ISSN (E): 2320-3862
ISSN (P): 2394-0530
NAAS Rating 2017: 3.53
JMPS 2017; 5(2): 148-151

Received: 11-01-2017
Accepted: 15-02-2017

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Heavy metal stress in crop plants: A review

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Abstract
The environment has been harmed by a plethora of human activities such as mining, contemporary farming methods, and industrialization. All of these variables raise the accumulation of heavy metals in air, soil, and water, Heavy metal pollution of soil may lead to a variety of environmental issues, as well as harmful effects on both plants and animals. In the ecosystem, enormous absorption and bio - magnification of heavy metals has become a problem for all living creatures, including plants. Intoxicating amounts of heavy metals have the tendency to communicate with numerous essential cellular macromolecules such as nuclear proteins and DNA, resulting in an over-abundance of reactive oxygen species. Defoliation and peroxidation as well as enzyme inactivation would be severe morphological, metabolic, and physiological abnormalities in plants. Over this, plants have developed many ways to combat heavy metal toxicity. This review considers our current understanding of the detrimental effects of different heavy metals as well as plant responses to these stresses.

Keywords: heavy metal stress, reactive oxygen species, lipid peroxidation, antioxidative enzymes

Introduction
In nature, plants are subjected to various biotic and abiotic stresses. There are many factors that affect crop yield and development, but heavy metal stress is one of the most important. Numerous ecosystems all across globe are suffering from heavy metal stress. As a result of the accumulation of heavy metals, in soil and plants due to industrialization, the production of crops is reduced (Shahid *et al.*, 2015) [28]. Heavy metals contamination reduces plant development directly or indirectly by interfering with different physiological and molecular processes (Panuccio *et al.*, 2009) [21]. Many biological activities and developmental pathways rely on heavy metals such as copper and zinc, as well as manganese, nickel, and molybdenum. (Salla *et al.*, 2011; Shahid *et al.*, 2015) [27, 28]. However, other extremely toxic heavy metals such as lead, cadmium, mercury and arsenic these metals can significantly impair agricultural productivity when their concentrations exceed optimum levels (Pierart *et al.*, 2015).
Anomalies in the redox homeostasis of cells occur from the formation of reactive oxygen species such as superoxide anion radical, hydrogen peroxide, and hydroxyl radical (Gill and Tuteja, 2010; Shahid *et al.*, 2015) [6, 28]. Heavy metal buildup in agricultural crops has been linked to adverse health effects in humans were reported in many previous researches (Shahid *et al.*, 2015) [28]. Plants species have evolved a variety of defensive strategies to deal with heavy metal stress and metal toxicity, including decreased heavy metal absorption, sequestration of metal within vacuoles, coupling to phytochelatins, and stimulation of different antioxidants (Shahid *et al.*, 2015) [28].

Different sources of heavy metals
Natural, agricultural, commercial, household effluents and atmospheric sources are sources of heavy metals in the environment. Mines, smelting activities, and agriculture have contaminated large parts of Japan, Indonesia, and China with heavy metals such as copper, cadmium, and zinc which have contaminated large portions of the planet (Herawati *et al.*, 2000) [10]. Heavy metals from natural sources are formed in the Earth crust, thus their presence in soil is merely a result of weathering. Desert wind dust in the Sahara, is rich in iron and low in zinc, chromium, manganese, nickel and lead (Ross, 1994) [26].
In several ecosystems, marine aerosols and wild fires have a significant impact on the movement of certain heavy metals. Carbonaceous matter generated after the burning contains volatile heavy metals like mercury and Selenium. Heavy metals are released into the soil and atmosphere by natural vegetation due to seeping from leaves and stems, degradation, and thermal decomposition.

Due to sea sprays and aerosols created by marine processes, several heavy metals have been found in inland coastal regions. Liming, sewage sludge, irrigation fluids, and pesticides are the most common sources of heavy metals in agricultural soil. Heavy metal levels in other products, such as fungicides, inorganic fertilizers, and phosphate fertilizers, vary depending on their origins. Cadmium is a major problem in plants because it accumulates at extremely high levels in leaves, which can be eaten by humans or other animals. Cadmium enriching can also be caused through the use of wastewater, manure, and limes (Yanqun *et al.*, 2005) [35].

Even though the concentrations of heavy metals in agricultural soil are extremely low but regular application of fertilizers, prolonged persistence, and period for metals, may result in a dangerously large buildup of particular metals. Manure from animals enriches the soil by adding metals such as manganese and cobalt as well as other elements such as cadmium, zinc, and copper (Verkleji, 1993) [32]. Numerous heavy metal-based insecticides are used to prevent diseases of grain, fruit, and vegetable crops, but they pollute the soil with heavy metals (Ross, 1994) [26]. Soil has been contaminated with high amounts of heavy metals in orchards where these chemicals have been employed regularly (Ross, 1994) [26].

Agrochemicals like lead arsenate have been used in Canadian orchards for over 60 years and have been reported to be enriched with lead, Arsenic, and Zinc, posing a higher risk of food contamination. Heavy metals like lead and Cadmium can accumulate in soils if it is irrigated continuously (Ross, 1994) [26]. Heavy metals come from industrial sources. Based on the kind of mining, various heavy metals are released. Coalmines, for example, are a source of arsenic, cadmium, iron, and other elements that enrich the soil around the coalfield, either actively or passively. Mercury is used in gold mining, and large quantities of Mercury are released from ancient mines (Lacerda, 1997) [13]. The use of detergents can provide a pollution risk, since typical household detergents can have a negative impact on the quality of water. Several detergents include trace quantities of the metals like iron, manganese, chromium, cobalt, zinc and boron according to Angino and colleagues (1970) [1].

Heavy metal mediated effects on plants

A number of heavy metals have been identified as the most hazardous, such as As, Pb, Cd, Hg and Ni (ATSDR, 2003) [2]. This is based on their toxicity, probability of occurrence, and most critically, their exposure potential to plants and animals. The origins of these heavy metals, as well as their effects on the environment and plant growth, are briefly explained below.

Arsenic

Naturally available arsenic poses significant health risks for masses across the world (Kumar *et al.*, 2015) [12]. Volcanic activity, abrasion of rocks and anthropogenic impacts such as pesticides and wood preservatives, mining and smelting are the most common causes (Neumann *et al.*, 2010) [17]. Contamination of groundwater with arsenic used for agriculture and consumption is a global concern since it not only reduces agricultural yield but also aggregates in various plant tissues, including grains, contaminating the food chain. Various recent research have looked at the physiological and molecular processes of arsenic poisoning, aggregation, detoxification and tolerance in plants such as spinach, rice, lettuce and carrots (Kumar *et al.*, 2015) [12]. Arsenic occurs in two different forms in the environment: inorganic arsenate and arsenite. Both are poisonous and are considered major polluters of the atmosphere (Tripathi *et al.*, 2007) [31].

Lead

Lead is among the most extensively dispersed and equally distributed trace metals found in geological sources. Contamination from leaded fuels, dust, old lead pipe lines, different industrial areas, or even ancient orchard spots in production where lead is utilized can impact soil, flora, and fauna (Tangahu *et al.*, 2011) [30]. Lead is non-biodegradable, and its prolonged exposure has been proven to be highly hazardous to both flora and fauna, as well as have a number of negative impacts on biological systems (Pehlivan *et al.*, 2009) [22].

Many biological processes in plants are affected by lead, including germination, plant growth, root length, transpiration, chlorophyll biosynthesis, and cell division (Pourrut *et al.*, 2011) [24]. Aside from that, it alters cell membrane permeability by interacting with the active groups of various key enzymes, with the phosphate groups of ADP or ATP, and by substituting necessary ions, producing cytotoxic effects (Pourrut *et al.*, 2011) [24]. Lead poisoning inhibits ATP synthesis, causes lipid peroxidation, and damages DNA by generating too many reactive oxygen species.

Cadmium

Cadmium is regarded as one of the most potentially toxic heavy metals, according to the Environmental Protection Agency. Being water-soluble, it is easily absorbed by plants, and posing severe health risks for humans (Buchet *et al.*, 1990) [5]. Cadmium has been designated as a strong human carcinogen (Gill and Tuteja, 2011) [8]. It has been observed that industrial operations and farming methods regularly release cadmium into cultivated soils, and these crops are the significant source of cadmium consumption by humans (Wagner, 1993; Gill and Tuteja, 2011) [33, 8]. At low levels of cadmium exposure, numerous enzyme activities, namely those engaged in the Calvin cycle, phosphorus metabolism, and carbon fixation, can be severely altered, resulting in growth retardation, necrotic lesions, leaf aplasia and changes in chloroplast structure and function, inhibition of photosynthesis and pollen germination (Sharma and Dubey, 2006: Gill and Tuteja, 2010) [29, 7].

Mercury

In terrestrial and aquatic ecosystems, mercury accumulates as a result of anthropogenic activities such as mining or industrial operations, but also as a result of natural processes like volcanic eruptions (Montero-Palmero *et al.*, 2014) [16]. Due to the huge amount of mercury input into fertile areas, mercury contamination has spread throughout the whole food chain. A number of different types of mercury may be found in the environment such as ionic, elemental or inorganic mercury. However, the ionic state of mercury occurs more frequently in soils (Azevedo and Rodriguez, 2012) [3]. Higher plants can easily accumulate mercury as evidenced by recent research (Yadav, 2010) [34].

However, at greater levels, mercury is highly deleterious to plant cells and can produce apparent damage and physiological problems (Ortega-Villasante *et al.*, 2005; Zhou *et al.*, 2007) [18, 36]. Moreover, it has been shown to interfere with mitochondrial function as well as other processes (Zhou *et al.*, 2008) [37]. Mercuric ions have also been known to trigger oxidative stress in plants by boosting the production of reactive oxygen species, resulting in disruption of membrane lipids and cell metabolism, and also elevated the antioxidant enzyme activities such as superoxide dismutase, peroxidase and ascorbate peroxidase, which reflects the extent of stress (Zhou *et al.*, 2007) [36].

Cobalt

Cobalt is found in the crust of the earth as cobaltite, erythrite, and smaltite. Deposits from the combustion of fossil fuels, the wearing of cobalt-containing alloys and the dissemination of sludges and fertilizers can all contribute to an increase in cobalt content in soils (Barceloux, 1999) [4]. Cobalt may be absorbed by plants in tiny amounts from the soil. The absorption and dispersion of cobalt in plants varies species to species and is influenced by a variety of processes (Li *et al.*, 2004) [15]. A recent research on cobalt toxicity on *Brassica napus*, *Hordeum vulgare and Lycopersicon esculentum* revealed that it had a negative impact on seedling growth and production (Li *et al.*, 2009) [14]. Excess of cobalt in cauliflower leaves reduced the amount of iron, chlorophyll, protein, and catalase activity. Furthermore, elevated cobalt levels hampered the transport of sulphur, zinc, potassium and copper from cauliflower roots to tops.

Nickel

Natural soil contains small amounts of nickel. Furthermore, anthropogenic activities like as mining, smelting, coal and oil burning, sewerage, fertilizers, and agrochemicals are boosting nickel concentrations in specific regions (Gimeno-Garcia *et al.*, 1996) [9]. A contaminated soil's nickel concentrations can be 10 times greater than those found in natural soil (Izosimova, 2005) [11]. There are a wide range of physiological changes and toxic indications in plants when there is a high concentration of nickel in the soil (Rahman *et al.*, 2005) [25]. Wheat plants exposed to high levels of nickel showed higher MDA levels (Pandolfini *et al.*, 1992) [20]. There were also alterations in water balance in nickel-treated plants. As a result, the water content of dicot and monocot plant species declined. To measure the severity of nickel poisoning in plants, the reduction in water absorption is employed as an indication (Pandey and Sharma, 2002) [19].

Conclusion

Heavy metal contamination of soil and water in a shifting climate poses a severe danger to food safety, and is already becoming a substantial human and plant health concern. Due to the fact that some heavy metals cannot be decomposed, they stay in soil and require treatment. Abiotic stresses such as heavy metals have grown increasingly prevalent and pronounced due to human-caused disruption of biological resources on the globe. As a result, plants are now more vulnerable to heavy metal toxicity than ever before. The many negative repercussions of heavy metal stress on plants were explored in the current review. Heavy metals including cadmium, copper, lead, chromium, and mercury are important environmental contaminants, especially in regions with a lot of human activity. Extremely high levels of reactive oxygen species and methylglyoxal, which can damage DNA, are typical effects of heavy metal poisoning. Nevertheless, it is now challenging to determine the environmental consequences of particular metals due to a lack of research about them.

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