Responses of plants against heavy metal-induced ROS: A Review

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ABSTRACT

Plants are vulnerable to many injurious, environmental situations like biotic and abiotic stress, ultimately affecting their growth and development. Biotic stress is caused by living organisms such as insects, nematodes, bacteria, fungi etc. On the other hand abiotic stress arise from high or low temperature, light, drought, salinity and heavy metals. Some heavy metals are important for the plant, i.e. Cu, Zn, Fe but these metals are present in the soil in very less quantity, so these are called an essential micronutrient. Toxicity of heavy metals cause a reduction in plant growth and ultimately leads to the death of the plant. Metal concentration increase in soil due to human activity or geological origin. All heavy metals are toxic, and they cause mutagenesis in the plant, animal and aquatic ecosystem also. In recent years, in agricultural practices, use of wastewater from cities has made the significant accumulation of heavy metal in soil and agricultural product. Metals are transported from water to soil that cause contamination in soil and inhibit plant growth. Heavy metal contaminations in soil and agriculture have raised potential risks to plant, human and animals. In Response to metal stress plant possesses various protective mechanisms like chelation, detoxification and so on. Plant posses many defensive strategies like antioxidative defence system, antioxidant and osmolytes that protect the plant from stress condition. This defensive system activates during stress condition. This review focus on the heavy metal effect on plant and its defensive system on the plant.

INTRODUCTION

Plants are affected by many injurious environmental situations like biotic and abiotic stress. Biotic stress such as pathogen or herbivores and abiotic stress such as drought, cold, temperature, salt stress, heavy metal stress, excess light (Lin and Kao, 2005). Heavy metal stress is most harmful abiotic stress. Heavy metal stress is related to a metallic compound that is toxic or has a high density at low concentration in soil (Monni et al., 2000).

Heavy metal stress is the major abiotic stress nowadays, which affects the world widely. Heavy metals are more effective in causing environmental pollution. They cause many problems in the plant, animal and human being (Kjaer and Elmegaard, 1996). Their increased concentration in soil cause toxicity in the plant (Munzuroglu and Geckil, 2002) and lead to a reduction in plant growth and ultimately death of plant (Nematshahi et al., 2012). Some heavy metals are important for the plant, such as Cu, Zn, Fe but these metals are present in the soil in very less
quantity, so these are called as essential micronutrient (Okuma et al., 2004). Metal concentration increase in soil due to human activity or geological origin (Raskin et al., 1994).

Heavy metals are very toxic for plant growth, seedling and yield of the plant. They are not easily metabolised and neither they break down in the environment (Shenker et al., 2004). The main source of heavy metal in the environment is anthropogenic activities, agricultural waste, industrial waste and natural activities that increase their concentration in soil and affect the plant life (Sheoran et al., 1990). Agricultural wastes are the main source of soil contamination. Farmers use herbicides and fungicides on the plant that increase the concentration in soil. The exposure of plants to heavy metal, change its metabolic activities and leads to an alteration in physiological conditions (Sheldon and Menzies, 2005).

Heavy metal is essential for the plant in less concentration but their enhanced concentration adversely affects plant growth and its metabolic activities. Most of the heavy metals are toxic and cause mutagenesis in plant, animal and aquatic ecosystem also. They are harmful to all the living organisms as they cause very serious effects on all living organism (Yourtchi and Bayat, 2013). In recent years, in agricultural practices, the use of wastewater from cities has made the significant accumulation of heavy metal in soil and agricultural product (Panda and Patra, 2000). Metals are transported from water to soil that cause contamination in soil and inhibit plant growth (Santner et al., 2009). Heavy metal contamination in soil and agriculture has raised potential risks to plant, human and animals (Nguyen, 2008). In Response to metal stress plant possesses various protective mechanisms like chelation, detoxification and so on (Singh and Prasad, 2014). High metal concentration in soil leads to a reduction of shoots and root growth in plants (Cook et al., 1997). Excess Cu causes oxidative stress in plants that leads to disturbance in metabolic pathways (Doncheva et al., 2001).

All heavy metal have their metallic properties such as conductivity, ligand specificity, cation stability. These properties decide the nature of heavy metal, which one is more effective and which one is least effective on the plant, animal or microorganism (Graeber et al., 2012). Heavy metals like Co, Cu, Fe, Mn, Mo, Ni, V, and Zn are required in small quantities for the organism and plant their high concentration are very harmful to plant (Table 2). They bind to plant active site and block the activities of plant and other organism (Hussain et al., 2013).

**Table 1: Source of contamination in the atmosphere**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Heavy metal</th>
<th>Sources of contamination</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>As</td>
<td>Fossil fuel combustion, smelting operation, use of pesticides and herbicides, volcanic eruption</td>
<td>Cook et al., 1997</td>
</tr>
<tr>
<td>2.</td>
<td>Cr</td>
<td>Battery manufacturing, chrome plating, mining &amp; smelting, dyes &amp; wood, tanning of the animal skin, pigments.</td>
<td>Graeber et al., 2012</td>
</tr>
<tr>
<td>3.</td>
<td>Ni</td>
<td>Biological cycle, industrial process, dissolution of rocks &amp; soil, stainless steel utensils, diesel oil and fuel oil, atmospheric fall out.</td>
<td>Barrachina et al., 1995</td>
</tr>
<tr>
<td>S.No</td>
<td>Heavy metal</td>
<td>Plants</td>
<td>Harmful effect on plant</td>
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<tr>
<td>5.</td>
<td>Copper(Cu)</td>
<td>Rhodes grass, Black bindweed</td>
<td>Decreased in plant root growth. Decreased biomass, seed production and mortality of plant</td>
</tr>
<tr>
<td>7.</td>
<td>Manganese (Mn)</td>
<td>Broad beam, Pea, Tomato</td>
<td>The decrease in growth &amp; chlorosis. Reduction in growth, photosynthetic rate and chlorophyll content. Reduced plant growth and chlorophyll content.</td>
</tr>
<tr>
<td>8.</td>
<td>Cobalt(Co)</td>
<td>Mung bean, Radish, Tomato</td>
<td>The decrease in antioxidant activity, amino acid, sugar and protein content. Reduction in sugar, protein content &amp; antioxidant level. Lower down the nutrient content.</td>
</tr>
<tr>
<td>9.</td>
<td>Arsenic(As)</td>
<td>Rice, Canola, Tomato</td>
<td>Decrease growth &amp; leaf area Wilting and chlorosis, reduction in growth. Decreased fruit yield and weight of leaves.</td>
</tr>
</tbody>
</table>
Ni). Redox-active heavy metals involve in a redox reaction and result in the formation of $O_2^-$, $H_2O_2$, and $OH$ production (Nieboer and Richardson, 1980).

Redox-inactive heavy metals result in oxidation stress through an indirect mechanism. Heavy metals strongly bind to oxygen, nitrogen; sulphur atoms and stops the activity of plant ultimately leads to death (Sharma et al., 2011) (Fig. 3, Table 2).

**Defensive Strategies in Plants Exposed to Heavy Metal Toxicity**

Plants have some defence mechanisms against stress condition. Plants have integrated the system in cells that show defence against heavy metal stress. The first defence in the plant is a physical barrier and second, that is structural barriers (Dubey, 2011). Heavy metal toxicity causes redox imbalance in the plant system and it generates an antioxidative defence system in the plant (Nguyen, 2008).

Overproduction of ROS in the plant due to heavy metal accumulation in plants is combated by two types of defence system, i.e., enzymatic and non-enzymatic, that protect the plant from abiotic stress (Doncheva et al., 2001). Enzymatic antioxidants are a peroxidase, superoxidase dismutase, catalase, glutathione-s-transferase (GST) and non-enzymatic antioxidant that are ascorbic acid, proline, and glutathione. These two antioxidant defence system professionally work in the plant system and protect the plant from oxidative stress (Abedin et al., 2002). Heavy metal cause quantitative and qualitative change in membrane lipids this leads to the structural and functional status of membrane and inhibition of chloroplast electron transport than it leads to growth inhibition of plant (Barrachina et al., 1995).

**Cellular homeostasis:** *Anacystis nidulans* under Cu stress after Proline application it protect plasma membrane from Cu harmful effect (Kabir et al., 2009). This defensive system protects the plant from the harmful effect of stress (Fig. 1).

Proline, an amino acid that plays a highly beneficial role in plants exposed to the various stress condition. In plant proline accumulation has been reported to occur after salt, drought, pathogen infection, low temperature, high temperature, U.V radiation, nutrient deficiency (Doncheva et al., 2005). Proline metabolism in plants has mainly been to osmotic stress. Proline is the most widely distributed osmolyte it occurs in plant and many other organism (Jayakumar et al., 2007) (Fig.2, Table 3).

![Figure 1: Cellular homeostasis (Modified after Ashraf et al., 2007)](image-url)
Conclusion: Heavy metal stress is the major abiotic stress now a day, which affects the world widely. Heavy metals are more effective in causing environmental pollution. It causes many problems in plant, animal and human being. Heavy metals are very toxic for plant growth, seedling and yield of the plant. Heavy metals are not metabolised easily and neither are they break down easily in the environment. Heavy metal contaminations in soil and agriculture have raised potential risks to plant, human and animals. All heavy metal have their metallic properties such as conductivity, ligand specificity, cation stability. These properties decide the nature of heavy metal which one is more effective and which one is least effective on the plant, animal or microorganism. Plant shows some defence mechanism against stress condition.

REFERENCES


the National Academy of Sciences, India. 70: 75–80.


