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Effect of Selenite and Selenate on Plant Uptake of Cadmium by Maize (*Zea mays*)

K. Shanker, S. Mishra, S. Srivastava, R. Srivastava, S. Dass, S. Prakash, M. M. Srivastava

Department of Chemistry, Faculty of Science, Dayalbagh Educational Institute, Dayalbagh, Agra-282005, India

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Selenium has been reported to posses remarkable capabilities for conferring tolerance to the toxicities of various heavy metals (Whanger 1981). Cadmium, a highly toxic and non essential heavy metal, which enters the food chain via plant uptake from soils, is known to be counteracted by selenium. Selenium has been shown to reduce availability of cadmium to plants along with other aspects of its toxicokinetics (Sugawara et al 1989; Oldfield 1992; Zakaria et al 1993). Asher et al (1997) found that plants, when supplied with selenite, had selenium concentrations in the xylem exudate lower than selenate. Most of the selenate was transported as selenate and unidentified organic Se compounds, with some modifications prior to its translocation in the plant. In contrast, Gissel Nielson (1987) noted that Se distribution among various Se fractions within plants did not depend significantly on whether selenite or selenate was used. Selenium has a strong tendency to form complexes with heavy metals like Cd, Hg, Ag and TI (Perizek et al 1971; Whanger 1992). It has been suggested that the protective effects of selenium are due to the formation of non toxic Se-metal complexes, although the mechanism by which this protective effect is exerted remains unclear (Gunn et al 1968; Chen et al 1975). Studies on the effect of selenium (selenite) and cadmium additions to the soil on their concentrations in lettuce and wheat has indicated the role of selenite in reduction of cadmium uptake (Cary 1981). The detoxifying effect of sodium selenite on cadmium ion in the freshwater fish *Polyacuthus cupanus* has been reported (Fiamakrishna et al 1988).

The discovery that an element like selenium, known to be toxic itself (at elevated levels), counteracts the toxicity, chemical carcinogenesis and reduces the plant uptake of other toxic metals, highlights the possibility of existance of a Se-metal interaction mechanism in soil plant systems. Limited studies are reported on Se-metal interactions, mainly confined to animal systems, and little attention has been paid to such interactions, particularly those with different oxidation states of selenium and heavy metals in soil-plant systems.

The uptake and translocation of root-absorbed chromium supplied through irrigation in the trivalent and hexavalant states in various parts of the onion plant *(Allium cepa)* grown in soil and sand culture has been recently reported by us (*Srivastava* et al 1994). In continuation of that, this preliminary report describes the effect of selenite and selenate pretreatment on the uptake of cadmium in the maize plant (Zea *mays).*

Correspondence to: M. M. Srivastava

MATERIALS AND METHODS

Pot-culture experiments were conducted in the laboratory on the maize plant for a growth period of 40 days. The plants were grown in plastic containers with 2.5 kg. soil of the following characteristics : pH 8.2, EC-0.23 mmhos/cm, organic carbon-0.08%, texture sandy loam. A basal dose of N:P:K (60:20:18) mg/kg fertilizer was initially applied to the soil. About eight seeds were sown in each pot and after ten days of germination four plants per pot were retained for the study. The plants were irrigated as required, using distilled water.

The sodium selenite (Na_2SeO_3) and sodium selenate (Na_2SeO_4) which represent the tetravalent and hexavalant forms of selenium, respectively, and cadmium nitrate ($CdNO_3$) used for treatment were of AR grade. Concentrations of selenite and selenate (Inactive) (0, 0.5, 1.0, 2.0, 4.0, 6.0 µg/ml) were mixed with two levels of cadmium (2 and 5 µg/ml), labeled with Cd-115m activity and supplied to the plants separately. Cd-115m was obtained from the Board of Radiation and Isotope Technology (BRIT), BARC, Bombay and was found radiochemically sufficiently pure.

The plants were subjected to the above treatment for a period of 10 days and were kept in a fumehood with a daily illumination of fourteen hours (600 w/m^2). After the treatment period, the plants were harvested and separated into roots and aerial parts. The plant parts were washed thoroughly with water, pH2 HNO_3 and finally with distilled water. The pH of the washings was tested to ensure that no detectable acidity was left and that there was no detectable external contamination of the plant parts by Cd-115m. The plants were oven-dried at 60°C for about 48 hr and were sized into smaller parts. Accurately weighed amounts of dried material were counted over a planar Nal (TI) detector coupled to a 4k MCA (Canberra Acuspec Card with PC-AT 386). The counting geometry was pre-calibrated for efficiency with known amounts of Cd-115m activity. From 0.934MeV photopeak area, the activity of Cd-115m was calculated and converted to total amounts of cadmium in the different plant parts per gm of dry weight.

RESULTS AND DISCUSSION

Summaries of the effects of varying concentrations of selenite and selenate (0.5-6.0 µg/ml) on the uptake and translocation of cadmium irrigated at two different levels (2µg/ml and 5µg/ml), done separately, are depicted in Tables 1 and 2.

Table 1. Plant-tissue concentrations of cadmium (µg//g dry weight) in various parts of maize irrigated with 2µg/ml of cadmium

Selenite/Selenate	Cadmium uptake µg/g in presence of selenite		Cadmium uptake µg/g in presence of selenate	
Conc. µg/ml	Root µg/g	Shoot µg/g	Root µg/g	Shoot µg/g
0.0	87.05	23.11	87.05	23.11
0.5	51.36	20.52	75.96	21.66
1.0	50.32	14.36	55.11	18.90
2.0	23.84	9.17	40.81	13.37
4.0	22.16	8.22	34.59	9.73
6.0	20.82	7.37	24.73	9.03

Table 2. Plant-tissue concentrations of cadmium (µg/g dry weight) in various parts of maize irrigated with 5µg/ml of cadmium

Selenite/Selenate	Cadmium uptake µg/g in presence of selenite		Cadmium uptake µg/g in presence of selenate	
Conc. µg/ml	Root µg/g	Shoot µg/g	Root µg/g	Shoot µg/g
0.0	173.48	44.96	173.48	44.96
0.5	113.79	37.94	126.27	38.24
1.0	102.38	28.78	112.86	30.31
2.0	95.14	24.72	104.28	28.01
4.0	81.20	21.66	83.90	23.10
6.0	63.06	19.97	76.79	21.10

The data represent the mean of four plants per concentration. Data were computed for correlation coefficient and the Mann-Whitney test (independent) 'U' statistic was calculated to determine whether the concentrations in the roots and shoots treated with selenite and selenate belonged to same population.

The data in Tables 1 and 2 suggest that in both the root and aerial part of the plant (shoot), an increase in the concentration (0.5-6.0 µg/ml) of selenite and selenate results in a decrease in the uptake of Cd at the 2 and 5 µg/ml Cd levels in feed water. The correlation coefficients between concentration of selenite, selenate and corresponding uptake values of cadmium were computed. The results revealed effective negative correlations between selenite vs uptake of Cd by root : -0.9268, selenate vs uptake by root : -0.8994, selenite vs uptake by shoot : -0.7762, selenate vs uptake by shoot -0.9268, significant at $p > 0.05$ level. However, the range of concentration (0.5-6.0 µg/ml) of selenite and selenate used appeared to be more effective in the reduction of uptake at the lower level (2µg/ml) of cadmium.

Figures la & b show the plot of the reduction in uptake (%) as a function of varying selenite and selenate concentrations. The levels of accumulation in different parts of the plant viz., root and shoot, indicate that a small amount of cadmium is translocated to the aerial part of the plant. Selenite and selenate additions to the soil through irrigation appeared to reduce the uptake (%) of cadmium more in the root than in the aerial part of the plant. A similar trend has been observed in both the experiments treated with 2 and 5µg/ml of cadmium. However, this effect was more pronounced at the cadmium concentration of 2µg/ml. Our observations confirm those of Francis and Rush (1973) who suggested that selenium may decrease Cd availability from the soil.

The reduction in the uptake of Cd at the concentration range studied was not found to vary significantly ($p= 0.2623$) with the species, selenate or selenite used. However, a relatively discernable reduction in cadmium observed in plants treated with selenite can be attributed to the tendency of the reduced form of Se (Cary 1981) or selenite (Whanger 1992) to form a Cd-Se complex which appears to be unavailable to the plants. Selenite seems to be less available to the plants, being less mobile (Arvy 1993), and may form complexes after being reduced directly to selenide, thereby causing a decrease In the uptake of cadmium by the plant. Selenate is, however, a rather mobile anion (Gustafsson and Johnson 1992) and is available for Cd-Se formation only after followlng

Fig 1a.

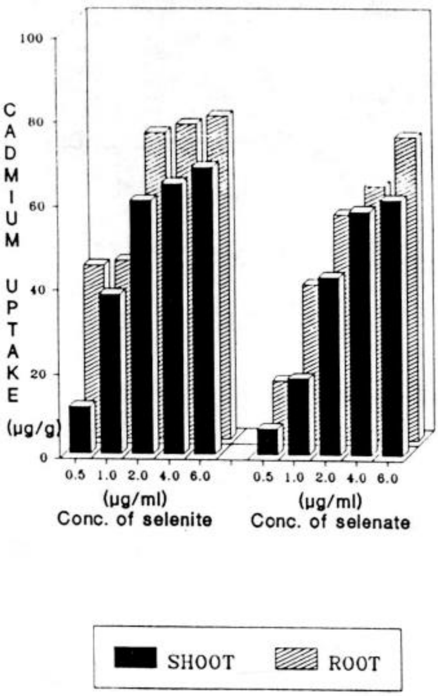

Fig 1b.

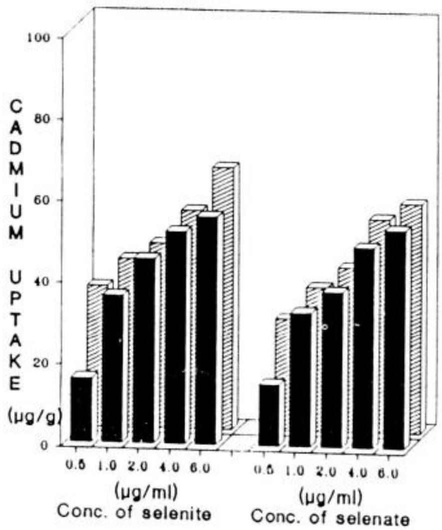

Figure 1. Percentage reduction of Cd uptake in plant tissue of maize in presence of selenite and selenate, irrigated with Cd (2 µg/ml, Fig. 1a.) and Cd (5 µg/ml, Fig 1b.)

a more complicated redox process involving (SeO_4^{--}, SeO_3^{--}, Se_o) species. Selenate is available in greater amounts to plants than selenite because the latter can be withdrawn from the soil by a number of processes (Alemi et al 1991). Further, selenite has also been reported to adsorb strongly on various metal species (Balistrieri et al 1990) and is considered a potentially important detoxifying chemical (Babicky and Benes 1971).

The present study demonstrates reduction in cadmium uptake with increasing concentrations of selenite and selenate treatments given to the maize plant. In general, for both selenite and selenate treatments, reduction in cadmium uptake is greater in the root than the corresponding value for the aerial part of the plant at a given concentration. However, no statistically significant difference in cadmium uptake was obtained for selenite and selenate amendments to the plant at either of the Cd concentrations (2 or 5 µg/ml) tested.

Further experiments on soil and sand cultures are required to explain the mechanistic aspects of the formation of Se-Cd complexes. Sand, being an inert matrix, would highlight the role of various ionic species involved in Cd-Se interaction, while a comparison of soil and sand is expected to explain the role of various species present in soil in modifying the interactive effects of Cd-Se, and their subsequent uptake by plants,

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REFERENCES

Alemi M H, Goldhamer D A, Nielsen DR (1991) Modelling selenium transport in steady-state unsaturated soil columns. J Environ Qual 20: 89-95

Arvy M P (1993) Selenate and selenite uptake and translocation in bean plants (*Phaseolus vulqaris*). J Exp Bot 44:1083-108

Asher C J, Butler G W, Peterson P J (1977) Selenium transport In root systems of tomato. J Exp Bot 103: 279-291

Babicky A, Benes J (1971) The toxifing effects of selenium: Interrelation between compounds of selenium and certain metals. In : Mettz W and Cormatzer W E (eds) Newer Trace Elements in Nutrition. Dekker N Y, pp. 85-119

Balistrieri L S, Chao T T (1990) Absorption of selenium by amorphous iron oxyhydroxide and manganese dioxide. Geo Chim et Cosmo Acta 54: 793-751

Cary E E (1981) Effect of selenium and cadmium additions to soil on their concentrations in lettuce and wheat. Agron J 73: 703-708

Chen R W, Whanger P D, Weswing P H (1975) Selenium induced redistribution of cadmium binding to tissue proteins : A possible mechanism of protection mechanism against cadmium toxicity. Bio Inorg Chem 4: 125-133

Francis C W Rush S G (1973) Factors affecting uptake and distribution of Cadmium in plants. In: Hemphil D D (ed) Trace Substances in Environmental Health-VII. University of Missouri, Columbia pp 75-81

Gissel–Nielsen G (1987) Fraction of selenium in barley and rye grass. J Plant Nutr 10: 2147-2152

Gunn S A, Gould T C, Anderson W A D (1968) Selectivity of organ response to cadmium injury and various protective measures. J Pathol Bacteriol 96:89-96

Gustafsson J F, Johnson L (1992) Selenium retention in the organic matter of Swedish forest soils. J Soil Sci 48:461-472

Oldfield J E (1992) Risk and benefits in agricultural uses of selenium. Environ Geochem Health 14::81-86

Perizek J, Beues T, Ostalova T, Babicky A (1971) The detoxifying effects of selenium: interrelations between compounds of selenium and certain toxic metals. In : Mertz W, Cormatzer W E (eds) Newer Trace Elements in Nutrition. Dekker N.Y. pp. 85-119

Ramakrishna T, Abhiriendra N, Vatsla S, Sreekumar O, Navaneeth V, Suudamini K K (1988) Selenite neutralizes the toxic effects of cadmium. Ind J Environ Helth 30: 355-359

Srivastava M M, Juneja A, Dass S, Srivastava R, Srivastava S, Mishra S, Srivastava S. Singh V, Prakash S (1994) Studies on the uptake of trivalent and hexavalant chromium by onion (*allium cepa*). Chem Speci Bioavail 6: 27-30

Sugawara N, Hirohata Y, Sugawora C (1989) Testicular dysfunction induced by cadmium and its improvement caused by selenium in the mouse. J Environ Pathol Toxicol Oncol 9: 53-64

Whanger P D (1981) Selenium and heavy metal toxicity. In : Spalholz J E, Martin J L, Ganther H E (eds) Selenium in Biology and Medicine. AVI Westport, Conn. pp. 230-255

Whanger P D (1992) Selenium in the treatment of heavy metal poisoning and chemical Carcinogenesis. J Trace Elem Electrol Health Dis 6:209-221

Zakaria Z, Wabha T, Coogan P, Rhodes S W, Waalkes M P (1993) Protective effects of selenium on cadmium toxicity in rats : Role of altered toxicokinetics and metallothionein. J Toxicol Environ Health 36: 171-182