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Inhibition of Ubiquitous Metal Uptake by Plants Due to the Presence of Cadmium In The Soil

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Abstract

Studies suggest that Cadmium (Cd), a heavy metal, is hazardous to human health. Cd is an ubiquitous metal and found in low concentration in earth's curst. However, anthropogenic activities may contribute to high level of Cd pollution in soil. Studies also suggest that Indian Mustard (*Brassica juncia*) plants can bioaccumulate considerable amounts of Cd from soils. To better understand the interactions of various omnipresent soil metals in the presence of a major soil pollutant, this study evaluates the plant uptake of different ubiquitous soil metals such as lead (Pb), copper (Cu), cobalt (Co), and nickel (Ni) in the presence of varied levels of soil Cd concentrations. *Brassica juncia* plants were grown in the laboratory under color corrected lights in Memphis silt loam soil containing 0, 100, and 250 ppm Cd. Plants were harvested on day 30 of the experiment. Dried plant samples were acid digested for tissue metal content analysis using Inductively Coupled Plasma Mass Spectrometry. Results indicated that Cd uptake by plants was dose related and the presence of Cd as a major soil contaminant, interfered with the uptake of other ubiquitous soil metals.

Keywords: Ubiquitous metals, Cadmium, Bioaccumulation, Indian Mustard plants.

1.0 Introduction

Various metals are ubiquitous in the biosphere and found in low concentrations in natural soils. Plants may uptake such metals from soils as part of their regular physiological processes. Some plant species have been reported to accumulate high concentrations of these metals in the plant tissues (Kumar *et al*., 1995; Saygideger, 2000; Addae *et al*., 2010; Shumaker, 2009; Lopez-Chuken, 2010; Zaman and Lockett, 2010; Shumaker *et al*., 2011) High concentrations of metals such as aluminum (Al), cadmium (Cd), copper (Cu), lead (Pb), manganese (Mn), nickel (Ni), zinc (Zn), etc. in soil pose crucial environmental concerns as they may get into the food chain through absorption into edible plant tissues, and induce hazardous effects (Adriano, 1992; ATSDR, 2009; de Vries, 2007). So far, over 400 plant species have been reported to accumulate metals from soil (Purakayastha and Chhonkar, 2010;).

Cadmium, a tasteless and odorless natural element in the earth's crust, is known to produce deleterious health effects (ATSDR, 2009). Due to anthropogenic activities over the past few decades, Cd soil concentrations have significantly increased, therefore, posing a serious health risk to humans. While Cd is naturally present in low concentrations in soil, its concentration can reach the 100 ppm level in areas immediately adjacent to mines, smelters, and Ni-Cd battery plants (ATSDR, 2009) which is considered to be a toxic level and must be remediated before the land can be used for public use.

Although numerous studies have been conducted on the plant absorption of major metal toxicants (Reeves and Brooks, 1983; Vassil *et al*., 1998; Walley, 2005; Moffat, 1995; Dudka *et al*., 1996; Wu *et al*., 1999; Zaman *et al*., 2003) from heavily contaminated soils, a careful review of literature reveals that to date, no study has been conducted to evaluate how the presence of a major soil metal contaminant may influence the plant uptake of other naturally occurring soil metals. This is an important piece of information as it will help to better understand the interactions of various ubiquitous soil metals among themselves and with major soil metal contaminants. This study investigates the bio-uptake of Cd by Indian Mustard (*Brassica juncea*) plants from Cd con-

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taminated soils and how it influences the uptake of other omnipresent soil metals.

2.0 Methods

2.1 Soil Preparation

Brassica juncea plants were grown in Memphis silt loam soil. This soil containing about 70% silt, 20% clay, 9% sand, and 1% organic matter with a pH of 6.9 (Panicker, 1992), and covers over 3-million acres of land in Mississippi, Louisiana, Alabama, and Tennessee. Surface soil (about 4" from the top) was collected from an undisturbed forest area of southwest Mississippi. Collected soil was air-dried, ground, and passed through a 2 mm sieve. Cadmium was added to this sieved soil at different concentrations as described in the following treatment protocol.

2.2 Planting and Treatment

Brassica juncea seeds were grown in 6.5 ounce-porous bottom planters with 150 grams of soil (dry weight) per planter. A one-centimeter depression was made in the center of the soil and one pre-germinated seed (radicle length of about 1 mm) was placed into each depression and then covered with soil. The planters were placed in reservoir trays. Each treatment group had its own separate reservoir tray. The plants were placed for 16-hour light and 8-hour dark cycles under color corrected lights with a light energy of 1.4 quanta/ sec/cm^2. Watering was done every other day or as needed with distilled water and once a week with modified Hoagland solution (Hoagland and Arnon, 1950). The plants were maintained under laboratory conditions for 30 days at 23.0 ± 0.45°C and a relative humidity of 59.0 ± 3.0%.

Plants were divided into a control group and two Cd treated groups (grown in soils containing 0, 100 and 250 ppm Cd, respectively). There were 12 plants per group. Cadmium was mixed with the soil in the form of $Cd(NO_3)_2$ (Fisher Scientific, New Jersey, USA).

2.3 Tissue Metal Analysis

For tissue metal content analysis, the USEPA Method 3050A (USEPA, 1986) was used to extract the Cd in the plant sample. Reagent blanks were used to determine if any contamination was detectable from the glassware, reagents, and/or other sources. To perform this procedure, 0.25 g of oven dried plant samples were transferred to 125 ml Erlenmeyer flasks. To each flask, 15 ml of nitric acid (HNO_3) and 10 ml of deionized water were then added. The samples were then heated on a hot plate for 45 minutes at medium heat. The samples were allowed to cool and after adding 5 ml of HNO_3, the samples were then refluxed again for 30 minutes. The last step was repeated to ensure complete oxidation. The samples were then heated (without boiling) to evaporate to 5 ml. After this, the samples were allowed to cool again, and 2 ml of deionized water was added along with 3 ml of 30% hydrogen peroxide (H_2O_2) to each sample. The samples were then heated to start the peroxide reaction. 30% H_2O_2 was continually added in 1 ml aliquots until the effervescence became minimal. The acid-peroxide digestate was heated for a final time to reduce the digestate down to 5 ml. After cooling, the samples were diluted to a total volume of 100 ml with deionized water. The digestate was then filtered using Whatman Number 1 filter paper (Fisher Scientific, New Jersey, USA) to remove any particulates that may have been present in the sample. The filtrate was then ready for heavy metal analysis. Metal concentrations in plants were determined using Inductively Coupled Plasma Mass Spectrometry following modifications of US EPA Method 6020 using a Perkin Elmer Elan DRC-II ICP-MS (Waltham, MA).

2.4 Statistical Analysis

Data obtained in this study was analyzed by one-way Analysis of Variance (ANOVA) and the Tukey test.

3.0 Results and Discussion

Results indicate that *B. juncea* plants could tolerate high Cd concentrations in soil and bio-absorb high concentrations of Cd in plant tissues. Tissue Cd concentration in treated plants were significantly higher ($p \leq 0.05$) than the control plants. Cadmium absorption in 100 and 250 ppm Cd treated plants were 25 and 100 times higher than the soil Cd levels (See Figure 1).

Results also indicate that control plants absorbed more naturally occurring soil metals (Pb, Co, Cu, and Ni) as compared to the Cd treated plants. Although, Pb and Co accumulations were elevated in control plants as compared to the 100 and 250 ppm Cd treated groups, the differences were statistically significant only between control and the 250 ppm Cd treated plants (see Figures 2A and2B). Although, copper and nickel accumulations in control plants were slightly higher as compared to the Cd treated plants, the differences were not statistically significant (See Figures C and D).

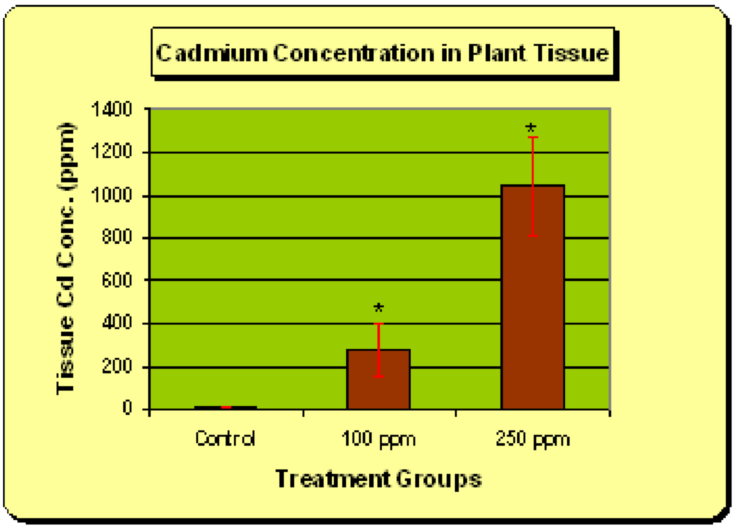

Figure 1: Cadmium accumulation (mean ± SEM, n = 12) in Indian Mustard plants grown in 0, 100, 250, and 500 mg/kg Cd contaminated soils (* Means are significantly different from the control at $p \leq 0.05$ level: Tukey Test).

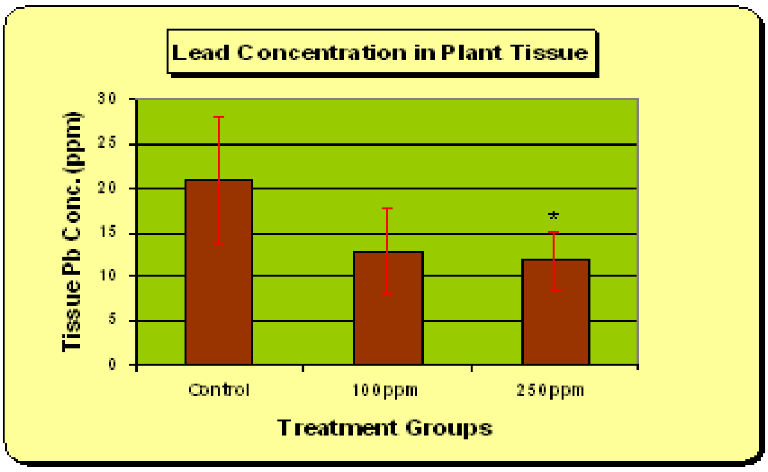

Figure 2A

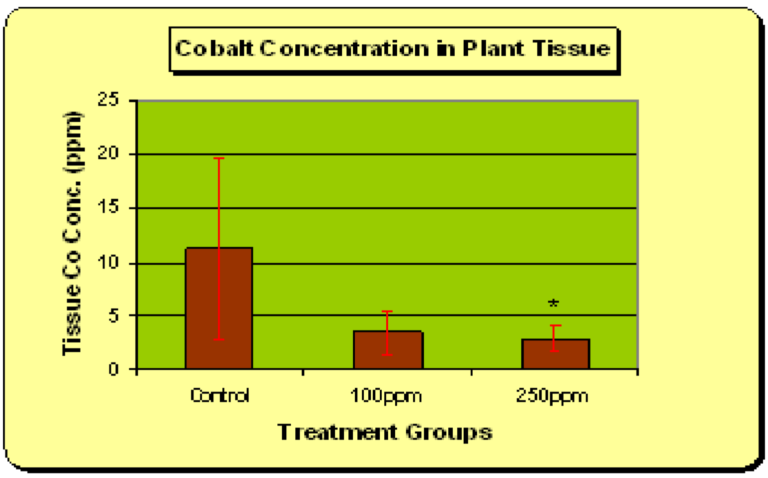

Figure 2B

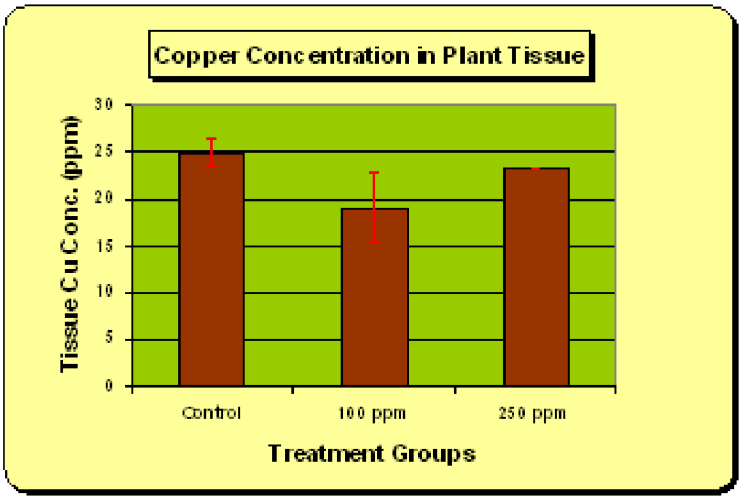

Figure 2C

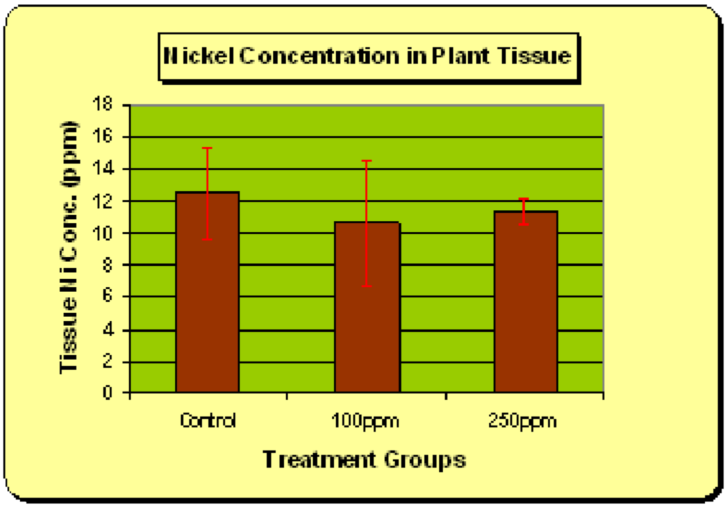

Figure 2D

Figure 2: Lead, Cobalt, Copper, and Nickel accumulation (mean ± SEM, n = 12) in Indian Mustard plants grown in 0, 100, 250, and 500 mg/kg Cd contaminated soils (* Means are significantly different from the control at $p \leq 0.05$ level: Tukey Test).

Metal bioaccumulation by plants occurs through a series of complex interactions between plants and soil. It depends on plants metal tolerance, and metal uptake efficiency, bioavailability of the metal, and the physicochemical properties of the contaminant and the media such as soil pH, soil texture, soil organic matter content, etc. (Adriano, 1992; Morel, 1997; Gerard *et al.*, 2000; Saygideger, 2000). In this study, decreased absorption of naturally occuring soil metal in Cd treated plants was probably due to a competition between ubiquitous soil metals and Cd for metal binding receptors in plant roots. As soil Cd concentration was higher than other metals, Cd engaged most of the plant root receptors, and thus enough receptors were unavailable to ubiquitous metals. Similarly, higher absorption of naturally occurring soil metals in control plants could be contributed by relatively higher availability of metal receptors in the roots of the control plants as compared to Cd treated plants. Thus this study indicates that the availability of metal receptors in plant roots and selectivity of these receptors to specific metal ions may play an important roll in plants capability to uptake soil metals. Further investigation is needed to fully understand the interactions among various soil metals and their uptakes by metal scavenging plants.

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