Cadmium in Plants: A Review

Seyed MeysamHoseini

Professor of Maziar University, Department of Plant Physiology, Islamic Azad University, Tonekabon Branch, Iran

Email id : Meysam_hoseini64@yahoo.com

Abstract

Cadmium (Cd) is a toxic metal for living organisms and an environmental contaminant. Of all the non-essential heavy metals, cadmium is perhaps the metal which has attracted the most attention in soil science and plant nutrition due to its potential toxicity to humans, and also its relative mobility in the soil-plant system. Plant root is the main organ for uptake of pollutants including heavy metals like cadmium. This review summarizes the toxic symptoms of cadmium in plants.

Keywords: Heavy Metals, Cadmium,Toxicity, ROS.

Introduction

Heavy metals are defined as metals having a density higher than 5 g cm^3. Of the total 90 naturally occurring elements, 53 are considered heavy metals and few are of biological importance (Hasan et al, 2009). Based on their solubility under physiological conditions, 17 heavy metals may be available to living cells and have significance for the plant and animal communities within various ecosystems (Weast, 1984). Increase in levels of heavy metals in soils could also beattributed to factors such as soil properties or different agriculturalpractices, for example application of sludge to agricultural land (Foy et al, 2005).Among the heavy metals Zn, Ni, Cu, V, Co, W and Cr are non-toxic heavy elements at low concentration. As, Hg, Ag, Sb, Cd, Pb and Al have no known function as nutrients and seems to be more or less toxic to plants and microorganisms (Beak et al, 2006).Accumulationof heavy metals such as cadmium in the environment is now becoming a major causeof environmental pollution.Cadmium (Cd) is one of the most deleterioustrace heavy metals both to plants and animals.With the development of modern industry andagriculture, Cd has become one of the most harmfuland widespread pollutants in agricultural soils,and soil-plant-environment system mainly due toindustrial emission, the application of Cd-containingsewage sludge and phosphate fertilizers andmunicipal waste disposal (Dong et al, 2007). The maximum tolerable intake of Cd for humans, recommended by FAO/WHO is70 μg/day (Vassilev andYordanov, 1997).Cd pollution is of increasing scientific interest since $Cd^{2+}$is readily taken up bythe roots of many plants species and its toxicity is generally considered to be 2–20 timeshigher than that of other heavy metals (Shah and Dubey, 1995).Cd phytotoxicityis a minor, but also important problem, especially in some highly heavy metalpolluted regions, where a decrease in agricultural crop productivity has been observed.The main goal of this review is to outline our current understanding of the factors limiting the growth of plants exposed to Cd treatment.

Heavy Metal Toxicity

The toxicity produced by transition metals generally involves Neurotoxicity, Hepatotoxicity and Nephrotoxicity (Benavides et al, 2005). Differences in solubility, absorbability, transport and chemical reactivity in these metal will lead to specific differences in toxicity within the body. The chemical form of heavy metals in soil solution is dependantof the metal concerned, pH and the presence of other ions (Das et al, 2001). The toxicity symptoms observed in plants in the presence of excessive amounts of heavy metals may be due to a range of interactions at the cellular level (Hall, 2002). Toxicity may result from the binding of metals to sulphydryl groups in proteins, leading to an inhibition of activity or disruption of structure (VanAssche, 1990). Enzymes are one of the main targets of heavy metal ions and prolonged exposure of soils to heavy metal results in marked decreases in soil enzymes activity (Tyler et al, 2003). In addition, heavy metal excess may stimulate the formation of free radicals and Reactive Oxygen Species (Fornazier et al, 2000).

Cadmium Toxicity in Higher Plants

Cadmium is non-essential element that negatively affects plant growth and development. It is released into the environment by power stations, heating systems, metal working industries or urban traffic. Cadmium is recognized as an extremely significant pollutant due to its high toxicity and large solubility in water (Pinto et al, 2004). Important sources of cadmium input to the marine environment include atmospheric deposition, domestic waste water and industrial discharges (Benavides et al, 2005). Wagner (1993) estimated that non-polluted soil solutions contain cadmium concentrations range from 0/04 to 0/32 mM.Soil solutions which have a cadmium concentration varying from 0/32 to about 1 mM can be regarded as polluted to a moderate level (Benavides et al, 2005). Hence, cadmium classified as an element of intermediate toxicity, but the mechanisms of cadmium toxicity are not completely understood yet. Stomatal Opening, Transpiration and Photosynthesis affected by cadmium, and Chlorosis, Leaf Rolls and Stunting are the main symptoms of cadmium toxicity in plants (Sandalio et al, 2001). Cadmium also reduced the absorption of nitrate and its transport from root to shoot by inhibiting the Nitrate Reductaseactivity in shoots (Hernandez et al, 1996). Several researches have suggested that an oxidative stress could be involved in cadmium toxicity, by either inducing oxygen free radical production, or by decreasing enzymatic and non-enzymatic antioxidants (Sandalio et al, 2001).

ROS Generation by Cadmium in Oxidative Stress

Plants are organisms that exposed to different of stresses such as Drought, Salinity, UV, Light, Freezing and Heavy Metals. The intoxication with pollutant metals induces oxidative stress because they are involved in several different types of ROS-generating mechanisms that showed in Figure 1 (Bagchi, 1995).

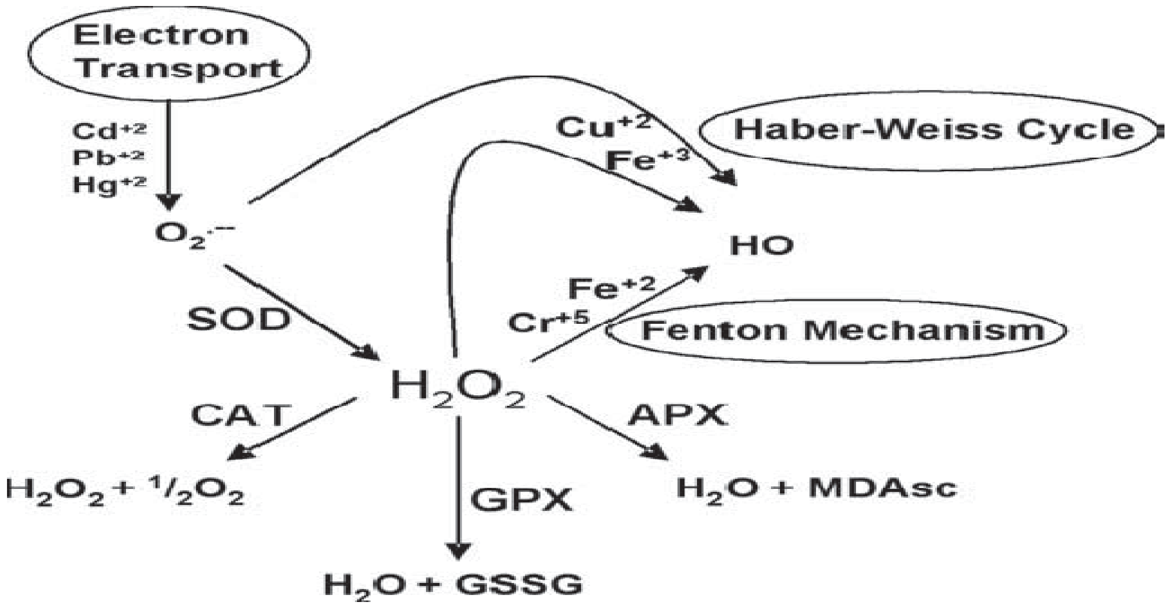

Fig 1.ROS Generation by Heavy Metal

Theseradicals occur transiently in Aerobic organisms because they are also generated in plant cells during normal metabolic processes, such as Respiration and Photosynthesis (Asada, 1987). ROS can be extremely harmful to plant at high concentrations. ROS can oxidize proteins, lipids and nucleic acid, often leading to alterations in cell structure and mutagenesis (Halliwell and Gutteridge, 2000). The balance between the steady-state levels of different ROS are determined by the interplay between different ROS-producing and ROS-scavenging mechanisms, and can change drastically depending upon the physiological condition of the plant and the integration of different environmental, developmental and biochemical stimuli (Polle, 2001). A variety proteins function as scavengers ROS such as Superoxide Dismutase (SOD), Catalase (CAT), Ascorbate Peroxidase (APOX), Glutathione Reductase (GR) and Thioredoxin (Benvides et al, 2005). Cadmium was found to produce oxidative stress, but, in contrast with other heavy metals such as Cu, it does not seem to act directly on the production of ROS (Salin, 2003). Examples of the oxidative responses to cadmium reported in higher plants showed in Table 1 (Benvides et al, 2005).

Number	Plant Species	Cadmium Concentrations (μM)	Antioxidant Enzymes Modified
1	*Pisumsativum*	5	CAT, APOX
2	*Triticum durum*	1-10	CAT, APOX, SOD
3	*Oryza sativa*	100-500	CAT, SOD, GR
4	*Arabidopsis thaliana*	300-500	CAT, SOD, GR, APOX
5	*Saccharumofficinarum*	500-700	CAT, SOD, GR

Table 1. Antioxidant Enzymes modified in plants exposed to different cadmium concentrations

Plant Growth Response to Cadmium Treatment

The inhibiting effect of Cd on fresh and dry mass accumulation, height, root length,leaf area, and other biometric parameters of plants are reported in almost all investigations.The following phytotoxic symptoms were observed: root browning, leaf red-brownish discolouration, leaf epinastyand leaf chlorosis (Vassilev and Yordanov, 1997).Differences in the degree of expressed phytotoxicity due to various Cd-concentrationsapplied to the root medium, theduration of treatment, as well as the characteristicsof species and cultivars were established.Increasing the duration of treatmentand/or the Cd-concentrations led to transition of leaf chlorosis into yellowing and necrosisof leaf tips.The symptoms of phytotoxicity were expressed more clearly in rootsbecause of the significantly higher heavy metal accumulation in them (Foy et al, 2005).The above pointed symptoms are not specific for Cd-treatment only, they have beenobserved in response to other heavy metals, too. The negative effect of Cd on plant growth was accompanied by an increase indry to fresh mass (DM/FM) ratio in all organs (Moya et al, 1993).

Conclusions

Although our knowledge of Cd toxicity in higherplants as well as in the soil- plant system has increased considerablyin the recent years, there are still many gaps in our knowledgeabout the basic mechanisms that control Cd movement and itsaccumulation in plants.Certainly more research is neededregarding the mechanism of Cd uptake by the root, translocation,and its deposition within plants.Additionally, the major forms of Cdin various staple plant foods (e.g. rice, wheat, corn, bean, andpotato) need to be identified. We must elaborate the knowledgeabout the biochemistry of metal homeostasis factors, physicalinteraction of transporters, chelators and chaperones.Geneticapproach as opposed to physiological/ biochemical investigationsmay assist in understanding the mechanism of metal tolerance.An improved knowledgein these crucial areas will help to elucidate the molecularmechanisms that lie beyond plant metal tolerance and homeostasis.

References

1. Asada, K. 1997. Production and scavenging of active oxygen in photosynthesis. J. Export. Bot., 227-297.
2. Bagchi, A. 1995. Plants thathyperaccumulate heavy metals. J. Plant Physiol., 31(2): 53-62.
3. Beak, KH., Chang, J., Chang Y., and Kim, J. 2006. Phytoremediation of soil contaminated with cadmium. J. Environ. Biol., 27: 311-316.
4. Benavides, MP., Susana, M., and Tomaro, M. 2005. Cadmium toxicity in plants. Braz. J. Plant Physiol., 17(1): 21-34.
5. Das, P., Samantaray, S., and Rout, GR. 2001. Studies on cadmium toxicity in plants. Environ. Pollution. J., 98: 26-36.
6. Dong, J., Mao, WH., Zhang, GP., and Cai, Y. 2007. Root excretion and plant tolerance to cadmium toxicity. Plant and Environ. J., 53(5): 193-200.
7. Fornazier, RF., Ferreira, RR., and Lea, PJ. 2000. Effects of cadmium on antioxidant enzyme activities in Sugar cane. Biol Plant. J., 45: 91-97.
8. Foy, CD., Chaney, RL., and White, M. 2005. The physiology of metal toxicity in plants. Ann. Rev. Plant Physiol. J., 29: 511-566.

9. Hall,JL. 2002. Cellular mechanisms for heavy metal detoxification and tolerance. J. Exp. Bot., 53: 1-11.
10. Halliwell, B., and Gutteridge, JM. 2000. Free radicals in biology and medicine. 3rd ed. Oxford University Press, New York.
11. Hernandez, LE.,Carpena, R., and Garate, A. 1996. Alterations in the mineral nutrition of Pea seedlings exposed to cadmium. J. Plant. Nutr., 19: 1581- 1598.
12. Hasan, SA.,Fariduddin, Q., Ali, B., Hayat, S., and Ahmad, A. 2009.Cadmium: Toxicity and tolerance in plants. J. Environ. Biol., 30(2): 165-174.
13. Moya, J., Ros, R., and Picazo, I. 1993. Influence of cadmium and nickel on growth, net photosynthesis and carbohydrate distribution in Rice plants. J. Photo. Res., 36: 75-80.
14. Pinto, AP., Mota, AM., and Pinto, FC. 2004. Influence of organic matter on the uptake of cadmium, zinc, copper and iron by Sorghum plants. Sci. Environ. J., 326: 239-247.
15. Saline, ML. 2003. Toxic oxygen species and protective systems of the chloroplast. Physiol. Plant. J., 72: 681-689.
16. Sandalio, LM.,Dalurzo, HC., and Gomez, M. 2001. Cadmium induced changes in the growth and oxidative metabolism of Pea plants. J. Exp. Bot., 52: 2115-2126.
17. Shah, K., and Dubey, S. 1995. Effect of cadmium on RNA level as well as activity and forms of Ribonuclease in growing Rice seedlings. Plant Physiol. J., 33: 577- 584.
18. Tyler, G., Pahlsson, AM., and Baath, E. 2003. Heavy metal ecology and terrestrial plants, microorganisms and invertebrates.Water, Air Soil Pollut. J., 47: 189-215.
19. VanAssche, F. 1990. Effects of metals on enzyme activity in plants. Plant Cell Environ. J., 13: 195-206.
20. Vassilev, A., and Yordanov, I. 1997. Reductive analysis of factors limiting growth of cadmium treated plants. Bulg. J. Plant Physiol., 23(3-4): 114-133.
21. Wanger, GJ. 1993. Accumulation of cadmium in crop plants and its consequences to human health. Adv. Agron. J., 51: 173-212.
22. Weast, RC. 1984. Handbook of chemistry and physics. 64thEdn. CRC Press, Baca Raton.