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Polyamines: the curtailment of cadmium toxicity in plants

Abstract

Cadmium as a trace element naturally occurs in soils and mineral fertilizers. Cadmium and their alloy compounds are relatively water soluble and mobile compound in most soils. With such specific characteristic it makes differ from other trace element. It helps to make it more bio- available and tends to bio- accumulate. It is the potent causative of cell damage and senescence by interfering with calcium (Ca) regulated cell signalling in biological system. Some plants have terrific potential to endure and mitigate the extensive concentration of heavy metal contamination. When plants exposed to cadmium nitrate, they exhibit phototoxic responses along with tolerance. Polyamines likewise, Putrescine, is involved in abiotic stress endure in plants. Increased polyamines level in stressed plants has adaptive significance because of their involvement in regulation of cellular ionic environment, maintenance of membrane integrity, prevention of chlorophyll loss and stimulation of protein, nucleic acid and protective alkaloids.

Keywords: cadmium, toxicity, polyamines, abiotic stress

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Introduction

There are many terms used to describe and categorize metals, including trace metals, transition metals, micronutrients, toxic metals, heavy metals. Bjerrum's[1] definition of "heavy metals" is based upon the density of the elemental form of the metal, and he classifies "heavy metals" as those metals with elemental densities above 7g cm^{-3}. In 1964, the editor of Van Nostrand's International Encyclopedia of Chemical Science and in 1987, the editors of Grant and Hackh's Chemical Dictionary included metals with a density greater than 4g cm^{-3}. The fate of various metals, including chromium, nickel, copper, manganese, mercury, cadmium, lead, and metalloids, including arsenic, antimony, and selenium, in the natural environment is of great concern[2] particularly near former mine sites, dumps, tailing piles, and impoundments, but also in urban and industrial centers. Cadmium is a naturally occurring trace chemical element with atomic number of 48, having representation Cd. It's a silvery transition metal with bluish tinge crystal show similarity with mercury and zinc with+2 oxidation state. It has a lower melting point. Cadmium is alloyed with silver to form solder, a metal with a relatively low melting point used to join electrical components, pipes and other metallic items. Cadmium based solders must be handled with care to prevent cadmium poisoning. Cadmium alloys are also used to make low friction bearings that are highly resistant to fatigue. Cadmium is a soft, ductile metal which is usually obtained as a by- product of the smelting of lead and zinc ores. The primary use of cadmium is as constituents in alloys and in the electroplating industry. Other uses of cadmium include paints and pottery pigments, corrosion resistant coating of nails, screws, etc, in process engraving, in cadmium-nickel batteries, and as fungicides.[3] The average concentration of cadmium in Earth's crust is between 0.1 and 0.5parts per million (ppm). It will remain present in several places or in different ecosystem on earth, i.e., terrestrial, aquatic and others. Benavides et al.,[4] studied that cadmium is one of the most hazardous heavy metals in the atmosphere, soil and aquatic system which is transferred into our food chain and responsible for the serious environmental disturbance cause and leading to the health assets for the living organism, for instance, lung cancer, convulsion, mutagenesis and brain damage.

Cadmium occurrence

The alleviation or inhibition of trace amount of cadmium in plants caused stress extensive attention of the whole society;[5] Wang et al., 2008. In an atmosphere, it can enter by the burning of coal, mining of metals as well as refining process which may lead to rise in Cd level in the soil by atmospheric fallout also. If we see the atmospheric fallout of Cd from atmospheric air, it follows in the order Remote area<Rural area< Urban areas. Due to long term effects of cadmium, the countries fixed its tolerance limit. The European Economic Committee proposed the concept of PTE i.e. Potential Toxic Elements. PTE for the Cadmium in soil is 1.0-3.0mg/kg of dry soil. If we think about the aging of the metal in the soil, then a distinction should be made between persistence of total metals in the soil and the persistence of bio available forms of metals. This ageing of the metals will depend on soil acidity. Evidence of the aging process is provided by studies of metal extractability and liability. Cadmium is also naturally present in soils and mineral fertilizers. Origin of cadmium in soil is described as agricultural wastes (20%), sludge (38%), fertilizers (2%) and atmospheric fallouts (40%). Cadmium is one of the most toxic elements with reported carcinogenic effects in humans (Goering et al., 1994). Cadmium and cadmium compounds are, compared to other heavy metals, relatively water soluble and mobile compound in most soils, generally more bio- available and tends to bio- accumulate. It induces cell injury and death by interfering with calcium (Ca) regulation in biological system. Cadmium is not essential for plant or animal life (IPCS monographs/WHO1995a; WHO1995b).[6] Cadmium is readily accumulated by many organisms, particularly by microorganism and mollusks where the bio-concentration factors are in the order of thousands. Its mobility essentially depends on the pH; the metal's adsorption to the soil's solid phase can be multiplied threefold for every unite increase in pH in a range from 4 to 8.

Terrestrial plants may accumulate cadmium in the roots and cadmium is found bound to the cell walls.[7] The pH level is one of the most important factors controlling cadmium absorption. Concentration in roots represents only 2 to 5 times that in the above ground parts, but cadmium is transferred only with difficulty to reproductive or storage organs of the plant.[8] No deficiency level for cadmium is known. On the opposing, cadmium is well known as a highly phytotoxic element. Besides decreasing growth and development, phytotoxicity also occurs above 5.0-30.0mg/kg dry weight, though chlorosis, which can be followed in the case of acute cadmium poisoning by necrosis. Other compounds, including Fe, Se, Mn and particularly Zn are antagonistic to Cd. A draft commission regulation practice to set maximum level for some heavy metals in foodstuff as 0.05mg kg^{-1} in fish, vegetables and fruits, excluding leafy vegetables, root vegetables and potatoes; 0.1mg kg^{-1} cereals, except wheat grain and rice; 0.2mg kg^{-1} in wheat grain and rice, leafy vegetables and mushrooms. Numerous standards and a great deal of suggestions persist all over the world regarding the amount of heavy metals in different plant types, which can be consumed by humans. Also, there are many values consequent to the amount of heavy metals in the sewers which may be released into environment. There are some standards showing permitted levels of the heavy metal, cadmium":

a. The WHO has presented the highest allowable concentration of cadmium accumulation in human diet 0.1mg/l

b. United Nation standard for nutritional and agricultural materials has determined a max level of 0.01ppm for cadmium accumulation in irrigational waters and maximum level of 7µg kg^{-1} body weight for humans' daily diets.

c. The United States Environmental Protection Agency (USEPA) has presented a standard which permits a maximum amount of 85ppm for cadmium in ooze which may be deposited in agricultural lands.

Oxidative stress in plants

Plants when exposed to cadmium nitrate, they exhibit phototoxic responses along with tolerance. The observations of specific responses were depending on treatment combinations. The significant hazardous effect and oxidative damage of cadmium were evident by increased in MDA content and hydrogen peroxide content. The metal tolerance and detoxification strategy adopted by the plant was investigated with reference to a non enzymatic antioxidant system and the synthesis of proline and total soluble sugar and antioxidant enzymes viz., Peroxidase (POD, EC 1.11.1.x), Ascorbate peroxidase (APX, EC 1.11.1.11), Catalase (CAT, EC 1.11.1.6) and Polyphenol oxidase (PPO, EC 1.14.18.1) shows induction for treating concentration of cadmium. There are several reports about heavy metal pollution affecting root activities of Graminaceous plants. For example, through the hydroponic way, the effect of sewage directly irrigated on root and seedlings of the wheat. The results showed that the stress of sewage irrigated accelerated the decline of wheat seedlings and root, reducing the root number and the root activities significantly. Infected soil made the roots of the rice seedlings yellow and red, enlarged the rhizome, root color was brown and yellow, while Huang[9] showed that under matrix or soil with cadmium the root activities significantly decreased. Some microorganism reduce the metal toxicity for plants by,

i. Decreasing their accumulation into the plants while some others increase the amount of metal extracted from plants or

ii. By increasing either the biomass of plants (diluting effects) or the concentration of metals accumulated in plants. Microorganisms just minimize the stress produced due to accumulation of excess metal in the plants.

Role of polyamines

The polyamine (PA) putrescine (Put) is important modulators of biological processes, influencing the growth, various development events and stress responses in plants[10] Dos Santos et al., 2002, Kuznetsov et al., 2006, Tun and Santa-Catarina et al., 2006, Santa-Catarina et al., 2007, Steiner et al., 2007, Baron and Stasolla,[11–12] as well as, apoptosis and programmed death in both animals and plants.[13] PAs are small, positively charged aliphatic amines at cellular pH values and therefore bind negatively charged molecules, including nucleic acids, acid phospholipids and proteins, consequently modulating replication, transcription, translation, membrane stabilization, cell division and expansion (Kuznetsov et al., 2006), as well as DNA-protein interactions and protein-protein interactions (Yoda et al., 2003). PAs biosynthesis and degradation, their conjugation with phenolic acids and intracellular transport, all contribute to the cellular levels of free PAs in plants and their pathway in biosynthesis was well established and revised by various authors (Minocha and Minocha, 1995; Bouchereau et al., 1999; Bhatnagar et al., 2002;[14] Kuznetsov et al., 2006; Kusano et al., 2008).[12] These inhibitory effects are manifestations of oxidative stress, which finally reduces crop productivity. Polyamines are involved in abiotic stress tolerance in plants. Increased polyamines level in stressed plants has adaptive significance because of their involvement in the regulation of cellular ionic environment, maintenance of membrane integrity, prevention of chlorophyll loss and stimulation of protein, nucleic acid and protective alkaloids. Interaction of polyamines with membrane phospholipids implicates membrane stability under stress conditions. Polyamines also protect the membrane from oxidative damage as they act as free radical scavengers. Response to abiotic injury and mineral nutrient deficiency is associated with the production of conjugated PAs in plants. Polyamine contents are altered in response to the exposure to heavy metals. These effectively stabilize and protect the membrane systems against the toxic effects of metal ions.

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Conflicts of interest

The authors declared there is no conflicts of interest.

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