

Review Article

A Review on the Effects of Cadmium Stress on Growth and Development of Plants

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Abstract: Cadmium (Cd) is a non-essential element readily taken up by the plants. Cadmium negatively affects plant metabolism affecting growth and development. It is released into the environment by a number of sources including power stations, metal working industries, heating systems, batteries and urban traffic. Cadmium is recognized as an extremely deleterious pollutant due to its high toxicity and large solubility in water, and has been ranked among the top toxins. Having significant concern with plant and human health, Cadmium has been widely studied for its impacts on plant at various levels including metabolism. The objective of this paper is to review the effect of cadmium stress on growth and development in plants.

Keywords: Cadmium, Growth and development, Heavy metals, Plants.

INTRODUCTION

Heavy metals are significant environmental pollutants [1] and their availability in soils depends on natural process, especially lithogenic and pedogenic, but also on anthropogenic factors such as mining, combustion of fossil fuels, urban waste disposal, soil runoff, metal working industries, boating activities, phosphate fertilizer application, sewage treatment plant effluents, and municipal solid waste disposal sites. 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 [2]. Household waste, municipal and industrial waste are also sources of heavy metals to soil [3]. Soil contaminated with the heavy metals above the permissible limit lead to declines in agricultural yields [4,5]. The accumulation of heavy metals in the environment is now becoming a major cause of environmental pollution.

Cadmium (Cd) is a naturally occurring metal situated in the Periodic Table of the Elements between zinc (Zn) and mercury (Hg), with chemical behavior similar to Zn. It generally exists as a divalent cation, complexed with other elements (e.g., CdCl₂). Cadmium exists in the earth's crust at about 0.1 part per million, usually being found as an impurity in Zn or lead (Pb) deposits, and therefore being produced primarily as a byproduct of Zn or Pb smelting [6]. The concentration of Cd in non-polluted soil solution ranges from 0.04 mM to 0.32 mM, and its concentration in the range of 0.32 to about 1 mM may be categorized as polluted [7].

Cadmium accumulation in plants has multiple direct and indirect effects on plant growth and alters many physiological functions [8] by forming complexes with O, N and S ligands [9]. They interfere with mineral uptake [10] protein metabolism [11] membrane functioning [12] water relations and seed germination [13]. Cadmium inhibited net photosynthesis in green algae, corn, soybean, and pigeon pea [14-16], O₂ evolution in *Anacystis nedulens* and photosystem II (PS II) in isolated chloroplasts of maize and spinach [14]. Moreover, they cause metabolic disturbance by altering essential biochemical reactions [17].

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Cadmium

Cadmium is 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 [18]. Important sources of cadmium input to the marine environment include atmospheric deposition, domestic waste water and industrial discharges [19]. Wagner [20] 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 [21]. 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 [22]. Cadmium also reduced the absorption of nitrate and its transport from root to shoot by inhibiting the Nitrate Reductase activity in shoots [23]. 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 [22].

Cadmium Stress in Plants

Effect of on fresh and dry mass

The inhibiting effect of Cadmium on fresh and dry mass accumulation, height, root length, leaf area, and other biometric parameters of plants are reported in almost all investigations. The interaction of Rhizobium in the nodules of chickpea was found to be very sensitive to heavy metals resulting in a decrease in dry mass of chickpea and green gram [24]. An increase in Cadmium concentration decreased the fresh mass in mung bean [25]. Moreover, a marked decrease in root and shoot mass of *Vigna ambacensis* was observed when treated with low concentration of Cadmium [26].

Effect on the plant growth

Cadmium is not an essential nutrient and at high concentration inhibits plant growth [27]. It has also been reported that even at relatively low concentrations it alters plant metabolism [9]. The presence of cadmium in the soil decreases the growth of soybean [28] and chickpea plants [29]. High concentrations of Cadmium decreased cell growth as well as whole plant growth [30].

Effect on photosynthesis

Cadmium is an effective inhibitor of photosynthesis [31]. A linear relationship between photosynthesis and inhibition of transpiration was observed in soybean that suggests Cadmium inhibited stomatal opening [32]. Cadmium damages the photosynthetic apparatus, in particular the light harvesting complex II [33] and photosystems I and II [34]. The inhibition of root Fe^{3+} reductase induced by Cadmium leads to Fe^{2+} deficiency which seriously affects photosynthesis [35]. Cadmium also causes stomatal closure in higher plants [36] and an overall inhibition of photosynthesis [37].

Effect on chlorophyll and protein content

The presence of Cadmium decreased the content of chlorophyll and carotenoids, and increased non-photochemical quenching in *Brassica napus* [38]. Similarly, the synthesis and level of chlorophyll decreased in other plant species under the influence of the cadmium [39,40]. Growth reduction associated with cadmium treatment was probably caused by inhibition of protein synthesis [2]. Phytotoxicity of the metal in other crop plants has been observed in the form of a loss in protein levels [11]. Moreover, the grains developed on the plants grown under Cadmium stress had lower protein content [41].

Effect on nodulation

The presence of heavy metals such as cadmium in the soil decreased the yield of symbiotic nitrogen-fixing organisms and the number of nodules per plant [42]. The presence of Cadmium decreased nodulation and nitrogenase activity in *Phaseolus vulgaris* [28,42], *Trifolium repens* [43], soybean [44], *Alnus rubra* [45] and in *Pisum sativum* [46]. Nitrogen assimilation in pea plants was severely affected on exposure to Cadmium [23, 46]. A positive correlation was observed between leghemoglobin content and nitrogenase activity [47] and both these parameters exhibited a parallel decrease in the presence of Cadmium [48]. The oxidation stress generated by Cd^{2+} accelerated senescence of nodules in soybean plants [49].

Effect on nitrate reductase activity

Nitrate reductase (NR), the primary enzyme in the nitrate assimilation pathway, is the limiting factor in plant growth and development [51] and its level is influenced by a variety of environmental factors [51]. The presence of Cadmium in the soil affected the assimilation of NO_3 in maize [23,52], pea [53], *Silene vulgaris* [54], bean and tomato [55] and in *Cicer arietinum* [56].

Effect on antioxidant systems

Plants possess a number of antioxidant systems that protect them from oxidative damage [57]. Superoxidase (SOD) is the first enzyme in the detoxifying process that converts O₂ - radicals to H₂O₂ at a very rapid rate [58]. Cadmium was found to result in oxidative stress [59] by either inducing oxygen free radical production [60] or by decreasing concentrations of enzymatic and non-enzymatic antioxidants [61]. These defense systems are composed of metabolites such as ascorbate, glutathione, tocopherol, etc., and enzymatic scavengers of activated oxygen such as peroxidases, catalases and superoxide dismutases [62]. Peroxidase induction is a general response of higher plants after uptake of toxic quantities of metals [9]. Cadmium ions can inhibit or sometimes stimulate the activity of several antioxidative enzymes. In *Halianthus annuus* leaves, Cadmium enhanced lipid peroxidation, increased lipoxygenase activity and decreased the activity of superoxidase [63], glutathione reductase, catalase, ascorbate peroxidase, glutathione reductase and dehydroascorbate reductase [64]. Cadmium induced the activity of peroxidase (POX) in soybean [65], bean leaves [66] and in roots and leaves of *Oryza sativa* [67].

CONCLUSION

Cadmium is a non-essential element readily taken up by the plants. Cadmium negatively affects plant metabolism affecting growth and development, nodulation, chlorophyll and protein content, as well as photosynthesis rate. Cadmium also reduced the absorption of nitrate and its transport from root to shoot by inhibiting the Nitrate Reductase activity.

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