Toxic Effects of Some Heavy Metals on Physiology of Plants: A Review

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ABSTRACT:

Heavy metals, such as cadmium, copper, lead, chromium and zinc are major environmental pollutants, particularly in areas with high anthropogenic pressure. Heavy metal accumulation in soils is of great concern in agricultural production due to the adverse effects on food safety and marketability, crop growth due to phytotoxicity, and environmental health of soil organisms. Soils polluted with heavy metals have become common due to increase in geologic and anthropogenic activities. The unplanned disposal of municipal waste, mining, use of extensive pesticides, insecticides, fungicides, and other agrochemicals uses were significant causes of environment pollution. The influence of geological and biological redistribution of heavy metals through pollution of the air, water and soil affects the plants and their metabolic activities. This review focuses on effect of some important heavy metals such as cadmium, chromium, lead, zinc, lead, copper and nickel on plant physiology.

Key Words: Cadmium, Lead, Chromium, Pyhtotoxicity.

INTRODUCTION:

Naturally plants are exposed to many adverse environmental conditions like biotic and abiotic stress. Despite all others stresses heavy metal stress is one of great important which has a notable adverse effects on crop productivity and growth. Heavy metal stress triggers different responses in plants, ranging from biochemical responses to crop yield. The term ‘‘heavy metals’’ refers to any metallic element that has a relatively high density and is toxic or poisonous even at low concentration (Lenntech Water Treatment and Air Purification, 2004). ‘‘Heavy metals’’ in a general collective term, applies to the group of metals and metalloids with atomic density greater than 4 g/cm3, or 5 times or more, greater than water (Hawkes, 1997). However, chemical properties of the heavy metals are the most influencing factors compared to their density.

Plants require certain heavy metals in minute quantities for their growth and development, excessive amounts of these metals can become toxic to plants and ability of plants to accumulate essential metals equally enables them to acquire other nonessential metals (Dijingova & Kuleff, 2000). As metals cannot be broken down, when concentrations within the plant exceed the optimal levels, they adversely affect the plants directly and indirectly and some of the direct toxic effects caused by high metal concentration include inhibition of cytoplasmic enzymes and damage to cell structures due to oxidative stress (Assche & Clijsters, 1990; Jadia & Fulekar, 1999.) and indirect toxic effect is the replacement of the essential nutrients at cation exchange sites of plants (Taiz & Zeiger, 2002). The exposure of plants to toxic levels of heavy metals triggers a wide range of physiological and metabolic alterations (Dubey, 2011). However, as different heavy metals have different sites of action within the plant, the overall visual toxic response differs between heavy metals. The most widespread visual evidence of heavy metal toxicity is a reduction in plant growth (Sharma and Dubey, 2007) including leaf chlorosis, necrosis, turgor loss, a decrease in the rate of seed germination, and a crippled photosynthetic apparatus, often correlated with progressing senescence processes or with plant death (Dalcarso *et al*., 2010; Carrier *et al*., 2003). All these effects are related to ultra structural, biochemical, and molecular changes in plant tissues and cells brought about by the presence of heavy metals (Gamalero *et al*., 2009).

According to Cheng (2003) plants interact with heavy metals in two ways, i.e., heavy metals either imparts negative effects or gets accumulated within plants due to their resistance mechanism against toxins. Excessive heavy metal concentrations in the contaminated soil is responsible for the observed retarded growth, different growth rate and the yellowish - green color of the leaves (Grath *et al.*, 1997). The influence of heavy metals on the growth and activities of soil microorganisms also affect the growth of plants. Reduction in the number of beneficial soil microorganisms due to high metal concentration may lead to decrease in organic matter decomposition leading to a less fertility of soil. Enzyme activities are very much useful for plant metabolism, hampered due to heavy metal interference with activities of soil microorganisms. These toxic effects (both direct and indirect) lead to a decrease in plant growth which finally results in the death of plant (Schaller & Diez, 1991).

Sources of Heavy Metal Contamination:

Heavy metals are the major pollutants that enters in the environment. Heavy metals enters the environment mainly from industrial processes, phosphate fertilizers and the sewage- sludge (Davis, 1984) and then transferred to the food chain (Wagner *et al.*, 1993). Other sources of heavy metals include refuse incineration, landfills and transportation (automobiles, diesel-powered vehicles and aircraft). Two main anthropogenic sources that contaminate the soil are fly ash produced due to coal burning and the corrosion of commercial waste products, which add Cr, Cu, Pb and galvanized metals (primarily Zn) into the environment. Coal burning adds heavy metals such as Cd, Hg, Mn, Ni, Al, Fe and Ti into the soils (Verkleji, 1993). Oil burning contributes V, Fe, Pb and Ni to the environment. Metal emission during the transportation of vehicles includes Ni and Zn from tires, Al from catalyst, Cd and Cu primarily from diesel engines and Ni and Zn from aerosol emissions. Lubricants, which are antiwear protectants for vehicles, emit Cd, Cr, Hg, Ni, Pb and Zn, particularly in case of inefficient engines. The burning of leaded gasoline has been an important source of Pb in the environment. Incinerations of municipal wastes generate significant concentrations of Zn, Pb, Al, Sn, Fe and Cu.

Animal manure enriches the soil by the addition of Mn, Zn, Cu and Co and sewage sludge by Zn, Cr, Pb, Ni, Cd and Cu (Verkleji, 1993). The increase in heavy metal contamination of agricultural soil depends on the rate of application of the contributors with its elemental concentration and soil characteristics to which it is applied. Heavy metal accumulation in soil is also due to application of soil amendments such as compost refusing and nitrate fertilizers (Ross, 1994). Liming increases the heavy metal levels in the soil more than the nitrate fertilizers and compost refuse. Sewage sludge is one of the most important sources of heavy metal contamination to the soil (Ross, 1994). Several heavy metal based pesticides are used to control the diseases of grain and fruit crops and vegetables and are sources of heavy metal pollution to the soil (Ross, 1994). The orchards where these compounds have been used frequently resulted into contamination of orchard soil with high levels of heavy metals such as Cu, As, Pb, Zn, Fe, Mn and Hg (Ross, 1994). Pesticides such as lead arsenate were used in Canadian orchards for more than six decades and were found to be enriched with Pb, As and Zn having greater consequences for food contamination. Continued irrigation of agricultural soil can lead to accumulation of heavy metals such as Pb and Cd (Ross, 1994).

Mining operation emits different heavy metals depending on the type of mining. For example, coalmines are sources of As, Cd, Fe, etc., which enrich the soil around the coalfield directly or indirectly. The utilization of Hg in gold mining and the mobilization of significantly high amounts of Hg from old mines have become a significant source of this pollutant to the environment (Lacerda, 1997). High temperature processing of metals such as smelting and castings emit metals in particulate and vapour forms. Vapour form of heavy metals such as As, Cd, Cu, Pb, Sn and Zn combine with water in the atmosphere to form aerosols. These may be either dispersed by wind (dry deposition) or precipitated in rainfall (wet deposition) causing contamination of soil or water bodies. Contamination of soil and water bodies can also occur through runoff from erosion of mine wastes, dusts produced during the transport of crude ores, corrosion of metals and leaching of heavy metals to soil and ground water.

Contamination of agricultural soil by heavy metals has become a critical environmental concern due to their potential adverse ecological effects. Such toxic elements are considered as soil pollutants due to their widespread occurrence and their acute and chronic toxic effect on plants grown of such soils. The inorganic and organic fertilizers (Fertilizer is a substance added to soil to improve plants growth and yield.) are the most important sources of heavy metals to agricultural soil include liming, sewage sludge, irrigation waters and pesticides, sources of heavy metals in the agricultural soils. Others, particularly fungicides, inorganic fertilizers and phosphate fertilizers have variable levels of Cd, Cr, Ni, Pb and Zn depending on their sources.

Chromium:

Chromium (Cr) is the seventh most abundant metal in the earth's crust and an important environmental contaminant released into the environment due to its huge industrial use. Chromium is mainly present in the environment as insoluble Cr (III) and Cr (VI) compounds (Surekha and Duhan, 2012). Chromium is known to be a toxic metal that can cause serve damage to plants and animals. Since seed germination is the first physiological process affected by Cr, the ability of a seed to germinate in a medium containing Cr would be indicative of its level of tolerance to this metal (Peralta *et al.*, 2001).

Chromium induced oxidative stress involves induction of lipid peroxidation in plants that causes severe damage to cell membranes. Oxidative stress induced by chromium initiates the degradation of photosynthetic pigments causing decline in growth. High chromium concentration can disturb the chloroplast ultra structure there by disturbing the photosynthetic process. Photosynthesis in terms of CO_2 fixation, electron transport, photophosphorylation and enzyme activities (Clijester & Van Assche 1985).

Lead:

Lead is a bluish-white lustrous metal. It is very soft, highly malleable, ductile, and a relatively poor conductor of electricity. It is very resistant to corrosion but tarnishes upon exposure to air. Lead isotopes are the end products of each of the three series of naturally occurring radioactive elements (Mohd Hilmi Bin Jaafar. 2010). Lead naturally occurs in soils but is in relatively low concentrations. Lead concentrations in uncontaminated soils are generally in the range of 20 to 50 mgkg-1 (Nriagu, 1978), with the median concentration in the United Kingdom of 40 mgkg-1 and arithmetic mean of 74 mg kg-1 (MAFF, 1993). Non-polluted soils usually contain less than 100 mgkg-1 Pb, with soils in unpolluted polar soils buried before the industrial revolution contain less than 5 mgkg-1 (Meggeson and Hall, 1999). Soils that contain 400 - 800 mg kg-1 lead, soil are regarded as significantly affected with a possibility that food grown on it will exceed the legal limit used in the United Kingdom (MAFF, 1993) if the pH is below 6.0. In industrialized areas up to 1000 mgkg-1 Pb and above has been recorded (Angelone and Bini, 1992). Although lead is not essential element for plants, it gets easily absorbed and accumulated in different plant parts. Uptake of Pb in plants is regulated by pH, particle size and cation exchange capacity of the soils as well as by root exudation and other physico-chemical parameters.

Lead (Pb) is one of the ubiquitously distributed most abundant toxic elements in the soil. It exerts adverse effect on morphology, growth and photosynthetic processes of plants. Pb has been found to decrease the seed germination in *Arachis hypogeae* L. (Abraham K *et al.*, 2013). Pb has been reported to inhibit / retard seed germination. Hussain *et al.* 2013 reported a continuous decrease in germination (10−100 %) of *Zea mays* with the increasing Pb concentration at 1−500 mM Pb, compared to the control. Lead is known to inhibit seed germination of *Spartiana alterniflora, Pinus helipensis* (Morzck *et al.*, 1982). Lead also inhibited root and stem elongation and leaf expansion in Allium species barley and *Raphanus sativas*

(Juwarkar & Shende. 1986). The degree to which root elongation is inhibited depends upon the concentration of lead and ionic composition and pH of the medium (Goldbold & Hutterman. 1986). In maize (*Zea mays*) reduction in germination percentage; suppressed growth; reduced plant biomass; decrease in plant protein content has been noticed (Hussain *et al.,* 2013).

Lead (Pb) induced toxicity in plants in terms of their growth, development, and biochemical attributes. Primary effects of Pb toxicity in plants include stunted root growth, probably due to inhibition of cell division in root tips. Secondarily, it induces oxidative stress via reactive oxygen species generation and results in cellular damage. Pb induces lipid peroxidation and causes greater accumulation of H2O2 and *O2•−*. Pb exposure not onlyalters ROS scavenging enzymes but also affects non-enzymatic antioxidants. (Gurpreet Kaur, 2014). The exposition of *Lemna polyrrhiza* to different concentrations of Cd and Pb results in an increase in growth, pigment content, proline, protein and sugar content at lower concentration; at higher concentrations their decrease was observed. Cd effect was more significant than that of Pb in hampering plant growth and development (Jhon *et al.,* 2008).

Nickel:

Nickel is silvery-white, hard, malleable and ductile metal. It is of the iron group and it takes on a high polish. It is a fairly good conductor of heat and electricity. Nickel is bivalent in its familiar compounds even though it assumes other valences. It also forms a number of complex compounds. Most nickel compounds are blue or green. Nickel dissolves slowly in dilute acids but like iron, becomes passive when treated with nitric acid (Mohd Hilmi Bin Jaafar. 2010). Nickel (N) is a transition metal and found in natural soils at trace concentrations except in ultramafic or serpentinic soils. However, Ni^{2+} is increasing in certain areas by human activities such as mining works, emission of smelters, burning of coal and oil, sewage, phosphate fertilizers and pesticides (Gimeno-Garcia *et al.*, 1996). Ni^{2+} concentration in polluted soil may range from 20- to 30fold (200–26,000 mg/kg) higher than the overall range (10–1,000 mg/kg) found in natural soil (Izosimova. 2005). Excess of Ni^{2+} in soil causes various physiological alterations and diverse toxicity symptoms such as chlorosis and necrosis in different plant species (Zornoza *et al.,* 1999; Pandey and Sharma 2002; Rahman *et al.,* 2005), including rice (Das *et al.,* 1997).

The heavy metal nickel had adversely affected the growth and biochemical parameters of the plant *Phaseolusmungo L.* (Selvaraj, 2018) .Decrease in shoot length, root length, fresh weight and dry weight may be due to nickel toxicity which caused reduction in water uptake (Foy *et al.,* 1998 & Nag *et al.,* 1981). The observed pronounced inhibition of shoot and root growth and leaf area are main cause for the decrease in fresh weight and dry weight of seedlings. For plants, uptake of metals occurs primarily through the roots, so this is the primary site for regulating their accumulation (Arduini *et al.*, 1996). The leaves of green gram plants supplied with excess nickel were smaller in size and developed chlorosis in the leaflets (Panday *et al.*, 2006). After seven days of nickel supply, these leaves developed black necrotic spots on either side of the midrib.

Zinc:

Zinc is a lustrous bluish-white metal. It is found in group IIb of the periodic table. It is brittle and crystalline at ordinary temperatures, but it becomes ductile and malleable when heated between 110°C and 150°C. It is a fairly reactive metal that will combine with oxygen and other non-metals, and will react with dilute acids to release hydrogen (Mohd Hilmi Bin Jaafar, 2010). Zinc toxicity in plants limited the growth of both root and shoot. Zinc toxicity also causes chlorosis in the younger leaves, which can extend to older leaves after prolonged exposure to high soil Zn levels (Ebbs and Kochian, 1997). The chlorosis may arise partly from an induced iron (Fe) deficiency as hydrated Zn^{+2} and Fe^{+2} ions have similar radii (Marschner, 1986). Excess Zn can also give rise to manganese (Mn) and copper (Cu) deficiencies in plant shoots. Such deficiencies have been ascribed to a hindered transfer of these micronutrients from root to shoot. This hindrance is based on the fact that the Fe and Mn concentrations in plants grown in Zn rich media are greater in the root than in the shoot (Ebbs and Kochian, 1997). Another typical effect of Zn toxicity is the appearance of a purplish red colour in leaves, which is ascribed to phosphorus (P) deficiency (Lee *et al.*, 1996).)

The phytotoxicity of Zn and Cd is indicated by decrease in growth and development, metabolism and an induction of oxidative damage in various plant species such as *Phaseolus vulgaris* (Fernades & Henriques 1991) and *Brassica juncea* (Prasad *et al.*,1999) Cd and Zn have reported to cause alternation in catalytic efficiency of enzymes in *Phaseolus vulgaris* (Van Assche *et al.*, 1998) and pea plants (Romero-Puertas *et al.*, 2004). Concentrations of Zn found in contaminated soils frequently exceed to those required as nutrients and may cause phytotoxicity. Zinc in excess reduces the germination, chlorophyll, carotenoid, sugar, amino acid and growth of cluster beans (*Cyamopsis tetragonoloba*) (Manivasagaperumal *et al.*, 2011). Whereas, in pea (*Pisum sativum*) reduces chlorophyll, photosynthesis and plant growth (Doncheva *et al.*, 2001). In rye grass (*Lolium perenne*) it reduces the growth, nutrient content and photosynthetic energy conversion (Bonnet *et al.*, 2000).

Copper:

Copper is a reddish metal with a face-centered cubic crystalline structure. It reflects red and orange light and absorbs other frequencies in the visible spectrum due to its band structure, so it as a nice reddish colour. Copper is malleable, ductile and an extremely good conductor of both heat and electricity. It is softer than iron but harder than zinc and can be polished to a bright finish. It is found in group Ib of the periodic table, together with silver and gold. Copper has low chemical reactivity. In moist air, it slowly forms a greenish surface film called patina; this coating protects the metal from further attack(Mohd Hilmi Bin Jaafar ,2010).

Copper (Cu) is an essential element for plants' growth, however, due to human activities large amounts of Cu have been released into the environment which adversely affect plant growth . 91mg kg^{-1} of dry weight of Cu in shoot and 810mg kg^{-1} of dry weight in root of Cu were accumulated when 200 mM Cu was applied. when 400 mM of Cu was applied majority of the plants did not survive. In each addition increment of Cu the biomass production decline consistently. Severely inhibition was seen in root growth then shoot growth. Root morphology of plant was adversely affected by Cu, however at low level of Cu no. of root tips and root surface area slightly increase. Under Cu stress slightly change was seen in root cell ultra structure and organells, in perticular mitrochondria,cell walls and xylem parenchyma (Chen *et al.*, 2014). Plant roots are the sole organs which are in direct contact with heavy metal-contaminated soils and thus are the first organs to experience the toxic effects (Panou-Filotheou and Bosabalidis, 2004). Exposure of plants to excess Cu generates oxidative stress and ROS (Stadtman and Oliver 1991). Oxidative stress causes disturbance of metabolic pathways and damage to macromolecules (Hegedus *et al.*, 2001). Copper toxicity affected the growth of Alyssum montanum (Ouzounidou. 1994) Copper and Cd in combination have affected adversely the germination, seedling length and number of lateral roots in Solanum melongena (Neelima and Reddy. 2002). Copper is an essential metal for normal plant growth and development, although it is also potentially toxic.

Copper (Cu) is considered as a micronutrient for plants (Kabir and Shafiq. 2009) and plays important role in CO2 assimilation and ATP synthesis . Study conducted at Malanzkhand Copper Project (MCP) of Hindustan Copper Limited (HCL) at Malanzkhand, district Balaghat, M.P in which it was found that copper dust had adverse effect on various photosynthesis pigmentation secretions in many trees species leaves . Cu is also an essential component of various proteins like plastocyanin of photosynthetic system and cytochrome oxidase of respiratory electron transport chain (Demirevska-Kepova *et al.*, 2004) But enhanced industrial and mining activities have contributed to the increasing occurrence of Cu in ecosystems. Cu is also added to soils from different human activities including mining and smelting of Cu containing ores. Mining activities generate a large amount of waste rocks and tailings, which get deposited at the surface. Excess of Cu in soil plays a cytotoxic role, induces stress and causes injury to plants. This leads to plant growth retardation and leaf chlorosis (Lewis. 2001). Exposure of plants to excess Cu generates oxidative stress and ROS (Stadtman and Oliver. 1991). Oxidative stress causes disturbance of metabolic pathways and damage to macromolecules (Hegedus *et al.*, 2001). Copper reduces the root growth in rhodes grass (*Chloris gayana*) (Mohnish and Nikhil,2015). In black bindweed (*Polygonum convolvulus*) the plant mortality, biomass and seed production is reduced due to copper toxicity (Kjaer and Elmegaard 1996) In bean (*Phaseolus vulgaris*) accumulation of Cu in plant roots and root malformation and reduction seen (Cook *et al.*, 1992).

Conclusion: From the above discussion it can be concluded that heavy metals poses a great risk on the plant physiology. it is evident from the several research reports that the presence of heavy metals have many toxic effects on plants. It is well needed to intensify the research programmes for better understanding of heavy metal toxicity on plants and allied areas to maintain the ecological harmony of the globe. Therefore, identification of suitable plants with essential mechanisms and subsequent transformation capacity of heavy metals to simpler and less toxic forms are necessary for future phytoremediation studies.

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