REVIEW ARTICLE

INTERNATIONAL JOURNAL OF RESEARCH IN PHARMACEUTICAL SCIENCES

Published by JK Welfare & Pharmascope Foundation Journal Home Page: https://ijrps.com

Responses of plants against heavy metal-induced ROS: A Review

Dhriti Kapoor[1], Dolly Kumari Sharma[1] and Amaninder Kaur Riat*[2]

[1]Department of Botany, School of Bioengineering and Biosciences, Lovely Professional University, Phagwara, India
[2]Department of Zoology, School of Bioengineering and Biosciences, Lovely Professional University, Phagwara, India

Article History:

Received on: 20.04.2018
Revised on: 17.07.2018
Accepted on: 24.07.2018

Keywords:

Heavy metal,
Oxidative stress,
ROS,
Osmolytes,
Antioxidative defence system

ABSTRACT

Plants are vulnerable to many injurious, environmental situations like biotic and abiotic stress, ultimately affecting their growth and development. Biotic stress is caused by living organisms such as insects, nematodes, bacteria, fungi etc. On the other hand abiotic stress arise from high or low temperature, light, drought, salinity and heavy metals. Some heavy metals are important for the plant, i.e. Cu, Zn, Fe but these metals are present in the soil in very less quantity, so these are called an essential micronutrient. Toxicity of heavy metals cause a reduction in plant growth and ultimately leads to the death of the plant. Metal concentration increase in soil due to human activity or geological origin. All heavy metals are toxic, and they cause mutagenesis in the plant, animal and aquatic ecosystem also. In recent years, in agricultural practices, use of wastewater from cities has made the significant accumulation of heavy metal in soil and agricultural product. Metals are transported from water to soil that cause contamination in soil and inhibit plant growth. Heavy metal contaminations in soil and agriculture have raised potential risks to plant, human and animals. In Response to metal stress plant possesses various protective mechanisms like chelation, detoxification and so on. Plant posses many defensive strategies like antioxidative defence system, antioxidant and osmolytes that protect the plant from stress condition. This defensive system activates during stress condition. This review focus on the heavy metal effect on plant and its defensive system on the plant.

* Corresponding Author

Name: Dr. Amaninder Kaur Riat
Phone: +91-9780727368
Email: amaninderkaur89@gmail.com

ISSN: 0975-7538
DOI: https://doi.org/10.26452/ijrps.v9i4.1680

Production and Hosted by
IJRPS | https://ijrps.com

INTRODUCTION

Plants are affected by many injurious environmental situations like biotic and abiotic stress. Biotic stress such as pathogen or herbivores and abiotic stress such as drought, cold, temperature, salt stress, heavy metal stress, excess light (Lin and Kao, 2005). Heavy metal stress is most harmful abiotic stress. Heavy metal stress is related to a metallic compound that is toxic or has a high density at low concentration in soil (Monni *et al.,* 2000).

Heavy metal stress is the major abiotic stress nowadays, which affects the world widely. Heavy metals are more effective in causing environmental pollution. They cause many problems in the plant, animal and human being (Kjjaer and Elmegaard, 1996). Their increased concentration in soil cause toxicity in the plant (Munzuroglu and Geckil, 2002) and lead to a reduction in plant growth and ultimately death of plant (Nematshahi *et al.,* 2012). Some heavy metals are important for the plant, such as Cu, Zn, Fe but these metals are present in the soil in very less

Table 1: Source of contamination in the atmosphere

S.No	Heavy metal	Sources of contamination	References
1.	As	Fossil fuel combustion, smelting operation, use of pesticides and herbicides, volcanic eruption	Cook *et al.,* 1997
2.	Cr	Battery manufacturing, chrome plating, mining & smelting, dyes & wood, tanning of the animal skin, pigments.	Graeber *et al.,* 2012
3.	Ni	Biological cycle, industrial process, dissolution of rocks & soil, stainless steel utensils, diesel oil and fuel oil, atmospheric fall out.	Barrachina *et al.,* 1995
4.	Pb	Paint, food, beverages, industrial application, automobile, mining and smelting activities.	Arya and Roy, 2011
5.	Cd	Zinc refining by-product.	Bonnet *et al.,* 2000

quantity, so these are called as essential micronutrient (Okuma *et al.,* 2004). Metal concentration increase in soil due to human activity or geological origin (Raskin *et al.,* 1994).

Heavy metals are very toxic for plant growth, seedling and yield of the plant. They are not easily metabolised and neither they break down in the environment (Shenker *et al.,* 2004). The main source of heavy metal in the environment is anthropogenic activities, agricultural waste, industrial waste and natural activities that increase their concentration in soil and affect the plant life (Sheoran *et al.,* 1990). Agricultural wastes are the main source of soil contamination. Farmers use herbicides and fungicides on the plant that increase the concentration in soil. The exposure of plants to heavy metal, change its metabolic activities and leads to an alteration in physiological conditions (Sheldon and Menzies, 2005).

Heavy metal is essential for the plant in less concentration but their enhanced concentration adversely affects plant growth and its metabolic activities. Most of the heavy metals are toxic and cause mutagenesis in plant, animal and aquatic ecosystem also. They are harmful to all the living organisms as they cause very serious effects on all living organism (Yourtchi and Bayat, 2013). In recent years, in agricultural practices, the use of wastewater from cities has made the significant accumulation of heavy metal in soil and agricultural product (Panda and Patra, 2000). Metals are transported from water to soil that cause contamination in soil and inhibit plant growth (Santner *et al.,* 2009). Heavy metal contamination in soil and agriculture has raised potential risks to plant, human and animals (Nguyen, 2008). In Response to metal stress plant possesses various protective mechanisms like chelation, detoxification and so on (Singh and Prasad, 2014). High metal concentration in soil leads to a reduction of shoots and root growth in plants (Cook *et al.,* 1997). Excess Cu causes oxidative stress in plants that leads to disturbance in metabolic pathways (Doncheva *et al.,* 2001).

All heavy metal have their metallic properties such as conductivity, ligand specificity, cation stability. These properties decide the nature of heavy metal, which one is more effective and which one is least effective on the plant, animal or microorganism (Graeber *et al.,* 2012). Heavy metals like Co, Cu, Fe, Mn, Mo, Ni, V, and Zn are required in small quantities for the organism and plant their high concentration are very harmful to plant (Table.2). They bind to plant active site and block the activities of plant and other organisms (Hussain *et al.,* 2013).

Source of contamination: There are many sources in an environment that cause heavy metal stress such as natural, agricultural, domestic waste, industrial waste and other waste. Natural source of heavy metals: - weathering process is the main source of heavy metal in soil. Heavy metal originates from earth crust. The quantity and mixture depend upon environmental status &activation of weathering process. Volcanoes, wind dust, sedimentary rocks, igneous rocks increase heavy metal composition in soil by a natural process (Abedin *et al.,* 2002). Agricultural soil includes sewage sludge, pesticides, irrigation water and phosphate fertilizer that increase Zn, Pb, As, Hg, Mn, Cu composition. Fertilizers are important for the improvement of the yield and growth of the plant (Barrachina *et al.,* 1995). The industrial source includes coal burning, petroleum combustion, power station high tension lines, processing of plastic, textile paper processing etc. Other sources are a volcanic eruption, automobiles, diesel-powered vehicles (Hussain *et al.,* 2013) (Table 1).

The heavy metal toxic effect in plant cell:-Heavy metal can be divided into two categories: redox active (Fe, Cu, Co, Cr) and redox inactive (Zn, Cd,

Table 2: Harmful effect of heavy metal on different plant species

S.No	Heavy metal	Plants	Harmful effect on plant	References
1.	Lead (Pb)	Maize Oats Portia tree	Reduction of protein content, plant biomass, and germination rate. Alteration in enzyme activity and Co_2 fixation site of the plant. Decreased number of leaves, plant height and its biomass.	Barrachina *et al.,* 1995 Bonnet *et al.,* 2000 Jayakumar *et al.,* 2013
2.	Zinc (Zn)	Pea Cluster bean Ryegrass	Reduction in plant growth, chlorophyll content, effect on photosystem. Reduction in growth, sugar, starch & amino acid content. Reduced plant growth, nutrient value and photosynthetic energy.	Khalid and Tinsley, 2013 Kibra, 2008 Ahmad *et al.,* 2012
3.	Mercury (Hg)	Rice Tomato	Reduction in plant height and yield. Reduction in flowering and fruit weight & germination rate.	Kibra, 2008 Barsukova and Gamzikova, 1999
4.	Chromium(Cr)	Wheat Tomato Onion	Reductions in plant root and shoot growth. Reduction in plant nutrient content. Decreased plant biomass and germination.	Barracchina *et al.,* 2011 Dubey, 2011
5.	Copper(Cu)	Rhodes grass Black bindweed	Decreased in plant root growth. Decreased biomass, seed production and mortality of plant	Dubey, 2011 Barracchina *et al.,* 2011
6.	Nickel(Ni)	Pigeon pea Ryegrass Wheat Rice	Reduction in enzymatic activity & chlorophyll content. Disturbance in the Calvin cycle. The decrease in growth & yield. Reduction in nutrient content. Decreased plant nutrient and yield. Reduction in root and shoot growth.	Herawati, 2000 Jayakumar *et al.,* 2008 Jiang *et al.,* 2001 Kabir *et al.,* 2009
7.	Manganese (Mn)	Broad beam Pea Tomato	The decrease in growth & chlorosis. Reduction in growth, photosynthetic rate and chlorophyll content. Reduced plant growth and chlorophyll content.	Kabir *et al.,* 2009 Cunningham *et al.,* 1997 Doncheva *et al.,* 2005
8.	Cobalt(Co)	Mung bean Radish Tomato	The decrease in antioxidant activity, amino acid, sugar and protein content. Reduction in sugar, protein content & antioxidant level. Lower down the nutrient content.	Doncheva *et al.,* 2005 Jayakumar *et al.,* 2007 Wang *et al.,* 2007
9.	Arsenic(As)	Rice Canola Tomato	Decrease growth & leaf area Wilting and chlorosis, reduction in growth. Decreased fruit yield and weight of leaves.	Kabir *et al.,* 2009 Cunningham *et al.,* 1997 Doncheva *et al.,* 2005
10.	Cadmium(Cd)	Wheat Garlic Maize	Reduction in seed germination and soot length. Reduction in shoot length and growth. Decreased shoot and root growth.	Dubey, 2011 Jiang *et al.,* 2001 Kabir *et al.,* 2009

Table 3: Proline importance in the plant under stress condition

Osmolyte	Heavy metal	Plant	Work	References
Proline	Pb	Indian senna	Participate in stress resistance mechanism.	Shekar *et al.,* 2011
	Hg	Rice	Decreased water potential and participated in Hg2+ resistance.	Schaller and Diez, 1991
	Cr	Tulsi	Improve the antioxidant system by detoxifying metal stress.	Wintz *et al.,* 2002
	Cd	Tabacco	Decreased oxidative stress, preserve cell membrane.	Marques *et al.,* 2009
	Ni	Wheat	Osmoprotective role	Moustakas *et al.,* 1994
	As	Sunflower	Preserved by hydroxyl radical and decreased metal uptake.	Nieboer and Richardson, 1980

Ni). Redox-active heavy metals involve in a redox reaction and result in the formation of O^{2+}, H_2O_2, and OH production (Nieboer and Richardson, 1980).

Redox-inactive heavy metals result in oxidation stress through an indirect mechanism. Heavy metals strongly bind to oxygen, nitrogen; sulphur atoms and stops the activity of plant ultimately leads to death (Sharma *et al.,* 2011) (Fig. 3, Table 2).

Defensive Strategies in Plants Exposed to Heavy Metal Toxicity

Plants have some defence mechanisms against stress condition. Plants have integrated the system in cells that show defence against heavy metal stress. The first defence in the plant is a physical barrier and second, that is structural barriers (Dubey, 2011). Heavy metal toxicity causes redox imbalance in the plant system and it generates an antioxidative defence system in the plant (Nguyen, 2008).

Overproduction of ROS in the plant due to heavy metal accumulation in plants is combated by two types of defence system, i.e., enzymatic and non-enzymatic, that protect the plant from abiotic stress (Doncheva *et al.,* 2001). Enzymatic antioxidants are a peroxidase, superoxidase dismutase, catalase, glutathione-*s*-transferase (GST) and non-enzymatic antioxidant that are ascorbic acid, proline, and glutathione. These two antioxidant defence system professionally work in the plant system and protect the plant from oxidative stress (Abedin *et al.,* 2002). Heavy metal cause quantitative and qualitative change in membrane lipids this leads to the structural and functional status of membrane and inhibition of chloroplast electron transport than it leads to growth inhibition of plant (Barrachina *et al.,* 1995).

Cellular homeostasis:-*Anacystis nidulans* under Cu stress after Proline application it protect plasma membrane from Cu harmful effect (Kabir *et al.,* 2009). This defensive system protects the plant from the harmful effect of stress (Fig. 1).

Proline, an amino acid that plays a highly beneficial role in plants exposed to the various stress condition. In plant proline accumulation has been reported to occur after salt, drought, pathogen infection, low temperature, high temperature, U.V radiation, nutrient deficiency (Doncheva *et al.,* 2005). Proline metabolism in plants has mainly been to osmotic stress. Proline is the most widely distributed osmolyte it occurs in plant and many other organisms (Jayakumar *et al.,* 2007) (Fig.2, Table 3).

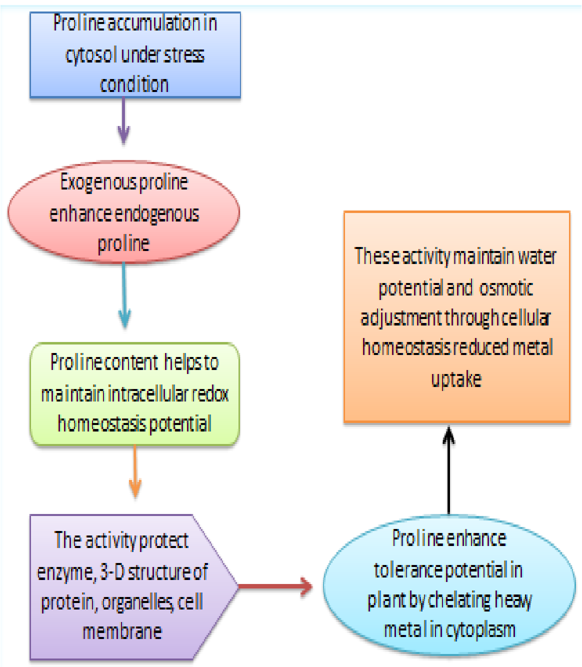

Figure 1: Cellular homeostasis (Modified after Ashraf *et al.,* 2007)

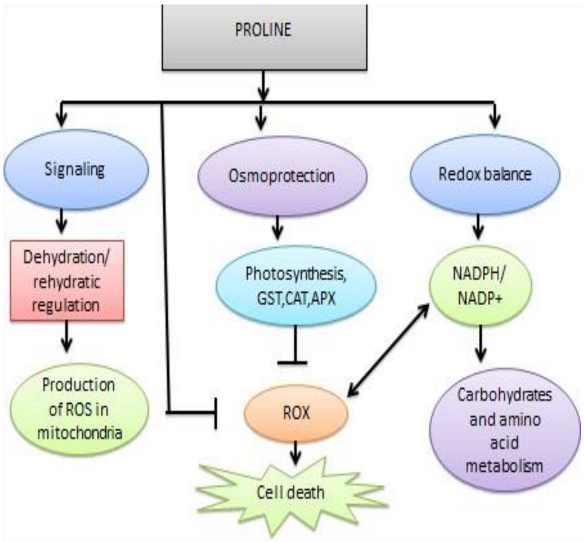

Figure 2: Role of Proline in the plant (modified after Singh *et al.,* 2015)

Conclusion: Heavy metal stress is the major abiotic stress now a day, which affects the world widely. Heavy metals are more effective in causing environmental pollution. It causes many problems in plant, animal and human being. Heavy metals are very toxic for plant growth, seedling and yield of the plant. Heavy metals are not metabolised easily and neither are they break down easily in the environment. Heavy metal contaminations in soil and agriculture have raised potential risks to plant, human and animals. All heavy metal have their metallic properties such as conductivity, ligand specificity, cation stability. These properties decide the nature of heavy metal which one is more effective and which one is least effective on the plant, animal or microorganism. Plant shows some defence mechanism against stress condition.

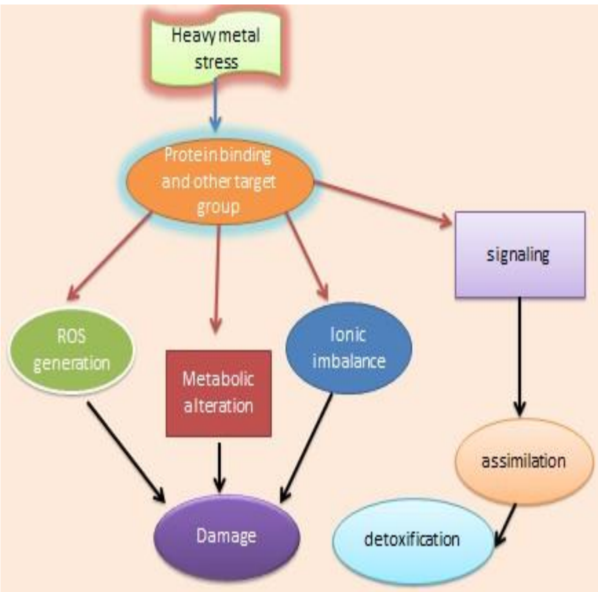

Figure 3: Crucial mechanism of heavy metal-induced injury in plant and its detoxification process (Modified after Panda *et al.,* 2014)

REFERENCES

Abedin, M.J., Cotter-Howells, J., Meharg, A.A. 2002. Arsenic uptake and accumulation in rice (*Oryza sativa* L.) irrigated with contaminated water. Plant and Soil. 240: 311–319.

Ahmad, I., Akhtar, M.J., Zahir, Z.A., Jamil, A. 2012. Effect of cadmium on seed germination and seedling growth of four wheat (Triticum aestivum L.) cultivars. Pakistan Journal of Botany. 44(5): 1569–1574.

Arya, S.K., Roy, B.K. 2011. Manganese-induced changes in growth, chlorophyll content and antioxidants activity in seedlings of broad bean (*Vicia faba* L.). Journal of Environmental Biology. 32(6): 707–711.

Barrachina, A.C., Carbonell, F.B., Beneyto, J.M. 1995. Arsenic uptake, distribution, and accumulation in tomato plants: effect of arsenite on plant growth and yield. Journal of Plant Nutrition. 18(6): 1237–1250.

Barrachina, A.C., Carbonell, F.B., Beneyto, J.M. 1995. Arsenic uptake, distribution, and accumulation in tomato plants: effect of arsenite on plant growth and yield. Journal of plant nutrition. 18:1237–1250.

Barsukova, V.S., Gamzikova, O.I. 1999. Effects of nickel surplus on the element content in wheat varieties contrasting in Ni resistance. Agrokhimiya. 1: 80–85.

Bonnet, M., Cameras, O., Veisseire, P. 2000. Effects of zinc and influence of *Acremonium lolii* on growth parameters, chlorophyll fluorescence and antioxidant enzyme activities of ryegrass (*Lolium perenne* L. cvApollo). Journal of Experimental Botany. 51(346): 945–953.

Cook, C.M, Kostidou, A., Vardaka, E., Lanaras, T. 1997. Effects of copper on the growth, photosynthesis and nutrient concentrations of *Phaseolus* plants. Photosynthetica. 34(2): 179–193.

Cunningham, S.D., Shann, J.R., Crowley, D.E., Anderson, T.A. 1997. Phytoremediation of contaminated water and soil. Phytoremediation of soil and water contaminants, American Chemical Society, Washington, DC., 2-17.

Doncheva, S., Stoynova, Z., Velikova, V. 2001. Influence of succinate on zinc toxicity of pea plants. Journal of Plant Nutrition. 24(6): 789–804.

Doncheva, S., Georgieva, K., Vassileva, V., Stoyanova, Z., Popov, N., Ignatov, G. 2005. Effects of succinate on manganese toxicity in pea plants. Journal of Plant Nutrition. 28(1): 47–62.

Dubey, R.S. 2011. Metal toxicity, oxidative stress and antioxidative defence system in plants. In Reactive Oxygen Species and Antioxidants in Higher Plants, S. D. Gupta, Ed., 177–203.

Graeber, K., Nakabayashi, K., Miatton, E., Leubner-Metzger, G., Soppe, W. 2012. Molecular mechanisms of seed dormancy. Plant Cell Environ. 35: 1769–1786.

Herawati, N., Suzuki, S., Hayashi, K., Rivai, I.F., Koyama, H. 2000. Cadmium, copper and zinc levels in rice and soil of Japan, Indonesia and China by soil type. Bull. Environ. Contam. Toxicol. 64: 33–39.

Hussain, A., Abbas, N., Arshad, F. 2013. Effects of diverse doses of lead (Pb) on different growth attributes of *Zea mays* L. Agricultural Sciences. 4(5): 262–265.

Hussain, K., Hussain, M., Majeed, A., Nawaz, K., Nisar, M.F., Afghan, S. 2010. Morphochemical Response of Scurf Pea (*Psoralea corylifolia* L.) to Indole Acetic Acid (IAA) and Nitrogen (N). World Applied Sciences Journal. 8(10): 1220-1225.

Jayakumar, K., Jaleel, C.A., Azooz, M.M. 2008. Phytochemical changes in green gram (*Vigna radiata*) under cobalt stress. Global Journal of Molecular Sciences. 3(2): 46–49.

Jayakumar, K., Jaleel, C.A., Vijayarengan, P. 2007. Changes in growth, biochemical constituents, and antioxidant potentials in radish (*Raphanus sativus* L.) under cobalt stress Turkish Journal of Biology. 31(3): 127–136.

Jayakumar, K., Rajesh, M. Baskaran, L., Vijayarengan, P. 2013. Changes in nutritional metabolism of tomato (*Lycopersicon esculantum* Mill.) plants exposed to increasing concentration of cobalt chloride. International Journal of Food Nutrition and Safety. 4(2): 62–69.

Jiang, W., Liu, D., Hou, W. 2001. Hyperaccumulation of cadmium by roots, bulbs and shoots of garlic. Bioresource Technology. 76(1): 9–13.

Kabir, M., Iqbal, M.Z., Shafiq, M. 2009. Effects of lead on seedling growth of *Thespesia populnea* L. Advances in Environmental Biology. 3(2): 184–190.

Khalid, B.Y., Tinsley, J. 1980. Some effects of nickel toxicity on ryegrass. Plant and Soil. 55(1): 139–144.

Kibra, M.G. 2008. Effects of mercury on some growth parameters of rice (*Oryza sativa* L.). Soil & Environment. 27(1): 23–28.

Kjær, C., Elmegaard, N. 1996. Effects of copper sulfate on black bindweed (*Polygonum convolvulus* L.) Ecotoxicology and Environmental Safety. 33(2): 110–117.

Lin, Y.C., Kao, C.H. 2005. Nickel toxicity of rice seedlings: Cell wall peroxidase, lignin, and NiSO4-inhibited root growth Crop. Environment Bioinformatics. 2: 131–136.

Manivasagaperumal, R., Balamurugan, S., Thiyagarajan, G., Sekar, J. 2011. Effect of zinc on germination, seedling growth and biochemical content of cluster bean (*Cyamopsis tetragonoloba* (L.) Taub). Current Botany. 2(5): 11–15.

Marques. A.P.G.C., Rangel, A.O.S.S., Castro, P.M.L. 2009. Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology. Critical Reviews in Environmental Science and Technology. 39(8): 622–654.

Monni, S., Salemma, M., Millar, N. 2000. The tolerance of Empetrum nigrum to copper and nickel. Environ Pollut 109: 221–229.

Moustakas, M., Lanaras, T., Symeonidis, L., Karataglis, S. 1994. Growth and some photosynthetic characteristics of field grown Avena sativa under copper and lead stress. Photosynthetica. 30(3): 389–396.

Munzuroglu, O., Geckil, H. 2002. Effects of metals on seed germination, root elongation, and coleoptile and hypocotyl growth in *Triticum aestivum* and *Cucumis sativus.* Arch. Environ. Contam. Toxicol*.* 43: 203–213.

Nematshahi, N., Lahouti, M., Ganjeali, A. 2012. Accumulation of chromium and its effect on the growth of (*Allium cepa* cv. Hybrid). European Journal of Experimental Biology. 2(4): 969– 974.

Nguyen, X. 2008. The Effects of Cu, Pb, Zn on growth and their accumulation in lettuce plants.Journal of Earth Science, Vietnam Academy of Science and Technology, 2(30): 119-123.

Nieboer, E., Richardson, D.H.S. 1980. The replacement of the nondescript term heavy metals by a biologically and chemistry significant classification of metal ions. Env. Pollut. Series. B 1: 3–26.

Okuma, E., Murakami, Y., Shimoishi, Y., Tada, M., Murata, Y. 2004. Effects of exogenous application of proline and betaine on the growth of cultured tobacco cells under saline conditions. Soil Sci Plant Nutr 50: 1301-1305.

Panda, S.K., Patra, H.K. 2000. Nitrate and ammonium ions effect on the chromium toxicity in developing wheat seedlings. Proceedings of the National Academy of Sciences, India. 70: 75–80.

Raskin, P.B., Kumar, A.N., Dushenkov, S., Salt, D.E. 1994. Bioconcentration of heavy metals by plants. Current Opinion in Biotechnology. 5(3): 285–290.

Santner, A., Calderon-Villalobos, L., Estelle, M. 2009. Plant hormones are versatile chemical regulators of plant growth. Nature Chem Biol. 5: 301–307.

Schaller, A. Diez, T. 1991. Plant-specific aspects of heavy metal uptake and comparison with quality standards for food and forage crops in Der Einfluß von fasten Abfallen¨auf Boden,¨ Pflanzen, D. Sauerbeck and S. Lubben,¨ Eds., 92–125.

Sharma, R.K., Agrawal, M., Marshall, F.M. 2008. Heavy metal (Cu, Zn, Cd, and Pb) contamination of vegetables in Urban India: a case study at Varanasi. Environ. Pollution. 154: 254-263.

Shekar, C.H.C., Sammaiah, D., Shasthree, T., Reddy, K.J. 2011. Effect of mercury on tomato growth and yield attributes. International Journal of Pharma and BioSciences. 2(2): 358–B364.

Sheldon, A.R., Menzies, N.W. 2005. The effect of copper toxicity on the growth and root morphology of Rhodes grass (*Chloris gayana* Knuth.) in resin buffered solution culture. Plant and Soil. 278(1): 341–349.

Shenker, M., Plessner, O.E., Telor, E. 2004. Manganese nutrition effects on tomato growth, chlorophyll concentration, and superoxide dismutase activity. Journal of Plant Physiology. 161(2): 197–202.

Sheoran, I.S., Singal, H.R., Singh, R. 1990. Effect of cadmium and nickel on photosynthesis and the enzymes of the photosynthetic carbon reduction cycle in pigeon pea (*Cajanus cajan* L.). Photosynthesis Research. 23(3): 345–351.

Singh, S., Prasad, S.M. 2014. Growth photosynthesis and oxidative responses of Solanum melongena L. seedlings to cadmium stress: Mechanism of toxicity amelioration by kinetin. Sci Hortic. 176: 1-10.

Wang, F., Zeng, B., Sun, Z., Zhu, C. 2009. The relationship between proline and Hg2+-induced oxidative stress in a tolerant rice mutant. Archives of Environmental Contamination and Toxicology. 56(4): 723–731.

Wang, M., Zou, J., Duan, X., Jiang, W., Liu, D. 2007. Cadmium accumulation and its effects on metal uptake in maize (*Zea mays* L.). Bioresource Technology. 98(1): 82–88.

Wintz, H., Fox, T., Vulpe, C. 2002. Responses of plants to iron, zinc and copper deficiencies. Biochem Soc Trans. 30: 766–768.

Yanqun, Z., Yuan, L., Jianjun, C., Haiyan, C., Li, Q., Schratz, C. 2005. Hyperaccumulation of Pb, Zn and Cd in herbaceous grown on lead-zinc mining area in Yunnan, China. Environ. Int. 31:755–762.

Yoruichi, M.S., Bayat, H.R. 2013. Effect of cadmium toxicity on growth, cadmium accumulation and macronutrient content of durum wheat (Dena CV.). International Journal of Agriculture and Crop Sciences. 6(15): 1099–1103.

