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Heavy metal accumulation resulted stress and consequently stress relevancy mechanism in plants: an critical analysis

Dr. Alka Rani
Associate Professor, Department of Chemistry, Hindu College Moradabad, UP

Abstract:
Detailed studies indicate that heavy metals and metalloids have effects on chlorophyll and amino acid content in plants. Heavy metals are known to interfere with chlorophyll synthesis either through direct inhibition of an enzymatic step or by inducing deficiency of an essential nutrient.). Proline accumulation, accepted as an indicator of environmental stress, is also considered to have important protective roles. Heavy metal stress leads to proline accumulation. Proline accumulation in plant tissues has been suggested to result from (a) a decrease in proline degradation, (b) an increase in proline biosynthesis, (c) a decrease in protein synthesis or proline utilization, and (d) hydrolysis of proteins.

I. Introduction

Heavy metals and metalloids make a significant contribution to environmental pollution as a result of human activities such as emissions from automobile, mining, smelting, electroplating, energy and fuel production, power transmission, intensive agriculture, sludge dumping and military operations (1). They present a risk for primary and secondary consumers and ultimately humans (2).Heavy metals such as Cu and Zn are essential for normal plant growth and development since they are constituents of many enzymes and other proteins. However, elevated concentrations of both essential and non-essential heavy metals in the soil can lead to toxicity symptoms and growth inhibition in most plants (3).Toxicity may result from the binding of metals to sulphydryl groups in proteins, leading to inhibition of activity or disruption of structure, or from displacement of an essential element, resulting in deficiency effects (4). In addition, a heavy metal excess may stimulate the formation of free radicals and reactive oxygen species, perhaps resulting in oxidative stress (5).The lifetime of active oxygen species within the cellular environment is determined by the antioxidant system, which provides crucial protection against oxidative damage. The anti-oxidative system comprises numerous enzymes and compounds of low molecular weight (6). The antioxidant properties of plants exposed to various stress factors have been studied (7), but studies related to the effect of heavy metal-induced stress on vitamin levels in plants are limited. Lead and mercury were reported to cause an increase in ascorbic acid levels in two *Oryza sativa* cultivars (8). Heavy metal pollution of agricultural soils is a major environmental problem that can affect plant productivity, food quality and human health (9). For example, at elevated blood concentrations, Pb can impair cognitive development and reduce intellectual performance of children and can cause a number of cardiovascular dysfunctions in adults (7-10). Cadmium (Cd) can cause kidney damage, impair skeletal and reproductive systems and other health problems (4). Cadmium and Pb have no essential biological function but are taken up by plants from metal-enriched soils (5). In the case of Cd which is readily taken up by plants, the subsequent problem is that the toxicity level for animals is in the range of 0.5–1 mg kg^{-1} dry plant material; whereas, crop plants tolerate at least tenfold of that concentration in tissue. Lead may be taken up by plant roots but only negligible amount would be transferred to above ground plant shoots (2). 90–99% of Pb in the leaf materials was due to foliar uptake. Copper, Mn and Zn are essential plant nutrients (11), however, they can cause toxicity at elevated concentrations (12). When any or several of these elements are present in soil above their respective background concentrations, remedial actions may be necessary. The use of traditional remediation technologies such excavation and chemical leaching of metals is expensive and in most cases unfeasible (13). A promising remediation technology for mildly heavy metal polluted soils is phytoextraction (14). However, the use of hyper accumulator plants for phytoextraction presents some challenges because these are mostly wild species with significant metal uptake but limited biomass production and provide no economic return (15). The challenges are greater in countries with limited resources, where governments cannot offer incentives to agricultural producers with contaminated soils, or the land could not be taken out of production 16).

Qualitative or quantitative determination of mineral elements present in plants is important because the concentration and type of minerals present must often be stipulated on the label of a food. The quality of many foods depends on the concentration and type of minerals what they contains, also play a very significant role against a variety of degenerative diseases and processes, they may also prevent and reduce injury from environmental pollutants and enhance the ability to work and learn, some minerals are essential to a healthy diet (e.g. Calcium, Phosphorus, Potassium and Sodium) where as some can be toxic (e.g. Lead, Mercury, Cadmium and Aluminium). It is clear that mineral nutrition is important to maintain good health and because of that determination of As, Ca, Fe, Mg, Na, K, Zn, Ni, Co etc. have been added to *Ayurvedic Pharmacopoeia of India* (The *Ayurvedic Pharmacopoeia* of India, 1999). These inorganic elements play an important role in physiological process involved in human health. K is important as diuretic and it takes part in ionic balance of the human body and maintains tissue excitability. Potassium is the principal intracellular cation and also consider as a very important constituent of the extracellular fluids. Potassium ions are concerned with the transmission of electrical impulse in the nerve cells and in maintaining the fluid balance of the body. Maximum concentration of Ca, Fe and K in nine plants traditionally used for jaundice and concluded that high concentration of K in the medicinal plants could be related to the diuretic action of drugs prepared from these plants. Calcium imparts strength and rigidity to bones and teeth. Calcium ions are also needed in neuromuscular transmission, in excitability of nerves for normal excitability of heart, in clotting of blood and promoting muscular contraction. It also acts as an activator of the enzymes phospholipase, argininekinase, adenosine triphosphatase and adenyl kinase. Excess quantity of Calcium ions in the extracellular fluids acts as a mental depressant. At the other extreme, low levels of Calcium causes spontaneous discharge of nerve fibers, resulting in tetany. Magnesium is the fourth most abundant cation in the body. Much of Magnesium is present in bones in association with Calcium and Phosphate and the rest in soft tissues and body fluids. In muscles and other tissues, intracellular Magnesium ions function as activators for many of the enzymes involved in carbohydrate metabolism and synthesis of nucleic acids (DNA and RNA). Magnesium also acts as an important binding agent of ribosomal particles where protein synthesis takes place. Increased extracellular concentration of magnesium depresses skeletal muscle contraction. On the other hand, low Magnesium concentration causes increased irritability of the (8) nervous system, peripheral vasodilation and cardiaar rhythmias (11). Manganese is essential for haemoglobin formation but excess is harmful. Zn is an essential component of a number of enzymes present in animal tissue including alcohol dehydrogenase, alkaline phosphatase, carbonic anhydrase and procarboxypeptidase, is also essential for the normal growth and reproduction and helps in the process of tissue repair and wound healing. Zinc deficiency causes growth retardation and skin lesions (12). The lower amount of Zn accumulation in the plants is due to its less absorption from the soil. Phosphate ions are the major anions of intracellular fluids, phospholipids and the coenzyme NAD and NADP and especially of ATP and other high energy compounds. It helps in the process of ossification of bones by getting deposited inthe form of Calcium Phosphate (13). Ni aids the synthesis of haemoglobin in the bone marrow. Iron is the most well known in biological system. It performs a wide range of biological functions. Many of these functions are connected with oxidation-reduction and processes by which energy is conserved in the body. It forms an integral part of cytochromes, haemoglobin, myoglobin, metallo flavoproteins and certain enzymes such as catalase and peroxidases. Thus, Iron is absolutely essential for transport of oxygen to the tissue and for operation of oxidation systems within the tissue cells, without which life would cease within a few seconds. Iron deficiency causes anemia (14).

Biosynthesis of secondary metabolites is not only controlled genetically but is also strongly affected by environmental parameters (15) Changes in essential oil content and composition under water stress, is reported in essential oil bearing plants like basil (16) and Artemisia (17). Drought stress also entails a concentration increase of nitrogen containing secondary plant products. Plants that suffer drought stress generate a high oversupply of reduction equivalents (18). Despite the fact that massive amounts of $NADPH^+$ H^+ are re oxidized by photorespiration and the xanthophyll cycle, under such stress conditions the corresponding strong reduction power enhances the synthesis of highly reduced compounds (isoprenoids, phenols or alkaloids). Consequently, the synthesis and accumulation of these reduced secondary plant products reveals apart from their ecological significance, a meaning within the metabolism to prevent too massive generation of oxygen radicals and the corresponding damage by photo inhibition (19).

Understanding the biophysical, biochemical, and physiological basis for the injury of photosynthesis in plants which experience internal water deficits becomes a major interest in order to improve plant responses to environmental stresses. There has been controversy regarding the main physiological targets responsible for photosynthetic impairment under drought such as CO_2 assimilation at the leaves (20). Evidences for metabolic impairment under drought stress have been assessed both by *in vitro* and *in vivo* measurements (11). A large portion of the carbohydrates that plants assimilate is used in respiration, which is needed to produce the energy and carbon skeletons to sustain plant growth (21) Hence, the carbon economy of plants, which will determine plant growth, can be viewed in terms of balance between photosynthesis and respiration. Studies on the effect of environmental stresses in general and water stress in particular on photosynthesis are abundant. However, such effects are less known on respiration (11). Since, photosynthesis occurs spatio-temporally and respiration occurs continuously in every plant organ, thus, respiration has been cited as substantial controlling factor for productivity in a condition when photosynthesis is largely depressed under drought (12).

Stress relevant compounds are mostly the accumulation of low molecular compounds, such as glycine betaine, sugars, sugar alcohols and proline, had a mechanism aimed at balancing water potential following drought (23). In addition to synthesis of these osmolytic compounds, specific proteins and translatable mRNA are induced and increased by drought stress (24).Although an adaptive role for organic osmolytes in mediating osmotic adjustment and protecting sub cellular structure has become a central dogma in stress physiology, the evidence in favour of this hypothesis is largely correlative (25) benefits of osmolyte accumulation may augment the classically accepted roles of these compounds. In reassessing the functional significance of compatible solute accumulation, it is suggested that proline and glycine betaine synthesis may buffer cellular redox potential (26). After recovery from drought, both total soluble sugar and reducing sugar contents of leaves tended to decrease on the other hand, the starch contents of the leaves of drought-treated plants also decreased when the drought treated plants were recovered, the starch contents of leaves tended to be equal to their respective controls.

Many solutes may be used in osmotic adjustment. Inorganic ions such as Na, K and Cl, accounted for most of the osmotic potential in several species (21) while sugars and amino acids, especially proline (8) are the major osmo-regulators in vascular plants (19). The reason is probably the convenience of osmolyte storage in large, osmotically inactive molecules, such as starch or protein, which may serve several functions and from which they can be retrieved under conditions of stress. It appears that neither the synthesis of new compounds nor biochemical pathways are involved during osmotic adjustment (21).

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