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Research Article

Toxicity and Plant Stress Management of Cadmium uptake by Plant

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ABSTRACT
Cadmium (Cd) is a toxic heavy metal that enters the environment through various anthropogenic sources, and inhibits plant growth and development. Cadmium toxicity may result from disturbance in plant metabolism as a consequence of disturbance in the uptake and translocation of mineral nutrients. Although plants do not require Cd for growth or reproduction, the bioaccumulation index of Cd in green plants exceeds that of all other trace elements. Heavy metal contamination is a serious environmental problem that can have detrimental impacts on human health. The amount of Cd accumulated and translocated in plants varies with species and with cultivars within species. Soil, environmental and management factors impact on the amount of Cd accumulated in plants.

Key words: Cadmium, Soil, genetics, uptake, heavy metal

INTRODUCTION
Cadmium is a heavy metal naturally present in soils. It may also be added to the soil as a contaminant in fertilizer, manure, sewage sludge and from aerial deposition. The amount of cadmium contributed from each source varies with location due to differences in soil formation, management practices and exposure to pollution sources, but the level of Cd in the soil appears to be increasing over time (1,2).

Although plants do not require Cd for growth or reproduction, the bioaccumulation index of Cd in green plants exceeds that of all other trace elements (3). Plants can accumulate relatively high levels of cadmium, without adverse effects on growth (4,5). Cadmium is retained for many years in the human body, so consumption of foods high in Cd may induce chronic toxicity (6,7). The World Health Organization set a maximum provisional tolerable intake limit for an adult at 60 to 70 µg Cd per day (8) and the Codex Alimentarius Commission of FAO/WHO is discussing a limit of 0.1 mg kg–1 for cereal grains and oilseeds traded on international markets. Australia has adopted maximum permissible concentrations for Cd in various foods, including 0.05 mg Cd kg–1 fresh weight for potatoes (9). Cd limits have also been adopted by other countries (Walker 1988).

Vast areas of crop land can be considered to be uncontaminated or only slightly contaminated with Cd from phosphate fertilizer, manure and aerial deposition. Under such conditions, some crops such as durum wheat, flax, sunflowers and potatoes can accumulate amounts of Cd which exceed current and proposed maximum acceptable Cd concentrations.

Cadmium concentration in sunflower kernels of nine major commercial non-oilseed hybrids grown at uncontaminated sites in North Dakota and Minnesota varied from 0.79 to 1.17 mg kg–1 (means across four locations) (11). The occurrence of potatoes containing greater than 0.05 mg Cd kg–1 fresh weight was associated with the use of saline irrigation water in areas of South Australia and not with Cd contamination (9).

MECHANISM OF PLANT CADMIUM UPTAKE AND DISTRIBUTION

Heavy metal contamination is a serious environmental problem that can have detrimental impacts on human health. The primary sources which contribute to the present level of metal pollution include burning of fossil fuels, mining and smelting of metalliferous ores, pesticides, downwash from power lines, fertilisers, sewage and the inappropriate disposal of residual waste (Migeon et al., 2010).

Iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), nickel (Ni), and cobalt (Co) are heavy metals known to be essential micronutrients for plant metabolism, but they can be highly toxic when present in excess (Williams et al., 2000). Non-essential heavy metals such as lead (Pb), cadmium (Cd) and mercury (Hg) are extremely toxic even if taken in at low concentrations due to their reactivity with S and N atoms in amino acid chains, and they have no biological functions (15-16).

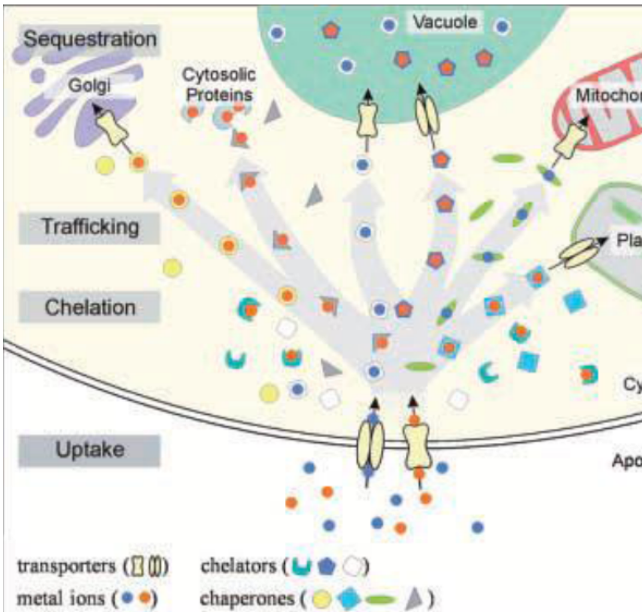

Figure 1.1: Simplified hypothetical scheme of the cellular plant metal homeostasis network (15).

The first step involved in plant metal homeostasis is the uptake of metals through metal transporters on the plasma membrane. A balance between both uptake and efflux is necessary to effectively regulate internal metal concentrations (17).

The uptake of metal ions is a passive process in most cases, through specific transporters. This process is passive mainly because of the membrane potential, which is negative on the inside of the plasma membrane and therefore creates a very powerful driving force for the influx of cations through channel proteins and carrier proteins (18).

Cadmium accumulation also varies among cultivars within a species (19-21). Accumulation of high levels of Cd in the root, as discussed under "Mechanism of Plant Uptake and Distribution", may limit the accumulation of Cd in edible aboveground portions of the plant. The root regulates Cd transfer to the shoot in tobacco lines (22).

Introduction of mouse metallothionein into several tobacco lines led to seedlings that contained leaf levels of Cd about 14% lower than in the controls, because the Cd was retained in the roots. Sequesteration of Cd in roots as Cd-metallothionein appears to have limited potential for reducing Cd content of above-root tissues in certain plants. Lack of absolute metal specificity of chelators such as metallothionein may impair their use for partitioning Cd into nonconsumed plant tissue, since the balance of other essential cations may be disrupted (22).

As we are focused of genetic selection, Low Cd concentration is also being used as a criterion in breeding of oilseed flax (Kenaschuk and Dribnenki, Pers. Commun., AAFC, Morden, MB, Canada). Biotechnological techniques for gene transfer across species may also play a role in development of low Cd food crops (22,23).

Effects of toxicity per cadmium on plants

Chlorosis may appear by exchanging Cd with Fe or Mg, in the latter case affecting the stability and biosynthesis of chlorophylls. Damages also associated with chlorosis are P deficiency and reduction in the transport of Mn (24)

The reduction in photosynthetic growth and activity, nutritional imbalance, oxidative stress and effects on enzymatic activities are the most pronounced damages that are in the different studies of toxicity with Cd frequently expressed. The Cd also causes inhibition in the activities of the metalloenzymes, due to the substitution of it with metals with similar load or size such as Zn and Mg, the latter present in the enzyme Rubisco and its exchange with the Cd results in dissociation of the enzyme in subunits (25)

Stress tolerance mechanisms for Cd

he specific adaptations of plants to Cd stress are two main strategies based on; some prevent or regulate the entry and transport of the same and others tolerate certain contents of Cd, through its detoxification, by chelation in intracellular organelles(26,27). Other tolerance mechanisms are, the increase of the antioxidant defense system, cell homeostasis(28), the increase in endogenous production of plant growth regulators and the modification of metabolism in function of repairing the damaged cell structure(29,30).

Subsequent research in other crops and other elements continued to promote adequate nutrition as a way to mitigate Cd stress. Among the different nutrients P, K, S, Fe and Zn showed significant favorable effects. The application of P in wheat plants increased the biomass of the shoots, the leaf area, and the content of photosynthetic pigments and, in turn, favoured the assimilation of other nutrients, such as K, Ca, Mg and Mn. It also increased the activity of antioxidant enzymes and decreased the content of Cd and H_2O_2 in the outbreaks (26,30)

The activity of antioxidant system maintains the redox status of plant cell, removes reactive oxygen species (ROS), mitigates Cd-induced stress at different level of their targeting sites and maintains functionality of photosynthetic system, resulting in increased plant dry mass, growth and yield. The potential of some of the important plant macro, micro and beneficial elements in alleviating Cd toxicity in plants

Primary nutrient elements (N, P, K) are integral part of our agricultural system for optimizing crop productivity and also for sustainable agriculture. Nitrogen supplementation to Cd-stressed plant leads to an enhanced Cd tolerance in plants by increasing the photosynthetic capacity of plants. Pankovic et al. [32]

Conclusion

Cd toxicity reduces growth, photosynthetic activity, and chlorophyll content and causes chlorosis mainly in young leaves. In addition, it interferes with the entry and transport of nutrients and causes oxidative stress and effects on enzymatic activities.

Nutrient management is one of the most efficient strategies to reduce the effects of Cd on plants. The studies carried out on this topic only evaluate the effects of certain independent nutrients and the simultaneous effects of the combination of several of them are not evaluated.

Mineral nutrition of crops is an essential component of our agricultural system. However, higher levels of Cd in soil alter the uptake and translocation of mineral nutrients elements, resulting in nutrient deficiencies, oxidative stress, and reduction in plant growth and development of agricultural crops.

REFERENCES

1. Jones, K. C. and Johnston, A. E. 1989. Cadmium in cereal grain and herbage from long-term experimental plots at Rothamsted, UK. Environ. Pollut. 57: 199–216.

2. Jones, K. C., Jackson, A. and Johnston, A. E. 1992. Evidence for an increase in the Cd content of herbage since 1860’s. Environ. Sci. Technol. 26: 834–836.
3. Kabata-Pendias, A. and Pendias, H. 1992. Trace elements in soils and plants. Chpt. 5. CRC Press, Boca Raton, FL.
4. Bingham, F. T., Page, A. L., Mahler, R. J. and Ganje, T. J. 1975. Growth and cadmium accumulation of plants grown on a soil treated with cadmium-enriched sewage sludge. J. Environ. Qual. 4: 207–211.
5. Bingham, F. T. 1979. Bioavailability of Cd to food crops in relation to heavy metal content of sludge-amended soils. Environ. Health Perspect. 28: 39–43.
6. Jackson, A. P. and Alloway, B. J. 1992. The transfer of cadmium from agricultural soils to the human food chain. Pages 109–158 in D. C. Adriano, ed. Biogeochemistry of trace metals. Lewis Publishers, Boca Raton, FL.
7. FAO/WHO. 1995. Joint Committee on Food Additives and Contaminants. Position paper on cadmium (prepared by France).
8. 27th Session. The Hague, The Netherlands. 20–24 March 1995. 32 pp.
9. World Health Organization. 1972. Evaluation of certain food additives and of the contaminants mercury, lead and cadmium. FAO Nutrition Meetings Report Series No. 51. WHO Technical Report Series 505. Food and Agriculture Organization of the United Nations. Rome. 33 p.
10. McLaughlin, M. J., Palmer, L. T., Tiller, K. G., Beech, T. A. and Smart, M. K. 1994. Increased soil salinity causes elevated cadmium concentrations in field-grown potato tubers. J. Environ. Qual. 23: 1013–1018.
11. McLaughlin, M. J., Walker, J. M. 1988. Regulation by other countries of cadmium in foods and the human environment. Pages 176–185 in J. Simpson and B. Curnow, eds. Cadmium accumulations in Australian agriculture: National symposium. Australian Government Publishing Service, Canberra, Australia.
12. Li, Y-M., Chaney, R. L., Schneiter, A. A. and Miller, J. F. 1995b. Genotypic variation in kernel cadmium concentration in sunflower germplasm under varying soil conditions. Crop Sci. 35: 137–141.
13. McLaughlin, M. J., Maier, N. A., Freeman, K., Tiller, K. G., Williams, C. M. J. and Smart, M. K. 1995. Effect of potassic and phosphatic fertilizer type, fertiizer Cd concentration and zinc rate on cadmium uptake by potatoes. Fertilizer Res. 40: 63–70.
14. Migeon A, Blaudez D, Wilkins O, Montanini B, Campbell M, Richaud P, Thomine S, Chalot M (2010) Genome-wide analysis of plant metal transporters, with an emphasis on poplar. Cellular and Molecular Life Sciences 67: 3763-3784
15. Williams LE, Pittman JK, Hall JL (2000) Emerging mechanisms for heavy metal transport in plants. Biochimica et Biophysica Acta (BBA) - Biomembranes 1465: 104-126
16. Clemens S (2001) Molecular mechanisms of plant metal tolerance and homeostasis. Planta 212: 475-486
17. Schneider T, Schellenberg M, Meyer S, Keller F, Gehrig P, Riedel K, Lee Y, Eberl L, Martinoia E (2009) Quantitative detection of changes in the leaf-mesophyll tonoplast proteome in dependency of a cadmium exposure of barley (Hordeum vulgare L.) plants. Proteomics 9: 2668-2677
18. Colangelo EP, Guerinot ML (2006) Put the metal to the petal: metal uptake and transport throughout plants. Current Opinion in Plant Biology 9: 322-330
19. Clemens S, Palmgren MG, Krämer U (2002) A long way ahead: understanding and engineering plant metal accumulation. Trends in Plant Science 7: 309-315
20. Pettersson, O. 1977. Differences in cadmium uptake between plant species and cultivars. Swed. J. Agric. Res. 7: 21–24.

21. Chang, A. C., Page, A. L., Foster, K. W. and Jones, T. E. 1982. A comparison of cadmium and zinc accumulation by four cultivars of barley grown in sludge-amended soils. J. Environ. Qual. 11:
22. 409–412.
23. Oliver, D. P., Gartrell, J. W., Tiller, K. G., Correll, R., Cozens, G. D. and Youngberg, B. L. 1995. Differential responses of Australian wheat cultivars to cadmium concentration in wheat
24. grain. Aust. J. Agric. Res. 46: 873–886.
25. Wagner, G. J. 1993. Accumulation of cadmium in crop plants and its consequences to human health. Adv. Agron. 51: 173–212.
26. Penner, G. A., Clarke, J., Bezte, L. J. and Leisle, D. 1995. Identification of RAPD markers linked to a gene governing cadmium uptake in durum wheat. Genome 38: 543–547.
27. Godbold DL, Hüttermann A. Effect of zinc, cadmium and mercury on root elongation of Picea abies (Karst.) seedlings, and the significance of these metals to forest die-back. Environmental Pollution Series A, Ecological and Biological. 1985;38(4):375-81.
28. Mysliwa-Kurdziel B, Prasad MNV, Strzaltka K. Photosynthesis in Heavy Metal Stressed Plants. In: Prasad MNV, editor. Heavy Metal Stress in Plants: From Biomolecules to Ecosystems [Internet]. Berlin, Heidelberg: Springer; 2004 [cited 2019 Nov 18]. p. 146-81. doi:10.1007/978-3-662-07743-6_6
29. Arshad M, Ali S, Noman A, Ali Q, Rizwan M, Farid M, et al. Phosphorus amendment decreased cadmium (Cd) uptake and ameliorates chlorophyll contents, gas exchange attributes, antioxidants, and mineral nutrients in wheat Triticum aestivum L. under Cd stress. Archives of Agronomy and Soil Science. 2016;62(4):533-46.
30. Clemens S, Palmgren MG, Krämer U. A long way ahead: understanding and engineering plant metal accumulation. Trends in plant science. 2002;7(7):309-15.
31. Clemens S. Toxic metal accumulation, responses to exposure and mechanisms of tolerance in plants. Biochimie. 2006;88(11):1707-19.
32. Florijn PJ, Van Beusichem ML. Uptake and distribution of cadmium in maize inbred lines. Plant and soil. 1993;150(1):25-32.
33. Shaw J. Heavy Metal Tolerance in Plants: Evolutionary Aspects. CRC Press; 1988. 372 p.
34. Wang X, Song Y, Ma Y, Zhuo R, Jin L. Screening of Cd tolerant genotypes and isolation of metallothionein genes in alfalfa Medicago sativa L.). Environmental pollution. 2011;159(12):3627-33.
35. D. Pankovic, M. Plesnicar, I. Arsenijeevic-Maksimovic, N. Petrovic, Z. Sakac and R. Kastori, "Effects of Nitrogen Nutrition on Photosynthesis in Cd-Treated Sunflower Plants" Annals of Botany, Vol. 86, No. 4, 2000, pp. 841- 847. doi:10.1006/anbo.2000.1250 [Citation Time(s):1]