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Mini Review

A review on toxicity and environmental implications of heavy metals

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Abstract

Heavy metals are metalloids that have high density and weight, at least 5 times greater as compared to water. In recent years, the industrial, agricultural, medicinal and technological activities have led to a sharp rise in heavy metal exposure in our environment. Even a small concentration of heavy metals is capable of inducing toxic effects on humans and on the overall environment. Toxicity may vary depending on the type of heavy metal, the form in which it is available and the type of individual it is exposed to. Among all the heavy metals, cadmium, arsenic, mercury and lead pose highest degree of toxicity and that is of great concern to plants and human health. This issue leads to challenge of environment conservation and protection from heavy metal exposure. This review provides an analysis about the occurrence of these metals in the environment, their toxicity potential in plants, and the plant defense mechanism against them for their survival.

Keywords defense mechanism in plants, heavy metals, environment, toxicity

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Introduction

Heavy metals are the elements that are naturally occurring and have high density of more than 5g/cm^3, atomic number greater than 20 and atomic weight, which is five times greater than water [1-2]. Metals are having high malleability, electrical conductivity and they voluntarily lose their electrons for the formation of cations. Naturally they are found in earth crust and their composition differs greatly among various localities, which result in spatial variations in the adjoining concentrations. Heavy metals have peculiar characteristics, they do not decay with passage of time, and are beneficial for organisms at certain levels. Mostly they come from non-anthropogenic origin as their concentration in soil is related to peadogenesis and weathering of parent rock. Commonly they occur as cations which are strongly interacting with soil matrix, so as a result of changes in the environmental conditions, heavy metals in the soils are mobile a situation that is referred as 'chemical timing bomb' [3].

Some metals like, copper (Cu), iron (Fe), zinc (Zn), cobalt (Co), chromium (Cr), molybdenum (Mo), magnesium (Mg), nickel (Ni), manganese (Mn) and selenium (Se) are among essential micronutrients which are required for normal physiological and biochemical functions [4-5] and their insufficient supply may result in syndromes, deficiencies and diseases. Both above ground and underground parts of the plants are capable to receive heavy metals.

Because of their presence in trace concentrations they are also known as trace elements in several environmental matrices. These metals are essential for normal functioning of living organisms but they become toxic when

they exceed threshold concentration [6-7]. Globally the exposure to heavy metals is increasing day by day. They act as significant pollutants in environment and their toxicity is increasing concern for evolutionary, ecological, environmental and nutritional reasons [8-9].

Toxicity potential of heavy metals for environment

Due to global development in industrial, economic and agricultural sectors, new challenges are raised especially regarding environmental conservation and protection [10-13]. Due to industrial revolution, mixing of toxic metals in soil has been dramatically increased. 90% emissions of heavy metals due to anthropogenic activities have occurred since the 1900 AD and now the level of these toxic compounds has increased substantially [14].

Environmental contamination may occur through soil erosion, leaching, atmospheric deposition, metal corrosion, and metal evaporation from ground and soil water and due to sediment re-suspension [15] natural volcanic eruptions and weathering also contribute to heavy metals pollution [12,14,16]. When released to the environment these substances lead to many toxic effects in food chain and also on living organisms by bio-magnification and bioaccumulation [17-19]. This phenomenon has become a serious dilemma for all of the living organisms. Documented cases of heavy metals creating toxicity issues have been reported.

Toxicity and heaviness are inter-related [20]. Toxicity of heavy metals is dependent on various factors such as exposure to roots, age and gender of infected persons, chemical species, nutritional status and genetics of the infected individuals. Due to high level of toxicity, lead, cadmium, chromium, mercury and arsenic are more toxic for plants survival and for public health. These are systemic toxicants which cause multiple organ damage even after exposure to the low levels. They are classified as carcinogenic [21].

Natural and anthropogenic sources of heavy metals

Heavy metals are naturally present in soil due to weathering process. Generally they are mined from mineral processing [22]. Heavy metals are present in rocks in different chemical forms which are recovered as minerals [23].

There are many natural and anthropogenic sources of heavy metals, as shown in Figure 1. The major origin is industrial activities like, mining, refining, smelting effluents, manufacturing progressions military operations, fuel production, use of chemicals in agriculture sector, brick kilns, small scale industries, disposal of municipal wastage in soil, excess and unsafe application of weedicides, fungicides, pesticides [24-25-26] coal burning, petroleum combustion, nuclear stations for power purposes, textiles, plastics, wood preservation, micro-electronics and plants for paper processing and high tension lines [16-17, 27-31]. Additional sources of metal pollution are from industrial discharge, incineration refuse, traffic emissions, transportation, landfills and open dumps [32]. Probably the effluents are largest contributors for higher concentration of metals in rivers, ponds and lakes. Generally these effluents consists of untreated or mechanical treated waste water, materials from the filters of biological treatment plants and waste substances from sewage outfalls which are being discharged into sea [33]. Additionally irrigating the crops with contaminated water by industrial effluents and sewage is also causing the contamination of soil and vegetables [34]. These metals can exert negative effects on human health. Generally human beings are exposed to heavy metals by breathing in polluted air or by ingestion (drinking and breathing) or by contact with skin [35].

Most common heavy metals in water are nickel, lead, copper, zinc, arsenic, chromium and cadmium which all cause problems for environment, for human and plant health.

The distribution of metals in the atmosphere is monitored by the properties of these metals and by the environmental factors [36]. These heavy metals are bio-accumulative and they slowly enter in plants, animals and human bodies through air, water and by the progression of food chain. Plants extract the metals from soil solution.

Later on metals pass from root surface to upper parts of plants. It may be a passive process or may be active process.

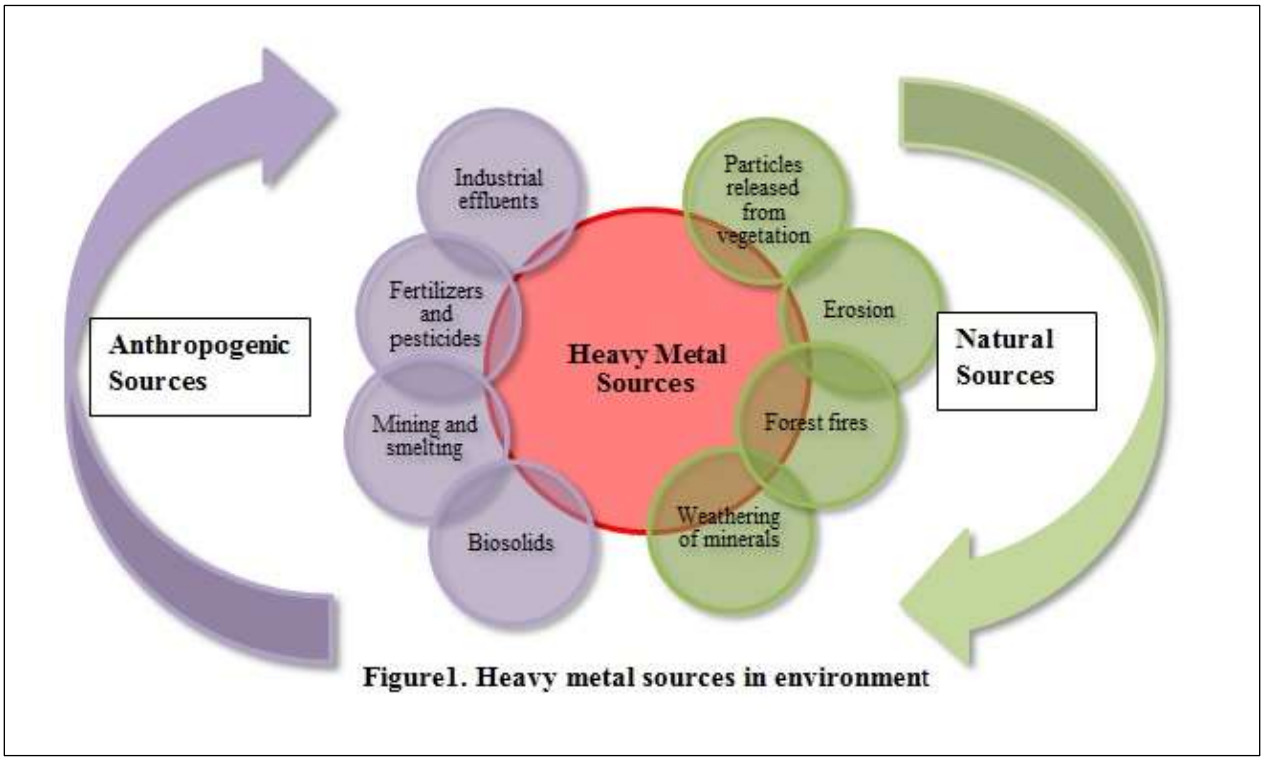

Figure 1. Heavy metal sources in environment

Bioavailability of heavy metals is greatly influenced by sequestration, temperature, adsorption and phase association. Chemical factors are also important regarding bioavailability of metals which influence lipid solubility, partition coefficients of water and complexation kinetics. Biological factors such as physiological and biochemical adaptation, interactions at trophic level and species characteristics are also significant factors for bioavailability and uptake of metals [37].

Effects of heavy metals toxicity on plants and their defense mechanisms for detoxification

Frequently plants are sensitive to higher levels of heavy metals. Their increased concentration adversely affects soil fertility and plant growth. Heavy metals toxicity is a major threat and various risks are associated with this toxicity. Sometimes heavy metals act as pseudo elements and even interfere with metabolic processes. When metals are accumulated in food chain and body they exhibit a chronic nature. It can cause various disorders and may cause excessive damage due to free radical formation under the oxidative stress [8].

Excessive concentrations of heavy metals in plant tissue are capable to induce various biochemical, physiological and morphological toxic effects. Heavy metal toxicity in plants disrupts water and nutrient uptake and their transport, alters nitrogen metabolism, affects ATPase activity, interferes plant growth by reducing photosynthesis and cause stomatal closure due to dysfunctioning of photosynthetic machinery of plants. Some invisible symptoms may also be induced due to heavy metals toxicity such as chlorosis, leaf rolling, necrosis and browning of roots [38].

Heavy metals bind with protein sites and displace the actual metals from their binding sites and cause malfunctioning of cell, ultimately causing toxicity. In biological systems heavy metals affects cell components and cellular organs lysosomes, nuclei, endoplasmic reticulum, mitochondria, enzymes related to metabolism and detoxification [39]. These metal ions interact with cellular components such as nuclear proteins and DNA and cause conformational changes and DNA damage which may lead to the modulation of cell cycle and apoptosis [40-42].

Previous studies showed that biological macromolecules have been deteriorated by oxidative reactions due to binding of heavy metals to nuclear proteins and DNA [43-47]. Heavy metals affects the structural components such as cells, tissues and organs either by direct or by indirect means by the modulation of cell signaling or by affecting metabolism that later appears as visible injuries. Heavy metals affect the signaling process in the cells, directly by the interactions of heavy metals with proteins or indirectly when ROS formation takes place due to metal induced stress [48-49]. The main reason for heavy metals toxicity and negative impacts on growth and development are due to disruption of signaling events. The interactions of heavy metals with cellular processes affects the significant processes such as growth factor receptors, interference with the signaling processes, regulation of gene expression and receptor tyrosine kinases [50]. Various studies have reported that heavy metals like Pb, Zn, Cu, Cd affects the signaling processes of mitogen kinase in plants [51-52]. Plasma cell membranes are the main target of heavy metals action in photosynthetic organisms that cause peroxidation of lipids by ROS production [53-54].

Plants have many extrinsic and inherent mechanisms to tolerate stress or for detoxification when they have to encounter stressful conditions due to increased concentrations of heavy metals. Among these strategies the first one is avoidance by restricting the uptake of metals from soil or by excluding these metals, thus preventing their entry into plant roots [55].

In order to minimize the effects of metal phyto-toxicity plants have anti-oxidative defense system comprising of many enzymes such as glutathione (GSH), glutathione reductase (GR), superoxide dismutase (SOD), catalase (CAT), peroxidase (POX), guaiacol peroxidase (GPX) and ascorbate peroxidase (APX) which plays vital role to scavenge excess ROS species [56-60]. Regarding heavy metals toxicity in higher plants free radicals are of significant importance [61]. Root cells also play an important role for the detoxification of heavy metals by making complexes with organic acids and amino acids [62].

Conclusion

Heavy metals have become a major concern for the environment, especially the plants and humans. All the recently published data shows that anthropogenic activities are the main source of heavy metal contamination in our soils. Plants experience multiple stresses in response to metal toxicity that may include oxidative stress through the production of ROS and disturbance in ionic balance inside of plant cell. In response to all this, plant activates its detoxification mechanism, mainly chelation and subcellular compartmentalization. The rising concentration of heavy metals in soils and then their potential uptake by edible plants is a concern because even the plant survives after uptake, but the human intake would ultimately create massive damage to health and wellbeing.

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