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The Effect of Heavy Metals on the Growth and Development of Different Plants: A Synoptic Review

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ABSTRACT

Heavy metals are non-essential elements for plants. If plentiful amounts are accumulated in the plants, heavy metals will adversely affect the absorption and transport of essential elements, disturb the metabolism, and have an impact on growth and reproduction. Toxic Levels of Lead (Pb), Cadmium (Cd), Mercury (Hg), Arsenic (As) affects plant processes at physiological and biochemical levels. When the metals reacts with important functional groups, the activity of several enzymes is influenced, some of which are important in photosynthesis and nitrogen metabolism. Research has identified several important aspects of metal tolerance in some plant, but there is no model species in which the entire process/ steps of tolerance has been determined. A better understanding of the knowledge is required to handle the acute problem of increasing metal toxicity to the plants and human life. Efforts to coordinate research to address all aspects of tolerance are required. In addition to provide the necessary data for the production of models that will accurately predict the impact of certain metal related industrial activities on the plant life, the study of metal tolerance may also provide methods to detoxify metal contaminated solid through the use of metal accumulating species. As such the pathway of metal detoxification in plants needs to be studied in depth.

Keywords: *Heavy metals, Contamination, Plants, Growth, Resistance*

The toxicity of lead to large extent depends upon its absorption, transportation and cellular localization. The susceptible plant species growing in a lead enriched environment are able to accommodate large quantities of lead in their organs [1,2,3,4]. The plants of *Cassia tora* and *C. occidentalis* growing by the road side accumulate upto 300 mg g^{-1} dry weight of lead [5]. The accumulation of lead depends upon the species, plant cultivar, plant organ, and the exogenous concentration of lead and the presence of other ions in the environment. Accumulation in roots and leaves of cv. HT-I, a sensitive variety of *Sesamum indicum* L. is about 20 times higher than those in the resistant variety [3,4]. The symbiotic root nodules of *Vigna radiata* accumulated significant amount of high lead level in different parts [5]. In most cases, it has been reported that the roots accumulate higher amount of the metal that the shoots and leaves.

The accumulated lead content generally increases with the increase in the metal in the environment as has been reported for maize and pea leaves [7], *Vigna* root nodules [6] and sesame roots and leaves [3,4]. The presence of inorganic salts such as K_2HPO_4, $CaCl_2$ and KNO_3 restrict lead uptakes and accumulation by mung bean seedlings [8]. The intracellular localization of lead is an important determination in its toxicity. Accumulation inside the vacuoles may not cause any deleterious effect. In onion tips, the metal is reported to be localized as lead orthophosphate in nucleolus [9]. In *Potamogeton pectinatus*, the metal gets bound to cell wall, probable by Donnan equilibrium [10]. It has been found that at 0.5 µM concentration the level of lead in *Vallisnisnerria spiralis* accumulated 1.41 µM lead g^{-1} and at 1.00 µM lead the accumulation was 2.5 times higher than 0.5 µM lead. The lead level at each back ground concentration was more in roots than in leaves [11]. Lead also disturbs the chromosomal region which varies with the lead concentration, in *Lactuca sativa* [12]. The metal caused spindle disturbances in root tip cells of *Allium cepa* [13]. Xin [14]have demonstrated that the addition of Cd, Zn and Pb on soil inhabited the soil enzyme activities. However, [15] concluded that the tolerance to lead in *Potamogeton arundinacea* is accompanied by an increase in Photosystem II concentration compared with photosystem I and a consequent increase in non-cycle electron transport rate compared with cyclic electron transport. Earlier experiments using isolated chloroplasts suggested that Photosystem II was a target for lead inhibition. Since the lower levels of lead administered to the leaf slices produced lead concentrations within the leaves comparable with those measured in leaves from tolerant *Potamogeton arundinacea* collected from the polluted site, the increased Photosystem II capacity which the leaves exhibit would suggest a suitable adaptation to the continuous presence of lead. Singh [16]studied the inhibition of seeding growth and nitrate reductase activity in 5 day old *Vigna radiata* (L.) *Wilczek cv. Pusa baisakhi* in the presence of 1.0 mM lead acetate increased drastically. If NaCl was also present in the nutrient media along with the metal salt. Correspondingly higher endogenous Na^+ levels were accumulated in the roots and leaves of seedlings in presence of the two stresses. On the other hand, the level of endogenous lead gets reduced in presence of NaCl in both roots and leaves. Roots accumulated more Pb^{2+} and Na^+ than the leaves. The two stresses affect more drastically in the additive or even synergistic manner during the early growth phase of the seedlings. Uveges [17] exposed plants of *Lythrum salicaria* to different concentrations of lead and found that plants treated with 2000 mg/l lead was smaller than these treated with 500 mg/l.

Cadmium is one of the most dangerous heavy metals due to its high mobility and the small concentration at which its effects on plants begin to show [18]. Jarvis [19] found that the roots of lettuce released much more of their absorbed Cd for translocation to the shoots than other crops (ryegrass and orchardgrass). The greater translocation is due to active transport or lack of metal absorption to fixed or soluble chelators in the root or perhaps due to exchange with the Ca, Mn and Zn moving through the roots [20,21] reported that Cd was easily transported to aerial parts of tomato and was not detected in fruits. Hinesly [22] reported that the pH of the soils had great influence on cadmium transportation in corn (*Zea mays L.*). The highest grain - Cd concentrations occurred at soil pH at about 6.0. The uptake of cadmium by corn was less from the most acidic soil that also had the highest organic matter content [23]. Miragaya and Page, [24]found that the ratios of complexed to uncomplexed Cd were independent of Cd concentration and slightly affected by pH over a range of 6.0-8.5. Many factors in the soils have been shown to influence the uptake of heavy metals by plants. The cadmium uptake increased with decreasing soil pH [125,26] and decreased with increasing soil cation exchange capacity [27].

The cadmium appears to be absorbed passively [28] and translocated freely [19]. The chelators in nutrient solutions can help in cadmium uptake [29]. The pronounced interactions between Zn and Cd occurred in cadmium uptake and translocation [30,31]. Apparently, part of Cd toxicity was a result of Cd interference in a Zn-dependent process [32].

The absorption of organic and inorganic mercury from soil by plants is low, and there is a barrier to mercury translocation from plant roots to tops. Thus large increases in soil mercury levels produce only modest increases in plant mercury levels by direct uptake from soil. Mercury salts in soil may be reduced by biological and chemical reactions to mercury metal or methylated compounds, which may volatilize and be taken up through the leaves. This is important for plants grown in enclosed spaces, such as greenhouses. The residues of mercury pesticide or fungicide sprays are, in some cases, taken up by plants (e.g., *Oryza sativa)* and translocated to edible portions. Phenyl mercury salts have been shown to hasten plant senescence and inhibit photosynthesis. Mercurial solutions, used as seed treatments may reduce seed viability if the mercury concentration is too high or if the seed is stored with high moisture content [31].

The phytotoxic effects of mercury compounds have been reported in several plants, including *Triticum aestivum Oryza sativa* [32], and several other grain crops [33]. In general, the degree of impact depends on the concentration, the formulation, and the mode of application, and the cultivation.

Inoculation of *Vigna radiata, V. mungo,* and *Arachis hypogaea* seeds with *Rhizobium* strains and treatment with emisan or bavistin (carbendazim) significantly reduced *Rhizobium* population and nodulation [37]. Treatment of seeds of two *Phaseolus aureus [Figna radiata]* cultivars with higher concentrations of mercuric acetate inhibited germination, hypocotyl length, mobilization of total nitrogen from cotyledons to seedlings, and protease activity in seeds during germination [38]. With increasing concentrations of $HgCI_2$, the respiration rates of seedlings declined, as did the levels of total nitrogen, total sugar, *DNA,* and RNA in embryos with concomitant accumulation in cotyledons.

Gel electrophoretic studies revealed major disruption and increase in number of protein bands [39].

High concentrations of $HgCl_2$ reduced seed germination in *Phaseolus vulgaris* and *Brassica campestris,* but very low concentrations somewhat increased the rate [40]. The effect of mercury ions with three constant temperatures on *Phaseolus vulgaris* cv. Contenaer was studied with respect to shoot and root length, dry matter, chlorophyll content. Similar effects were seen with jute, *Corchorus olitorius* cv. JRO 524 and *C. capsularis* cv. JRC 321 [41]. In sugarbeet cv. amethyst seeds, effects of mercurials in reducing fungi and affects on germination were related to the fungicide and the concentration of mercury [42]. The effect of mercury on root length, stem length, leaf area, and dry-matter production of *Abelmoschus esculentus* is inversely proportional to the concentration [43]. *Allium cepa, Amaranthus* sp., *Beta vulgaris, Brassica oleracea* L. var. *capitata,* Chinese cabbage, *Coleus blumei, Cucumis sativus, Hibiscus esculentus, Pisum sativum, Raphanus sativus,* and *Lycopersicon esculentum were* exposed to mercury, radicle emergence was not substantially reduced, but in *Mentha sylvestris* and *Lactuca sativa* it was reduced by 50%. *Allium cepa, Lactuca sativa,* and *Pisum sativum* showed reduction in the growth of both seedling roots and shoots. Others showed inhibition in either shoot or root growth, while in some plants there was no inhibition and occasionally some stimulation of growth [44].

The pollen germination and tube growth of *Lilium longiflorum* were affected by concentrations of Hg^{2+}. The main effect was abnormal cell wall organization [45]. In field trials, foliar administration to *Sorghum vulgare* cv. CSH 5 of different formulations of phenyl mercury acetate did not affect grain or fodder yields and yield components [46].

Application of dried sewage sludge and a superabsorbent hydrogel (Evergreen 500) in the first year significantly increased the growth of apple seedlings in perforated bags [47]. In long-term experiments, high application rates of sewage sludge and pig slurry were tolerated by silage maize and grass. The mercury content was influenced only by the excessive application of sewage sludge [48]. In Styria, Austria, both silage maize and grass showed better growth after sewage sludge application, with no significant negative effects on soils or plants [48]. Three aquatic plants, *Hydrilla verticillata, Pistia stratiotes, and Salvinia molesta,* treated with different concentration of mercury were severely affected. Foliar injury, chlorophyll content, and phytomass showed perceptible effects with increasing exposure. In floating plants, a positive relation was obtained between leaf injury Index (LII) and concentration [49]. Bioaccumulation led to physiological changes in *Hydrilla verticillata* [50].

Recently, a pot experiment was designed and conducted to investigate the effect of arsenic on photosynthetic pigments, Chlorophyll-a and b, growth behavior, and its accumulation in the tissues of different parts of onion plants (*Allium cepa*) and at the end it is concluded that Onion plants can be cultivated in the area where Arsenic containing water is being utilized for irrigating crops but, a chain of in-vitro studies are required to understand the biochemistry and mechanism that influenced growth and productivity of the onion plants [51].

Daily vegetable requirement are mostly fulfilled in Bangladesh through homestead garden production which are usually irrigated with arsenic-rich underground water. Garden vegetables grown in arsenic-tainted soil may uptake and accumulate significant amount of arsenic in their tissue. Mean, minimum and maximum arsenic content in some common garden vegetables, e.g. bean, bitter gourd, bottle gourd, brinjal, chilli, green papaya, mint, okra, palwal, potato, red amaranth, string bean and sweet gourd, from an arsenic prone locality have been assessed [52].

Arsenic is not a heavy metal, but it is related to them. In plant, arsenic is accumulated mainly in the root system,to a lesser degree in the aboveground organ, and causes physiological changes and damages [53, 54]. and reduction of the crop productivity. Arsenic inhibits the growth and fresh and dry biomass accumulation [55]. Arsenic is not a redox metal. Nevertheless, there is significant evidence that exposure of plants to inorganic arsenic dose result in the generation of ROS (Reactive oxygen species), which is connected with arsenic valance change, a process that readily occurs in plants [56]. The rate of CO_2 fixation in young plant treated with arsenic decreased by about 20% and function activity of PS2 was reduced significantly. Arsenic damaged the chloroplast membrane and disorganized the membrane structure [57].

The presence of high concentrations of arsenic (As) decreased the shoot and root dry weight, chlorophyll and P and Mg content of *Eucalyptus globulus* colonized with the arbuscular mycorrhizal

(AM) fungi *Glomus deserticola* or *G. claroideum*, but these parameters were higher than in non-AM plants. Arsenic increased the percentage of AM length colonization and succinate dehydrogenase (SDH) activity in the root of *E. globules* [58].

The literature available on the impact of heavy metals lead, cadmium, mercury and arsenic indicate that the plants are responsive to the metals. The accumulation of the metals in the plants organs and their consequent effects, however, vary according to the species, concentration of the metal and soil or nutrient composition. Normally, when organic matter, minerals, certain inorganic salts especially salts containing phosphates and potassium, and lime are in abundance, metal toxicity is not severe. However, it has been found that all types of plants are affected when they get exposed to heavy metals beyond the threshold limit.

Toxic Levels of Lead (Pb), Cadmium (Cd), Mercury (Hg), Arsenic (As) affects plant processes at physiological and biochemical levels. When the metals reacts with important functional groups, the activity of several enzymes is influenced, some of which are important in photosynthesis and nitrogen metabolism. Research has identified several important aspects of metal tolerance in some plant, but there is no model species in which the entire process/ steps of tolerance has been determined. It appears that plant responses to metals is complex phenomenon and, is controlled by multiple gene systems in the plant.

A better understanding of the knowledge is required to handle the acute problem of increasing metal toxicity to the plants and human life. Efforts to coordinate research to address all aspects of tolerance are required. In addition to provide the necessary data for the production of models that will accurately predict the impact of certain metal related industrial activities on the plant life, the study of metal tolerance may also provide methods to detoxify metal contaminated solid through the use of metal accumulating species. As such the pathway of metal detoxification in plants needs to be studied in depth.

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