toxic symptoms at 0.1 mM to 0.2 mM of Cr(VI) in the form of leaf fall and wilting of leaves at 0.4 to 0.5 mM Cr(VI) in soil [97, 102]. A similar reduction in the height of Curcumas sativus, *Lactuca sativa* and *Panicum miliaceum* due to Cr(VI) was observed (1995). In *Medicago sativa*, shoot growth is inhibited by Cr(III) [98]. Sharma and Sharma [99] noted a significant drop in the height of *Triticum aestivum* when sown in sand with 0.5 μM sodium dichromate in a glasshouse experiment after 32 and 96 days [103]. In *Zea mays*, Acacia holosericeaOryza sativa, and *Leucaena leucocephala* plants treated with tannery effluent of varying concentrations, leaf dry weight and leaf area slowly decreases [104]. The effect of Cr(III) and Cr(VI) on the *Spinacia oleracea* plant was found in a study. Singh [105] reported that Cr applied to soil at a rate of 60 mg kg^{-1} and higher levels decreased the size of the leaves, causing leaf foliage, leaf tips or margins to burn, and slowed the rate of leaf growth.

7. Effect on physiological process of plant

The physiological process of the plant is severely affected by heavy metal elements. In reaction to heavy metal stress, plants show morphological, physiological, biochemical and metabolic changes which are thought to be adaptive responses [106]. Cd not only inhibits growth, for example, but also changes different physiological and biochemical features such as water balance, nutrient uptake, photosynthesis, breathing, mineral, nutrition and ion uptake, translocation, plant hormone [107–109] and Photosynthetic electron transport around PS I and PS II photosystems [110–112]. Likewise, Cr inhibits electron transport, decreases

CO2 fixation, malformation of chloroplast [113–115], decreases water potential, increases transpiration rate, decreases diffusive resistance, and causes a reduction intercalary meristem [116].

7.1 Photosynthesis

The photosynthetic mechanism is significantly impacted by the heavy metal elements. The photosynthetic apparatus tends to be very susceptible to the toxicity of heavy metals, which directly or indirectly affect the photosynthetic process by inhibiting the enzyme activities of the Calvin cycle and CO2 deficiency in the plant body due to stomatal closure [59, 117, 118]. Cr has a well-cited detrimental effect on the photosynthic process in terrestrial plants. The influence of Cr on the PS I was more conspicuous than on the PS II operation in isolated chloroplasts of Pisumsativum plant [119] according to different reports. Photo inhibition in the leaves of *Lolium perenne* due to the influence of 250 μM Cr on the primary photochemistry of PS II, according to the Vernay et al. [120] report and A decrease in the overall photochemical efficiency of plant PS II at 500 μM of Cr was noted. Shanker et al. [61] argued that Cr triggered oxidative stress in plants because, due to the loss of molecular oxygen, Cr improves alternate sinks for the electrons. The ultimate influence of Cr ions on photosynthesis and conversion of excitation energy will be attributed to Cr-induced anomalies such as thylakoid expansion and reduction in the amount of grana in the ultrastructure of the chloroplast [121]. The impact of Cr on photosynthesis in higher plants is widely known [122, 123], it is not well known to what degree Cr induces photosynthesis inhibition either because of ultra-structure chloroplast malformation and the influence of Cr on the Calvin cycle enzymes or because of electron transport inhibition [116]. Krupa and Baszynski explained in 1995 that some theories applied to all photosynthesis pathways of heavy metal toxicity and introduced a list of primary photosynthetic carbon reduction enzymes that inhibited mainly cereal and legume crops in heavy metal treated plants. The 40 percent inhibition of whole plant photosynthesis in 52-day-old *Pisum sativum* seedlings at 0.1 mM Cr(VI) was further increased to 65 and 95 percent after 76 and 89 days of growth respectively [119]. A potential explanation of Cr mediated reduction rate of photosynthetic is a malformation of the chloroplast ultra structure and inhibition or returdation of electron transport processes due to Cr and a diversion of electrons from the electron donation side of PS-I to Cr (VI). It is likely that, as demonstrated by the low photosynthetic rate of the Cr stressed plants, electrons generated by the photo chemical process are not generally used for carbon fixation. According to [124–126], bioaccumulation of Cr and its toxicity to photosynthetic pigments in various crops and trees has been investigated. [127]; has extensively studied the effect of Cr present in tannery effluent sludge which directly get into chloroplast pigment content in *Vigna radiata* and reported that irrespective of Cr concentration, chlorophyll a, chlorophyll b, chlorophyll d and total chlorophyll decreased in 6 days old seedlings as compared to control. Chatterjee and Chatterjee [128] have reported that a dramatic decrease in chlorophylls a, b and d in leaves was recorded in *Brassica oleracea* grown in distilled sand with full nutrition with control and Co, Cr and Cu at 0.5 mM each. The stress order was Co > Cu > Cr. Conversely, a broad analysis on the tolerance of Cr and Ni in *Echinochloa colona* found that in terms of survival under elevated Cr concentration, the chlorophyll content was high in resistant calluses [129]. Chromium (VI) at 1 and 2 mg L^{-1} significantly decreased chlorophylls a, b and d and carotenoid concentrations in *Salvinia minima* [130]. The decrease in the chlorophyll a/b ratio brought about by Cr indicates that Cr toxicity possibly reduces the size of the peripheral part of the antenna complex [114]. It has been hypothesized that the decrease in chlorophyll b due to Cr could be due to the destabilization and degradation of the proteins of the peripheral part [61]. The interaction of heavy metals with the functional SH groups of proteins according to Van Assche and Clijsters [131, 132] is a possible mechanism of action for heavy metals.

7.2 Water relation

Every physiological process is directly linked to water's chemical potential. Water's chemical potential is a quantitative expression of water-related energy. In plant growth regulation, water can be considered as the most important factor because it affects all growth processes directly or indirectly [133]. Plants grown in contaminated heavy metal soils often suffer from drought stress due primarily to poor physicochemical properties of the soil and shallow root system; researchers are interested in investigations on plant water relation under heavy metal stress. According to Barcelo et al. [134], Selection of drought resistance species can be considered to be an important trait in phytoremediation of soils polluted with heavy metals. The heavy metal stress can induce stress in plants through a series of events leading to decreased water loss like enhanced water conservation, decrease in number and size of leaves, decrease in root hair, malformation of parenchymatous cells stomatal size, number and diameter of xylem vessels, increased stomatal resistance, enhancement of leaf rolling and leaf abscission, higher degree of root suberization [90]. It has been suggested that through various mechanisms operating on the apoplastic and/or the symplastic pathway, heavy metals may influence root hydraulic conductivity. Reduced cell expansion can occur in the growth medium at relatively low concentrations without damaging the integrity of the cells. In bean plants, for instance, leaf expansion growth was inhibited after 48 h in bean plants exposed to 3 uM Cd. The most significant higher toxic effect of Cr (VI) is to degenerate the stomatal conductance that could damage the cells and membranes of stomatal guard cells. In this way, the relationship between water and many plant species has been affected.

8. Mechanism of metal tolerance

Complex processes has used by plants to adjust their metabolism to rapidly changing environment. These processes include transduction, transcription, perception, and transmission of stress stimuli [135–137]. During stressing conditions plants adopt various process likes mechanisms of resistance and tolerance, later involves the immobilization of a metal in roots and in cell walls [138]. The plants adopt a series of mechanisms to avoid heavy metal toxicity which include: (i) Through auto oxidation and Fenton reaction plant produce reactive oxygen, (ii) blocking of main functional group, and (iii) from biomolecules displacement of metal ions, [139]. Plants are capable of growing in polluted soils because; (i) plants avoid metal absorption by aerial components or sustain low metal concentrations over a wide range of metal concentrations in soil by trapping metals in their roots [140]; (ii) plants deliberately absorb metals in their epidermal tissues due to the development of metal binding chelators (iii) they storing metals in non-sensitive parts by alter metal compartmentalisation pattern that is called metal indicators, and (iv) by the process of hyperaccumulators i.e. they can accumulate metals at much higher levels than soil in their aerial components [141, 142]. The processes used for hyperaccumulation are still unclear. Plants that can accumulate either As, Cu, Cr, Ni, Pb, or Co > 1000 mg kg^{-1} or zinc >10,000 mg kg^{-1} in their shot dry matter ([141, 143–145]; Baker and Reeves 2000) or Mo > 1500 mg kg^{-1} [146] are the standard for classifying plants as hyperaccumulators. (ii) Plants that absorb metals 10–500 times higher than average amounts in shoots [147], (iii) plants that accumulate metal components more in shoots than in roots [141]. Very few higher plant species have adaptations that enable them to live and replicate with Zn, Cu, Pb, Cd, Ni, and As highly polluted soils. [148, 149]. The tree roots of these plants can deliberately forage towards less polluted soil areas [150] and can "rest and wait" for optimal growth conditions even with highly reduced growth [151].

9. Conclusion

For the biological, biochemical and physiological functions of plants, various types of heavy metal elements are very important, including protein biosynthesis, lipids, nucleic acids, growth substances, hormones, chlorophyll and secondary metabolism synthesis, stress tolerance, morphological, structural and functional integrity of different membranes and other cellular compounds. These metal components, however, become poisonous in nature, above allowable limits, depending on the types of plants and the nature of the metal. Metal toxicity can inhibit the transport chain of electrons, reduce CO2 fixation, decrease the production of biomass, and cause chloroplast malformation. It can also affect plant growth by generating free radicals and ROS and other substances, which, by decreasing important cellular components, pose a threat to continuous oxidative damage. In addition, heavy metal stress can induce many events in plants leading to decrease in number and size of leaves, enhancement of leaf rolling and leaf abscission, leave erosion, changes in stomatal size, guard cell size, and stomatal resistance, and higher degree of root ligninization, suberization. Symptoms that are visible in plant by the affect of heavy metal toxicity include drying of older leaves, chlorosis, and necrosis of young leaves, stunting, wilting, canker, colour changes, blotch wrinkling and yield reduction. However, plants use complex processes (perception, transduction, and transmission of stress stimuli) and several non enzymatic and enzymatic mechanisms such as CAT, SOD, POD, and APX that activate the cell for their metabolism to heavy metal stress.

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