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Environmental Exposures and Toxic Effects of Cadmium: A Review

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ABSTRACT: As other elements are the part of soils composition in the same way Heavy metals are also found in this naturally. Cadmium is also considered as a heavy metal. It is also found in the soil but in a very minute quantity. High concentrations are confined primarily in to polluted soil. This review emphasizes cadmium toxicity on plants with regards to ecological, physiological and biochemical aspects. Cadmium toxicity in plants and problems concerning tolerance are discussed. Efforts have been made to compare the relative sensitivity of various plant groups. Cadmium is a non-essential heavy metal so it is considered as pollutant. Its presence in environment resulting from various agricultural, mining and industrial activities and also from the exhaust gases of automobiles. It may help in interdisciplinary studies to assess the ecological significance of metal stress.

Keywords: Phytoremediation; contaminated soils; chlorosis; cadmium; heavy metals.

INTRODUCTION

Since the discovery of "itai-itai disease" in Japan in 1950s, adverse effect of cadmium (Cd) on human health due to consumption of Cd contaminated diet have received much attention (Yanai *et al.*, 2006). A total of 2.2 x 10^4 tons of Cd has been discharged into the environment during the past half-century. Cadmium has no essential biological function. It is highly toxic to plants and animals. However, the concentration of Cd normally encountered in the environment not cause acute toxicity. Cadmium, a potentially toxic metal, has been shown to accumulate in plants (Chaney *et al.*, 1997; and Turgut *et al.*, 2004). It is well known that Cd disturbs plant water relations and mineral nutrition. It also provokes significant disturbances in structural organization and functional activity of photosynthetic apparatus (Vassilev *et al.*, 2002and Maxted et al 2007). The increasing level of Cd in agricultural soils due to the disposal of sewage, industrial and municipal wastes and phosphatic fertilizers etc. pose potential cadmium toxicity to plants, animals and human population (Mahler *et al.* 1978, Huang *et al.* 1997).

Certain minerals usually present in forms which are not easily available but may be sensitive to higher concentrations. Heavy metals occur naturally in soils as rare elements.

High concentrations are confined primarily to certain minerals usually but may be sensitive to higher concentrations. The release of heavy metals in biologically available forms may affect adversely both natural and anthropogenic ecosystems (Aery *et al*., 1991, Blaylock *et al*., 1997). The chemical form (speciation) of heavy metals in soil solution is greatly dependent on the metal element, pH and presence of other ions, etc. Toxic actions of heavy metal ions are essentially exerted on the enzymes. Prolonged exposure of soils to heavy metals may result in marked decreases in soil enzyme activity (Chaney *et al.*, 1997, Foy *et al.*, 1978). Impeded litter decomposition and soil respiration are common features of heavy metal pollution of soils. Several other studies also indicated toxic effects of heavy metals on cellular organs like mitochondria and extracellular soil enzymes (Chaney *et al.*, 1997). Cadmium is a non-essential heavy metal pollutant of the environment. It enters in a new ecosystem from various agricultural, mining and industrial activities and also from the exhaust gases of automobiles.

Eco-toxicity of cadmium in animals and other aspects were reported by various researchers (Narwal *et al.*, 1983; Turget *et al.*, 2004). It has been considered as an extremely significant pollutant due to its high toxicity and greater solubility in soil and water. It determines wide distributions in crop land and aquatic ecosystems. Aquatic organisms may acquire cadmium directly from contaminated water or through the food chain. Water hyacinth is a good bioindicator of water pollution due to heavy metals (Yanai *et al.*, 2006). The toxic effects of cadmium on biological systems were reported by various authors (Clijsters *et al*. 1985; Huang *et al.*, 1997; Mahler *et al.*, 1978).

Cadmium is naturally present in the environment. It is present in soil and sediments at concentrations which are generally more than 1mg Kg^{-1} and its total concentrations in unpolluted seawater, where it exists mainly as chloro complexes is generally <1 µg/Kg^{-1} (Chaney *et al.*, 1997, Foy *et al.*, 1978). In addition, indirect effects of the metal on the physical environment, such as variations in pH value and oxygen concentration in water resulting from toxic effects of the metal on photosynthesis were reported (Chaney *et al.*, 1997, Yanai *et al.*, 2006). Recent progress in the study of heavy metals and their interactions with essential elements has greatly increased our understanding of the mechanism of toxicity at the biochemical level (Clemens 2002 and Pushpendra *et al.*, 2005). In this review the salient features of cadmium toxicity in flora and their interactions with essential elements are highlighted.

Toxicity Due to Cadmium and Its Symptoms: The symptoms of cadmium toxicity are easily identifiable. In plants, the most general symptoms are stunting and chlorosis. The chlorosis may appear similar to Fe deficiency. Chlorosis from excess cadmium appears to be due to a direct or an indirect interaction with foliar iron. Researchers reported that high cadmium content in the growing medium suppresses the iron uptake by the plants. Several Research workers felt that Cd-induced chlorosis in corn leaves could be due to changes in Fe: Zn ratios. In others, Cd toxicity appeared to induce phosphorous deficiency or reduce manganese transport problems (Narwal *et al.*, 1983; Turget *et al.*, 2004). Physiological research on the mechanism of Cd toxicity has involved a single plant species or variety. In general, Cd has been shown to interfere with the uptake, transport and use of several elements (Ca, Mg, P and K) and water by plants. Many factors affect the interactions between metals as reported earlier in biological systems (Foy *et al.*, 1978). In many other species toxicity probably decreases with temperature. Increasing pH usually increases the mortality in a wide range of species.

Cytogenetic Effects of Cadmium: Being a non-essential heavy metal and a powerful enzyme inhibitor, Cd has been considered as an extremely significant pollutant due to its high toxicity and great solubility in soil solutions. Exposure of three species of green algae to $CdCI_2$ resulted in the formation of intra-mitochondrial granules containing cadmium (Clemens 2002 and Pushpendra *et al.*, 2005). Swelling, vacuolization and degeneration of mitochondria were observed, implying significant cyto-toxicity. Researchers also reports that cadmium inhibited cell proliferation. It is also reported that if plants exposed to cadmium for 24 h than it infiltrate into the cells inducing physiological and genetical damages, especially at concentrations of 1.5 to 10mg liter $^{-1}$ (Clijsters *et al.*, 1985, Cobbett 2000, and Ebbs *et al.*, 2002). The cytotoxic action of cadmium in plants was reported earlier by many workers. Cadmium inhibited cell division and altered the chromosomes. The inhibition of cell proliferation, shown by the low mitotic index, was proportional to the concentration and time of exposure. The induction of pycnosis in root cells confirmed the cytotoxic action of cadmium. This effect has also been reported in the protoplast of *Nicotiana tabacum*.

Interactions between Cd and Other Metals: Toxicity of cadmium cannot be considered without taking into account the translocation of several other essential elements. In the plant system, toxic effects of cadmium have been shown to be modified by essential elements like zinc, calcium, iron, copper and manganese. In addition, proteins and vitamins have also been reported to alter cadmium toxicity (Strickland *et al.*, 1979, and Pushpendra *et al.*, 2005). Scientists hypothesized that elements whose physical and chemical properties are similar biologically will act antagonistically to each other. Elements of similar type help to compete for the same transport and storage sites in the cell and displace each other from reactive enzymatic and receptor proteins (Clemens 2002, Clijsters *et al.*, 1985 and Cobbett 2000).

Selenium may act as a synergist to cadmium, whereas cadmium may inhibit copper toxicity. Although low levels (< 1.0mg/litre^{-1}) of lead increased the toxicity of cadmium (0.1 mg/litre^{-1}) in phytoplankton, antagonism occurs when the concentration of lead exceeds that of cadmium. Pretreatment of algae with metals (Ni and Hg) reduced cadmium toxicity; this may reflect competition among metals for cellular binding sites.

Interaction between Cadmium and Zinc: Zinc and cadmium have many physical and chemical similarities as they both belong to group II of the periodic table. They are usually found together in the ores and compete with each other for various ligands. Thus interaction between those two elements in the biological system is likely to be similar (Clijsters *et al.*, 1985, Cobbett 2000, and Ebbs *et al.*, 2002). The fact that cadmium is a toxic heavy metal and zinc an essential element makes this association interesting as it raises the possibility that the toxic effects of cadmium may be preventable or treatable by zinc. Foy *et al.*, 1978 showed that Cd had toxic effects in plants in the way of photosynthesis and also indicated various changes in biological activities.

Subsequent studies have confirmed these findings and extended the interaction to other toxic effects of cadmium like inhibition of cell proliferation, and cytotoxic action and growth suppression in plants. The biochemical mechanisms of Cd-Zn interaction are unknown, but various cellular and subcellular processes like the ratio of Cd to Zn in the tissues, induction of synthesis of different types of metallothionein, binding characteristics of metallothionein, alteration of absorption and tissue distribution of one metal by another, and competition at the level of zinc containing metallo-enzymes are known to be involved in the interactions (Clemens 2002, Clijsters *et al.*, 1985 and Cobbett 2000). In recent years it has been suggested that Cd-binding complex similar to the metallothionein exists in several higher plants such as tomato kidney bean and cabbage.

Differential Cadmium Tolerance in Plants: The phenomenon of heavy metal tolerance in plants has attracted the interest of plant ecologists, physiologists and evolutionary biologists (Foy *et al.*, 1978). Development of metal tolerance is a major way to reduce the harmful effects of excessive exposure to heavy metal ions (Cobbett 2000 and Ebbs *et al.*, 2002). Classical studies on vascular plant species do not unequivocally indicate that tolerant races should be competitively inferior in normal soils. The tolerance of vascular plants to heavy metals does not usually import a restricted uptake of these elements by the roots. This means that tolerant plants with a high capacity of immobilizing heavy metal ions in their root tissues might have to renew the most active parts of their below-ground biomass more often than non-tolerant plants in normal soils. Plant species and varieties vary widely in tolerance to excess cadmium in the growth medium (Huang *et al.*, 1997; Mahler *et al.*, 1978). In several species, these differences are genetically controlled. Closely related genotypes are valuable tools for studying the physiological mechanisms of toxicity or tolerance. The inter population variation of plant species tolerant to Cd were reported by various authors (Cobbett 2000 and Ebbs *et al.*, 2002). So many scientists pointed out that an element present in excess could interfere with metabolism through competition for uptake, inactivation of enzymes, displacement of essential elements from functional sites, or alteration of the structure of water. Many of these probably effect modification of membrane structure and function.

Other effects: Impairment of the pulmonary function suggestive of mild obstructive syndrome has been reported in workers exposed to relatively high concentrations of Cd by inhalation. Changes in lung function were however slight as compared to that caused by tobacco smoking. With improvement of working conditions in most Cd plants, pulmonary changes are much less likely to occur than biological signs of renal damage. Although Cd can cause liver injury in animals receiving high doses, no study has reported signs of hepatic damage either in Cd workers or among inhabitants of polluted areas. Similarly, there is no report of adverse effects on the nervous system or the reproductive system caused by occupational or environmental exposure to Cd. Although epidemiologic studies assessing the effects of Cd exposure on blood pressure have provided largely inconsistent results, a recent study in US adults who participated in the 1999-2004 National Health and Nutrition Examination Survey (NHANES) found that Cd levels in blood, but not in urine, were associated with a modest elevation in blood pressure levels.

CONCLUSION

The exact physiological mechanism of cadmium toxicity or tolerance is still debated. This may vary with the plant species and varieties controlled by different genes. Obviously, cadmium-tolerant plants must be able to prevent the absorption of excess cadmium or detoxify the Cd after it has been absorbed. Various physiological factors are associated with differential Cd tolerance, e.g. pH and other factors. In accordance with, it may be assumed that there exist different specific mechanisms of tolerance within each of the populations which are related to the contamination of their original habitat.

They also reported changes in the activities of enzymes like peroxidase and acid phosphatase to indicate metabolic responses of plants to stress conditions. Several workers reported that the acid phosphatase and peroxidase activity increased in cadmium-tolerant plants. Cobbett 2000 and Ebbs *et al.*, 2002 reported that Cd concentrations in plants were quite often different in roots and shoots. Metal-tolerant plants showing a diminished accumulation of the respective metal in shoots have been found to accumulate higher amounts in roots as compared to non-tolerant ones of the same species (Clemens 2002 and Clijsters *et al.*, 1985). Different species of aquatic macro and micro-flora were reported to accumulate high concentrations of cadmium.

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