Effect of heavy metals on germination of seeds

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Abstract

With the expansion of the world population, the environmental pollution and toxicity by chemicals raises concern. Rapid industrialization and urbanization processes has led to the incorporation of pollutants such as pesticides, petroleum products, acids and heavy metals in the natural resources like soil, water and air thus degrading not only the quality of the environment, but also affecting both plants and animals. Heavy metals including lead, nickel, cadmium, copper, cobalt, chromium and mercury are important environmental pollutants that cause toxic effects to plants; thus, lessening productivity and posing dangerous threats to the agro-ecosystems. They act as stress to plants and affect the plant physiology. In this review, we have summarized the effects of heavy metals on seeds of different plants affecting the germination process. Although reports exist on mechanisms by which the heavy metals act as stress and how plants have learnt to overcome, the future scope of this review remains in excavating the signaling mechanisms in germinating seeds in response to heavy metal stress.

Key words: Germination, heavy metals, stress, seed

INTRODUCTION

Soil is a valuable and non-renewable resource essential for germination of seeds, survival and growth of plants thus supporting every live form on earth. However in the modern world, numerous soil pollutants restrict the growth of plants. Abiotic stress factors including salinity, drought, extreme temperatures, chemical toxicity and oxidative stress from the environment are the major causes of worldwide crop loss that pose serious threats to agricultural produce. With the ongoing technological advancements in industrialization and urbanization process, release of toxic contaminants like heavy metals in the natural resources has become a serious problem worldwide. Metal toxicity affects crop yields, soil biomass and fertility.

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Presence of heavy metals, like nickel, cobalt, cadmium, copper, lead, chromium and mercury in air, soil and water can cause bioaccumulation affecting the entire ecosystem and pose harmful health consequences in all life forms. The major sources of pollution in the state of Odisha in India are overburdens of mine, industrial effluent, fertilizers and pesticides, extra salts and elements that degrade the soil quality.[1] Metals and chemicals in higher concentration hamper the plant germination, growth and production mainly associated with the physiological, biochemical and genetic elements of the plant system.

In the mining areas located in the districts of Jajpur, Keonjhar, Mayurbhanj and Sundargarh districts of Odisha in India, nearly 45% to 67% of iron and 45% to 54% of chromium contamination are reported.[1] This high concentration of salts and metals acts as stress to plants affecting the yield of crops and viability of flora and fauna adversely not only in the area of location but all adjoining areas by spreading thus raising concern. The major effects of heavy metals on seeds [Figure 1] are manifested by overall abnormalities and decrease in germination, reduced root and shoot elongation, dry weight, total soluble protein level,[2] oxidative damage, membrane alteration, altered sugar and protein metabolisms, nutrient loss[3,4]

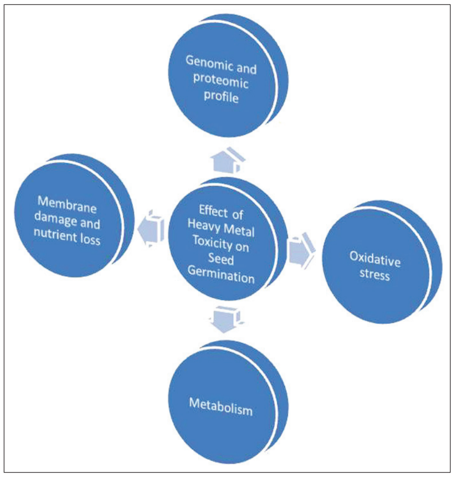

Figure 1: Different effects of heavy metals on seed germination

all contributing to seed toxicity and productivity loss. The heavy metal toxicity on *Arabidopsis* manifested by decreased seed germination rate was reported in the order of Hg>Cd>Pb>Cu.[5]

Although reports exist over effect of the metal toxicity on plants, very few reports exist on how heavy metals affect seed physiology. While keeping in mind the rising concerns over heavy metal stress affecting agriculture produce, in this review we focus our attention to the effect of different heavy metals on seeds of different plants affecting germination.

Effect of heavy metals on seeds

Nickel (Ni) is reported to be toxic to most plant species affecting amylase, protease and ribonuclease enzyme activity thus retarding seed germination and growth of many crops.[3] It has been reported to affect the digestion and mobilization of food reserves like proteins and carbohydrates in germinating seeds,[3,6] reducing plant height, root length, fresh and dry weight, chlorophyll content and enzyme carbonic anhydrase activity, and increasing malondialdehyde content (MDA) and electrolyte leakage.[7] Ni stress has been reported to affect photosynthetic pigments, lessen yield and cause accumulation of Na^+, K^+ and Ca^{2+} in mung bean.[8] The combination of Ni and NaCl in germinating seeds of *Brassica nigra* causes significant decline in growth, leaf water potential, pigments and photosynthetic machinery by increased electrolyte leakage, lipid peroxidation, H_2O_2 content, activity of anti-oxidative enzymes and the level of proline. It is also reported to decrease membrane stability and nitrate reductase and carbonic anhydrase activity.[9]

Lead (Pb) has been reported to strongly affect the seed morphology and physiology. It inhibits germination, root elongation, seedling development, plant growth, transpiration, chlorophyll production, and water and protein content, causing alterations in chloroplast, obstructing electron transport chain, inhibition of Calvin cycle enzymes, impaired uptake of essential elements, Mg and Fe, and induced deficiency of CO_2 due to stomatal closure.[4] Pb toxicity has been reported to retard the radical emergence via enhanced protein and carbohydrate contents, affecting the activity of peroxidases and polyphenol oxidases, oxidizing ability of roots and overall lowering of carbohydrate-metabolizing enzymes–α-amylases, β-amylases, acid invertases and acid phosphatases,[10] and altering genomic DNA profile.[11] Pb-polluted soils have been shown to inhibit seedling growth via increased lipid peroxidation, and activation of superoxide dismutase (SOD), guaiacol peroxidase (POD) and ascorbate peroxidase (APX) enzymes and the glutathione (GSH)-ascorbate cycle thus playing dominant role in removing H_2O_2. It also caused up-regulation of HSP70. Together with lipid peroxidation, HSP70 are reported to be markers for Pb-induced stress in soils.[12]

Copper (Cu) has been reported to be toxic to sunflower seedlings inducing oxidative stress via generation of reactive oxygen species (ROS) and by decreased catalase (CAT) activity via oxidation of protein structure.[13] Cu stress leads to reduced germination rate[13-15] and induces biomass mobilization by release of glucose and fructose thereby inhibiting the breakdown of starch and sucrose in reserve tissue by inhibition in the activities of alpha-amylase and invertase isoenzymes.[13] Metallothionein-like protein, membrane-associated protein-like protein, putative wall-associated protein kinase, pathogenesis-related proteins and the putative small GTP-binding protein Rab2, were up-regulated while cytochrome P450 (CYP90D2), thioredoxin and GTPase were down-regulated by Cu stress.[16] Cu toxicity generated oxidative stress by up-regulating antioxidant and stress-related proteins like glyoxalase I, peroxiredoxin, aldose reductase, and regulatory proteins like DnaK-type molecular chaperone, UlpI protease and receptor-like kinase thereby disruptive metabolic processes. Proteomics studies has revealed that Cu toxicity inhibit seed germination by down-regulating activity of alpha-amylase or enolase. It has been reported to affect overall metabolism, water uptake and failure to mobilize reserve food.[17]

Cadmium (Cd) has been shown to cause delay in germination, induce membrane damage, impair food reserve mobilization by increased cotyledon/embryo ratios of total soluble sugars, glucose, fructose and amino acids,[18] mineral leakage leading to nutrient loss,[19] accumulation in seeds and over-accumulation of lipid peroxidation products[20,21] in seeds. It has been reported to reduce the germination percent, embryo growth and distribution of biomass, and inhibit the activities of alpha-amylase and invertases: Soluble acid (INV-AS), soluble neutral (INV-NS), cell wall bound acid (INV-AW), impair membrane integrity by high MDA content and lipoxygenase (LOX) activity,[19] reduce water content, shoot elongation and biomass.[20] Cd toxicity led to stimulated expression of Gpx (a thioredoxin-dependent enzyme in plants) and a drastic reduction in glutathione reductase (GR) activity thereby modulating the level of thiol during the germination.[21] Cd has been reported to impair mitochondrial functioning by altering redox regulation via levels of glutaredoxin (Grx), glutathione reductase (GR) activities and glutathione (GSH) concentrations in cotyledons and the embryo.[21] Cd toxicity leading to up-regulated protein synthesis of the defense and detoxification, antioxidant and germination processes is reported.[20] Cobalt (Co) has been reported to induce DNA methylation in *Vicia faba* seeds.[22]

Plant strategies to overcome heavy metal stress

Plants have evolved strategies to combat heavy metal stress. A few studies have reported the genetic and biochemical elements in plants helping them overcome heavy metal stress. The toxic effects of Cr manifested by reduced growth, lowered contents of chlorophyll, protein, proline, increased MDA content and elevated metal uptake were reported to be overcome by plant hormone 28-homobrassinolide (28-HBL) belonging to brassinosteroids (BRs) group via regulation of antioxidant enzymes.[23] Overproduction of glyoxylase enzymes GLY I and/or GLY II enzymes that detoxify methyl-glyoxal in *Arabidopsis* transgenic plants have been reported to provide tolerance toward salinity and heavy metal stresses.[24] The gene CDR3 isolated from Cd-resistant *Arabidopsis* plant indicated their role in the regulation of heavy metal resistance as well as seed development and flowering by increased expression of GSH1 gene leading to GSH synthesis and increased GSH content.[25] ACBP1 has been reported to enable tolerance to Pb toxicity in *Arabidopsis*.[26] Regulated expression of sulfur metabolism by ATP sulfurylase (APS) and adenosine 5' phosphosulfate reductase (APR), up-regulated expression of Ser acetyl transferase (SAT) and O-acetyl-ser (thiol)-lyase (OASTL) are reported to enable plants overcome Cd toxicity. Glutamyl cysteine synthetase (GCS) and glutathione synthetase (GS) over-expression has been reported to catalyze GSH synthesis from Cys, and is reported to improve Cd tolerance in plant. Phytochelatin synthase (PCS), activated plant antioxidative system, metal transporter genes also have been reported to contribute to Cd tolerance.[27]

DISCUSSION

Although plant defense strategies exist to cope with heavy metal toxicity via reduced uptake into the cell, sequestration into vacuoles by the formation of complexes, binding by phytochelatins, synthesis of osmolytes, activation of various antioxidants to combat ROS, altered expression of enzymes, overexpression of genes exist,[1,23-28] mechanisms by which germinating seeds combat heavy metal stress remains largely unknown. The future scope of this review remains in understanding the biochemistry of heavy metal toxicity in germinating seeds. Understanding such strategies in seeds to overcome such stress and manipulation of pathways and biomolecules involved will lead to better agricultural produce despite heavy metal toxicity from contaminated soil.

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