**Cadmium in Plants: A Review**

Seyed Meysam Hoseini\(^1\)* and Fatemeh Zargari\(^2\)

1. Young Researchers of Islamic Azad University of Noor Branch
2. Medicinal Engineer Student, Maziar University, Noor

**Corresponding author:** Seyed Meysam Hoseini

**ABSTRACT:** Cadmium (Cd) is a toxic metal for living organisms and an environmental contaminant. Of all the non-essential heavy metals, cadmium is perhaps the metal which has attracted the most attention in soil science and plant nutrition due to its potential toxicity to humans, and also its relative mobility in the soil-plant system. Plant root is the main organ for uptake of pollutants including heavy metals like cadmium. This review summarizes the toxic symptoms of cadmium in plants.

**Keywords:** Heavy Metals, Cadmium, Toxicity, ROS

**INTRODUCTION**

Heavy metals are defined as metals having a density higher than 5 g cm\(^{-3}\). Of the total 90 naturally occurring elements, 53 are considered heavy metals and few are of biological importance (Hasan et al., 2009). Based on their solubility under physiological conditions, 17 heavy metals may be available to living cells and have significance for the plant and animal communities within various ecosystems (Weast, 1984). Increase in levels of heavy metals in soils could also be attributed to factors such as soil properties or different agricultural practices, for example application of sludge to agricultural land (Foy et al., 2005). Among the heavy metals Zn, Ni, Cu, V, Co, W and Cr are non-toxic heavy elements at low concentration. As, Hg, Ag, Sb, Cd, Pb and Al have no known function as nutrients and seems to be more or less toxic to plants and microorganisms (Beak et al., 2006). Accumulation of heavy metals such as cadmium in the environment is now becoming a major cause of environmental pollution. Cadmium (Cd) is one of the most deleterious trace heavy metals both to plants and animals. With the development of modern industry and agriculture, Cd has become one of the most harmful and widespread pollutants in agricultural soils, and soil-plant-environment system mainly due to industrial emission, the application of Cd-containing sewage sludge and phosphate fertilizers and municipal waste disposal (Dong et al., 2007). The maximum tolerable intake of Cd for humans, recommended by FAO/WHO is 70 μg/day (Vassilev and Yordanov, 1997). Cd pollution is of increasing scientific interest since Cd\(^{2+}\) is readily taken up by the roots of many plants species and its toxicity is generally considered to be 2–20 times higher than that of other heavy metals (Shah and Dubey, 1995). Cd phytotoxicity is a minor, but also important problem, especially in some highly heavy metal polluted regions, where a decrease in agricultural crop productivity has been observed. The main goal of this review is to outline our current understanding of the factors limiting the growth of plants exposed to Cd treatment.

**Heavy Metal Toxicity**

The toxicity produced by transition metals generally involves Neurotoxicity, Hepatotoxicity and Nephrotoxicity (Benavides et al, 2005). Differences in solubility, absorbability, transport and chemical reactivity in these metal will lead to specific differences in toxicity within the body. The chemical form of heavy metals in soil solution is dependant of the metal concerned, pH and the presence of other ions (Das et al., 2001). The toxicity symptoms observed in plants in the presence of excessive amounts of heavy metals may be due to a range of interactions at the cellular level (Hall, 2002). Toxicity may result from the binding of metals to sulphydryl groups in proteins,
leading to an inhibition of activity or disruption of structure (VanAssche, 1990). Enzymes are one of the main targets of heavy metal ions and prolonged exposure of soils to heavy metal results in marked decreases in soil enzymes activity (Tyler et al., 2003). In addition, heavy metal excess may stimulate the formation of free radicals and Reactive Oxygen Species (Fornazier et al., 2000).

**Cadmium Toxicity in Higher Plants**

Cadmium is a non-essential element that negatively affects plant growth and development. It is released into the environment by power stations, heating systems, metal working industries or urban traffic. Cadmium is recognized as an extremely significant pollutant due to its high toxicity and large solubility in water (Pinto et al., 2004). Important sources of cadmium input to the marine environment include atmospheric deposition, domestic waste water and industrial discharges (Benavides et al., 2005). Wagner (1993) estimated that non-polluted soil solutions contain cadmium concentrations range from 0.04 to 0.32 mM. Soil solutions which have a cadmium concentration varying from 0.32 to about 1 mM can be regarded as polluted to a moderate level (Benavides et al., 2005). Hence, cadmium classified as an element of intermediate toxicity, but the mechanisms of cadmium toxicity are not completely understood yet. Stomatal Opening, Transpiration and Photosynthesis affected by cadmium, and Chlorosis, Leaf Rolls and Stunting are the main symptoms of cadmium toxicity in plants (Sandalio et al., 2001). Cadmium also reduced the absorption of nitrate and its transport from root to shoot by inhibiting the Nitrate Reductase activity in shoots (Hernandez et al., 1996). Several researches have suggested that an oxidative stress could be involved in cadmium toxicity, by either inducing oxygen free radical production, or by decreasing enzymatic and non-enzymatic antioxidants (Sandalio et al., 2001).

**ROS Generation by Cadmium in Oxidative Stress**

Plants are organisms that exposed to different of stresses such as Drought, Salinity, UV, Light, Freezing and Heavy Metals. The intoxication with pollutant metals induces oxidative stress because they are involved in several different types of ROS-generating mechanisms that showed in Figure 1 (Bagchi, 1995).

![Fig 1. ROS Generation by Heavy Metals](image)

These radicals occur transiently in Aerobic organisms because they are also generated in plant cells during normal metabolic processes, such as Respiration and Photosynthesis (Asada, 1987). ROS can be extremely harmful to plant at high concentrations. ROS can oxidize proteins, lipids and nucleic acid, often leading to alterations in cell structure and mutagenesis (Halliwell and Gutteridge, 2000). The balance between the steady-state levels of different ROS are determined by the interplay between different ROS-producing and ROS-scavenging mechanisms, and can change drastically depending upon the physiological condition of the plant and the integration of different environmental, developmental and biochemical stimuli (Polle, 2001). A variety proteins function as scavengers ROS such as Superoxide Dismutase (SOD), Catalase (CAT), Ascorbate Peroxidase (APOX), Glutathione Reductase (GR) and Thioredoxin (Benvides et al, 2005). Cadmium was found to produce oxidative stress, but, in contrast with other heavy metals such as Cu, it does not seem to act directly on the production of ROS (Salin, 2003). Examples of the oxidative responses to cadmium reported in higher plants showed in Table 1 (Benvides et al, 2005).
Table 1. Antioxidant Enzymes modified in plants exposed to different cadmium concentrations

<table>
<thead>
<tr>
<th>Number</th>
<th>Plant Species</th>
<th>Cadmium Concentrations (µM)</th>
<th>Antioxidant Enzymes Modified</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pisum sativum</td>
<td>5</td>
<td>CAT, APOX</td>
</tr>
<tr>
<td>2</td>
<td>Triticum durum</td>
<td>1-10</td>
<td>CAT, APOX, SOD</td>
</tr>
<tr>
<td>3</td>
<td>Oryza sativa</td>
<td>100-500</td>
<td>CAT, SOD, GR</td>
</tr>
<tr>
<td>4</td>
<td>Arabidopsis thaliana</td>
<td>300-500</td>
<td>CAT, SOD, GR, APOX</td>
</tr>
<tr>
<td>5</td>
<td>Saccharum officinarum</td>
<td>500-700</td>
<td>CAT, SOD, GR</td>
</tr>
</tbody>
</table>

Plant Growth Response to Cadmium Treatment

The inhibiting effect of Cd on fresh and dry mass accumulation, height, root length, leaf area, and other biometric parameters of plants are reported in almost all investigations. The following phytotoxic symptoms were observed: root browning, leaf red-brownish discoloration, leaf epinasty and leaf chlorosis (Vassilev and Yordanov, 1997). Differences in the degree of expressed phytotoxicity due to various Cd-concentrations applied to the root medium, the duration of treatment, as well as the characteristics of species and cultivars were established. Increasing the duration of treatment and/or the Cd-concentrations led to transition of leaf chlorosis into yellowing and necrosis of leaf tips. The symptoms of phytotoxicity were expressed more clearly in roots because of the significantly higher heavy metal accumulation in them (Foy et al., 2005). The above pointed symptoms are not specific for Cd-treatment only, they have been observed in response to other heavy metals, too. The negative effect of Cd on plant growth was accompanied by an increase in dry to fresh mass (DM/DM) ratio in all organs (Moya et al., 1993).

CONCLUSION

Although our knowledge of Cd toxicity in higher plants as well as in the soil-plant system has increased considerably in the recent years, there are still many gaps in our knowledge about the basic mechanisms that control Cd movement and its accumulation in plants. Certainly more research is needed regarding the mechanism of Cd uptake by the root, translocation, and its deposition within plants. Additionally, the major forms of Cd in various staple plant foods (e.g. rice, wheat, corn, bean, and potato) need to be identified. We must elaborate the knowledge about the biochemistry of metal homeostasis factors, physical interaction of transporters, chelators and chaperones. Genetic approach as opposed to physiological/ biochemical investigations may assist in understanding the mechanism of metal tolerance. An improved knowledge in these crucial areas will help to elucidate the molecular mechanisms that lie beyond plant metal tolerance and homeostasis.

REFERENCES


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