



Editorial

AN ASSESSMENT TO SHOW TOXIC NATURE OF BENEFICIAL TRACE METALS: TOO MUCH OF GOOD THING CAN BE BAD

Anita Singh¹, Parul Parihar², Rachna Singh³, Sheo Mohan Prasad^{4*}

Department of Botany, University of Allahabad, Allahabad, U.P., India

ARTICLE INFO

Article History:

Received 15th, December, 2015

Received in revised form

28th, December, 2015

Accepted 16th, January, 2016

Published online

28th, January, 2016

Keywords:

Trace metal; Beneficial; Toxic; Plant; Antioxidants

ABSTRACT

Some metals are required in very small amount known as trace elements such as copper (Cu), manganese (Mn), molybdenum (Mo), cobalt (Co), nickel (Ni) and zinc (Zn). Although up to their threshold value they act as beneficial element but same elements become toxic at their higher concentration. These elements at their higher concentration disturb the metabolic functioning of plant, animal as well as human beings. The present report is also based upon brief overview on both beneficial as well as toxic impacts of several elements particularly on plant system.

Copyright © 2016 Sheo Mohan Prasad et al., This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

INTRODUCTION

Requirement of trace metals viz., iron (Fe), copper (Cu), manganese (Mn), molybdenum (Mo), cobalt (Co), nickel (Ni) and zinc (Zn) is essential for maintaining optimal growth, development and productivity. However, concentrations higher than that required by the plants could pose toxicity in plants. Toxic consequences of trace metals include replacement of essential functional groups, cellular damage, enhanced production of reactive oxygen species leading to oxidative stress and dis-functioning of metabolic processes, modulation in activity of enzymes and metabolites involved in detoxification process (Anjum et al., 2014). Considering the above facts regarding the beneficial and toxic role of trace metals due to change in concentration, the following information has tried to remove the paucity on earlier available literature for “plant-metal interaction” at their different levels. These trace metal act as two sides of same coin and that can be explained by following reports:

Role of beneficial trace metals in plant system

Cobalt

Cobalt (Co), a transition element found in trace amount in plants and its concentration in plants has been reported to be as low as 0.1-10 $\mu\text{g g}^{-1}$ dry weight (d.w.) (Jaleel et al., 2009) and the critical level has been found to be 30-40 $\mu\text{g g}^{-1}$ dry weight that may vary with plant species.

Co has significant role in plant growth and development, as it is essential component of several enzymes as well as co-enzymes and is key component of vitamin B₁₂ (cobalamin), which is essential for all organisms. Jaleel et al. (2009) have reported Co enhances plant growth and development at lower concentration. On the other hand at certain concentration it exerts toxic effect on plant system. Tiwari et al. (2002) reported that Co above 50 μM decreases growth and dry matter.

Decreased growth at higher concentration of Co is attributed to inhibition in PSII activity and hence light reaction, which is due to inhibition at reaction center or either by modifying secondary quinone-binding site (Sheekh et al., 2003). Co has also been reported to displace either metal from several proteins including iron-sulphur or Rubisco (Bracher et al., 2015). Elevated Co also modulates oxidative stress and ROS- metabolizing system (Tewari et al., 2002). Co compounds have also been reported to inhibit karyokinesis and cytokinesis as well as significant increase in DNA damage has been reported in *Allium cepa* roots (Yildiz et al., 2009). Co ions alter conformation of biomolecules (protein or nucleic acid) and metabolic reactions, by binding with the hydroxyl, carboxyl and sulphhydryl groups that are the reactive groups (Cavusoglu and Yalcin, 2010).

Copper

Copper is a natural element found in variable concentration in soil. Soil exhibit Cu in range of 2-100 mgKg^{-1} (Ruyters et al., 2012) or 1-40 mgKg^{-1} and Cu at 9.0 mgKg^{-1} have been considered to be beneficial for plant growth and development. Cu is an important cofactor of protein components of many enzymes in photosynthetic electron transport as well as cofactor of Cu/Zn-SOD enzymes (Cohu and Pilon, 2007). Cu range between 2.0-20 mgKg^{-1} d.w. (Mengel et al., 2001) or 5.0-30

*✉ **Corresponding author: Sheo Mohan Prasad**
Department of Botany, University of Allahabad,
Allahabad, U.P., India

mgKg⁻¹ d.w. is adequately required by plants whereas, critical concentration causing toxicity in plants is 20-1000 mgKg⁻¹ (Jones, 1991). Cu at higher concentration alters the chloroplast development leading to loss in photosynthetic activity (Thounaojan et al., 2014). Elevated Cu damage membrane by enhancing lipid peroxidation and thus increased leakage of electrolyte (Hong et al., 2012). Yu et al., (2008) reported that elevated level of Cu enhances ROS production thereby exerting damage to biomolecules.

Iron

Iron (Fe) is an abundant metal ranging from 20,000-5,50,000 mgKg⁻¹ in soil and Fe contents in plant tissue is about 2.0µMg⁻¹ plant d.w. (Marschner, 1995). It is an essential element required in photosynthetic, respiratory, nitrogen fixation system as well as also required by for synthesis and hormone production (Moller et al., 2007). It is an important constituent of ferredoxin and cytochromes as well as of several antioxidative enzymes.

Toxic consequences of Fe could be due to its deficiency and also because of higher concentrations. Fe concentrations above than 200 µM has been reported to decrease the growth in *Chlorella vulgaris* (Estevez et al., 2001). Elevated Fe level leads to decreased growth by altering photosynthesis and chlorophyll concentration (Chatterjee et al., 2006). Higher Fe concentration enhances ROS production via Fenton reaction (Schutzendubel and Polle, 2002). Enhanced ROS production and their accumulation directly damage the lipids, proteins and nucleic acid that in turn may lead to programmed cell death (Connolly and Guerenot, 2002).

Manganese

Manganese (Mn) is a ubiquitous element that ranges 450-4,000 mgKg⁻¹ in soil (Adriano 2003). Mn is an important component of photosynthetic protein like oxygen evolving complex and enzymes and thus influences biosynthesis of growth substances. Mn is also involved in modulating carbohydrate and lipid metabolism, nucleic acid biosynthesis (Marschner and Rengel, 2007). Elevated Mn level leads to loss of chlorophyll, leaf cupping, distortion and disintegration in chloroplast (Kitao et al., 2001). In addition excess Mn affects photosynthesis, CO₂ assimilation and stomatal conductance and it also stimulated generation of ROS (Makasimovic et al., 2012). Elevated Mn level has also been reported to alter chromosome and mitosis as well as frequency of chromosomal aberration (Fiskesjo, 1998).

Molybdenum

Molybdenum (Mo) is a rare transition element, whose concentration ranges from 0.2-6.0 mgKg⁻¹ in soil, whereas its concentration ranges from 10-100 mgMoKg⁻¹ in metal-rich soil. Mo is important cofactor (molybdopterin) of more than 50 proteins and enzymes (Mendel, 2013). Mo required by the plants ranges from 0.1-1.0ppm (Mcgrath et al., 2010). Elevated Mo level has been reported to interfere with metabolic processes and thus causing physiological damage (Rout and Das, 2002).

Nickel

Nickel (Ni) is a naturally occurring element, and its concentration ranges from 3.0-1,000 mgKg⁻¹ in agricultural soil (Brown, 2006) and in plants it ranges from 0.01-5.0 mgKg⁻¹ d.w. (Lopez and Maganitskiy, 2011). It is an important constituent of several metalloenzymes like urease, methyl coenzyme M reductase, hydrogenase etc. Ni at elevated level inhibits germination, increases Fe deficiency, distorts plants parts and also decrease crop yield (Negi et al., 2014). In addition, excess Ni also interferes with physiological and metabolic processes (Negi et al., 2014) and also decreases photosynthetic pigments, inhibits chlorophyll biosynthesis (Seregin and Kozhevnikova, 2006) and inhibits enzyme activity involved in Calvin cycle (Dan et al., 2002). The excessive toxicity of Ni other than trace element is due to its involvement in direct production of •OH (Kehrer, 2000). Elevated Ni level inhibits root meristem mitotic activity, induces chromosomal aberration (Fargasova, 2012).

Zinc

Zinc (Zn) is a transition metal, whose concentration ranges in agricultural soil from 10-300 mg Kg⁻¹ Zn (Barber 1995). Zn plays important role in protein synthesis gene expression and it is also a cofactor of various enzymes (such as SOD and Carbonic anhydrases) proteins (Alloway, 2009). Zn is required by the plants in the ranges of 30-100 mgKg⁻¹d.w. and concentration > 300mgKg⁻¹ Zn is considered phytotoxic (Marschner, 1995). Excess Zn alters leaf morphology and anatomy, increases water potential, impairs PSII activity and thus decreases photosynthesis, impairs nutrient uptake, disrupts electron chain in chloroplast (Sensi et al., 2003).

Crosstalk between interactions of trace metals

Although these trace metal has their own significance depending upon their concentration but some of them also interact with each other either synergistically or antagonistically to induce or modulate the toxic effect of these trace metals. It was reported that level of Fe and Zn can be increased in presence of higher concentration of Mn (Zhao et al., 2012), whereas excess concentration of Zn led to the hindrance in the transport of Mn and Cu from root to shoot. At higher concentration of Co, deficiency of Fe is reported in plant parts (Chatterji and Chatterji, 2003). They have also reported that application of Fe in presence of excess concentration of Co may lead to reduction in toxicity of Co by maintaining physiological activities of plant. It was also found that that Fe interacts antagonistically with Ni, Cu and Zn (Pandey and Sharma, 2002). Excess concentration of Ni has also resulted modulation of antioxidative enzyme containing Fe as cofactor such as Fe SOD and CAT (Pandey and Sharma, 2002).

Therefore, it can be manifested by these research reports that only required amount of trace metal metals improve the physiological characteristics of plants whereas beyond the certain limit they act as toxic substance. Thus, it is well needed to exaggerate the research programmes for better understanding of whole mechanism behind the synergistic and antagonistic action of trace metal on plants as well as on allied areas to maintain the ecological harmony of the globe.

References

1. Alloway, B.J. (2009). Zinc in soils and crop nutrition. 2nd ed. International Zinc Association, Brussels Belgium, and International Fertilizer Industry Association, Paris, France.
2. Anjum, N.A., Duarte, A.C., Pereira, E., Ahmad, I. (2014). Plant-beneficial elements status assessment in soil-plant system in the vicinity of a chemical industry complex: shedding light on forage grass safety issues. *Environ Sci. Pollut. Res.* doi:10.1007/s11356-014-3478-3.
3. Barber, S.A. (1995) Soil nutrient bioavailability, 2nd edn. Wiley, New York.
4. Bracher, A., Hauser, T., Liu, C., Ulrich, H. F., Hart, M.H. (2015). Structural Analysis of the Rubisco-Assembly Chaperone RbcX-II from *Chlamydomonas reinhardtii*. *PLoS One.* 10(8), e0135448.
5. Cavusoglu, K., Yalcin, E. (2010). Detection of lipid peroxidation and cytotoxicity induced by aluminium (Al) and cobalt (Co) ions in barbunia root tip cells. *J. Environ. Biol.* 31, 661–666.
6. Chatterjee, C., Gopal, R., Dube, B.K., (2006). Impact of iron stress on biomass, yield, metabolism and quality of potato (*Solanum tuberosum L.*). *Sci. Hortic.* 108, 1–6.
7. Chatterjee, J., Chatterjee, C. (2003). Management of hytotoxicity of cobalt in tomato by chemical measures. *Plant Sci.* 164,795-801.
8. Cohu, C. M., Pilon, M. (2007). Regulation of superoxide dismutase expression by copper availability. *Physiol. Plant.* 129, 747–755.
9. Connolly, E.L., Guerinot, M.L. (2002). Iron stress in plants. *Genome Biol.* 3, 10241–10245.
10. Estevez, MS., Malanga C., Puntarulo S (2001). Iron-dependent oxidative stress in *Chlorella vulgaris*. *Plant Sci.* 161, 9-17.
11. Fargašová, A. (2012). Plants as models for chromium and nickel risk assessment. *Ecotoxicology* 21, 1476–1483.
12. Fiskesjö, G. (1988). The Allium test - an alternative in environmental studies: the relative toxicity of metal ions. *Mutat. Res.* 197,243–260.
13. Hong, R., KangT.Y., Michels, C.A., Gaduraa, N. (2012). Membrane Lipid Peroxidation in Copper Alloy-Mediated Contact Killing of *Escherichia coli*. *Appl. Environ. Microbiol.* 78 (6), 1776 –1784.
14. Jaleel, C.A., Jayakumar, K., Zhao, C.X., Iqbal, M. (2009). Low concentration of cobalt increases growth, biochemical constituents, mineral status and yield in *Zea Mays*. *J. Sci. Res.* 1,128–137.
15. Jones, J.B. (1991). Bacterial spot. In: Jones JB, Jones JP et al (eds) *Compendium of tomato diseases*. Ame. Phytopathol.Soc. St. Paul, 27.
16. Kehrer, J.P. (2000). The Haber-Weiss reaction and mechanisms of toxicity. *Toxicol.* 149, 43–50.
17. Kitao, M., Lei, T.T., Nakamura, T., Koike, T. (2001). Manganese toxicity as indicated by visible foliar symptoms of Japanese white birch (*Betula platyphylla* var. japonica). *Environ. Pollut.* 111, 89–94.
18. López, M.A., Magnitskiy, S. (2011). Nickel: the last of the essential micronutrients. *Agron Colomb* 29,49–56.
19. Maksimovi, J.M., Mojovi, M., Maksimovi, V., Römheld, V., Nikolic, M. (2012). Silicon ameliorates manganese toxicity in cucumber by decreasing hydroxyl radical accumulation in the leaf apoplast. *J. Exp. Bot.* 63, 2411–2420.
20. Marschner, H. (1995). Mineral nutrition in higher plants, 2nd edn. Academic, London.
21. Marschner, P., Rengel, Z. (2007). Nutrient cycling in terrestrial ecosystems. Springer, Heidelberg, p 121.
22. McGrath, S.P., Micó, C., Curdy, R., Zhao, F.J. (2010). Predicting molybdenum toxicity to higher plants: influence of soil properties. *Environ Pollut* 158, 3095–3102.
23. Mendel, R.R. (2013). The molybdenum cofactor. *J. Biol. Chem.* 288, 13165–13172.
24. Mengel, K., Kirkby, E.A, Kosegarten, H., Appel, T. (2001). Principles of plant nutrition. Kluwer, Dordrecht.
25. Møller, I.M., Jensen, P.E., Hansson, A. (2007). Oxidative modifications to cellular components in plants. *Annu. Rev. Plant Biol.* 58,459–481.
26. Negi, A., Singh, H.P., Batish, D.R., Kohli, R.K. (2014). Ni²⁺-inhibited radicle growth in germinating wheat seeds involves alterations in sugar metabolism. *Acta Physiol. Plant.* 36,923–929.
27. Pandey, N., Sharma, C.P. (2002). Effect of heavy metals Co²⁺, Ni²⁺ and Cd²⁺ on growth and metabolism of cabbage. *Plant Sci.* 163,753–758.
28. Rout, G.R., Das, P. (2002). Rapid hydroponic screening for molybdenum tolerance in rice through morphological and biochemical analysis. *Rostl. Vyroba* 48,505-512.
29. Ruyters, S., Salaets, P., Oorts, K., Smolders, E. (2012). Copper toxicity in soils under established vineyards in Europe: A survey. *Sci. Total Environ.* 443C, 470-477.
30. Schützendubel, A., Polle, A. (2002). Plant responses to abiotic stress heavy metal induces oxidative stress and protection by mycorrhization. *J. Exp. Bot.* 53(372), 1351-1365.
31. Sensi, S.L., Ton-That, D., Sullivan, P.G., Jonas, E.A. et al. (2003). Modulation of mitochondrial function by endogenous Zn²⁺ pools. *Proc. Natl. Acad. Sci. U S A* 100, 6157–6162.
32. Seregin, I.V., Kozhevnikova, A.D. (2006). Physiological role of nickel and its toxic effects on higher plants. *Russ.J. Plant Physiol.* 53:257–277.

33. Sheekh, El.M.M., El-Naggar, A.H., Osman M.E.H., El-Mazaly E. (2003). Effect of cobalt on growth, pigments and the photosynthetic electron transport in *Monoraphidium minutum* and *Nitzschia perminuta*. Braz. J. Plant Physiol. 15(3), 159-166.
34. Tewari, R.K., Kumar, P., Sharma, P.N., Bisht, S.S. (2002). Modulation of oxidative stress responsive enzymes by excess cobalt. Plant Sci. 162, 381–388.
35. Thounaojam, T.C., Panda, P., Choudhury, S., Patra, H.K., Panda, S.K. (2014). Zinc ameliorates copper-induced oxidative stress in developing rice (*Oryza sativa* L.) seedlings. Protoplasma 251,61–69.
36. Yıldız, M., Ci erci, I.H., Konuk, M., Fidan, A.F., Terzi, H. (2009). Determination of genotoxic effects of copper sulphate and cobalt chloride in *Allium cepa* root cells by chromosome aberration and comet assays. Chemosphere 75,934–938.
37. Yu, Z.L., Zhang, J.G., Wang, X.C., Chen, J. (2008). Excessive copper induces the production of reactive oxygen species, which is mediated by phospholipase D, nicotinamide adenine dinucleotide phosphate oxidase and antioxidant systems. J. Integr. Plant Biol. 50(2),157-67.
38. Zhao, H., Wu, L., Chai, T. Zhang, Y., Tan, J., Ma, S. (2012). The effect of copper, manganese and zinc on plant growth and elemental accumulation in the manganese hyperaccumulation phytolacca American. J. plant physiol. 169,1243-1252.



36. Yıldız, M., Ci erci, I.H., Konuk, M., Fidan, A.F., Terzi, H. (2009). Determination of genotoxic effects of copper sulphate and cobalt chloride in *Allium cepa* root cells