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RESPONSE OF TOMATO AND CORN PLANTS TO INCREASING Cd LEVELS IN NUTRIENT CULTURE

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Abstract

The aim of this study was to determine the effect of increasing Cd levels (0, 0.05, 0.1, 1, 2,5,10 and 20 µg mL^{-1} Cd) on plant dry matter, mineral content and plant tolerance of tomato and corn grown in nutrient culture. Tomato and corn seedlings were transferred to the nutrient solution and Cd was added. Growth differences were evaluated after 3 weeks of Cd applications. Growth sharply increased in tomato but more gradually in maize. Growth in tomato declined faster than in corn. Statistical analysis of data showed that there was a significant relationship between dry matter decrease and mineral content of tomato and corn.

Introduction

In recent years there have been a large number of reports on the presence of heavy metals, including cadmium, chromium, lead and mercury in higher plants. Most of these reports were concerned mainly with environmental pollution. The presence of heavy metals in the food chain and genotypical differences in the critical toxicity levels of heavy metals in plants has been reported (Marschner, 1983).

The most common heavy metal contaminants are Cd, Cr, Cu, Hg, Pb and Zn. Metals are natural components in soil. Contamination, however, has resulted from industrial activities, such as mining and smelting of metalliferous ores, fertilizer, pesticide application and generation of municipal waste (Kabata-Pendias & Pendias, 1989)

The amount of cadmium that accumulates in plant is limited by several factors including: (1) Cd bioavailability within the rhizosphere, (2) rates of Cd transport into roots *via* either the apoplastic or sympllastic pathways, (3) the proportion of Cd fixed within roots as a Cd- phytocchelatin complex and accumulated within the vacuole, and (4) rates of xylem loading and translocation of Cd (Salt *et al*., 1995).

Cadmium (Cd) is highly toxic to animals and plants. In plants exposure to Cd causes reductions in photosynthesis, water and nutrient uptake (Sanità di Toppi & Gabbrielli, 1999). As a consequence, Cd-exposed plants show various symptoms of injury such as chlorosis, growth inhibition, browning of root tips and finally death (Kahle, 1993). Since, the presence of Cd or other heavy metals prevents the development of a normal vegetation cover, biotechnological efforts are under way to develop more stress-tolerant species. For this purpose, it is important to understand the mechanisms of Cd toxicity and tolerance in plants (Schützendübel *et al*., 2002). This metal disrupts the physiological processes by binding to protein sulpohydryl groups or causing deficiency/substitution of essential metal(s) (Van Assche & Clijsters, 1990).

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The ability of plants to accumulate metals and possibility other contaminants varies with both the nature of plants species and the nature of metal contaminants. Laboratory studies consistently demonstrate that the capacity of plants to bioaccumulate metals varies extensively with the nature of metals as well as with plant types. Plants readily take up cadmium, even though it is not an essential plant nutrient. Due to its chemical similarity to zinc (an essential plant nutrient), cadmium can readily interfere with some plant metabolic processes and is therefore toxic to many plants. Plants, however, do vary in their sensitivity to cadmium. Nutrient solution concentrations of 0.1 mg L^{-1} reduce the yields of bean, beets and turnips by 25%, whereas cabbage and barley yields of field crops grown in soil were found at cadmium concentrations varying from 4 mg L^{-1} for spinach to 640 mg L^{-1} for rice. The regular consumption of cadmium-enriched foods over decades results in the accumulation of cadmium to concentrations that are detrimental to human health (APHA, 1989; Ayers & Westcott, 1985).

Heavy metals such as Cd, Cr, Hg and Pb in agricultural eco-systems take place in biological cycles. They may be deposited in different plant tissues and their availabilities depend on concentrations and mobility. In both fruits and vegetables, the critical level of Hg and Cd is very low (0.05 mg L^{-1}) (Haktanır & Arcak, 1978).

Extractable heavy metal concentrations in soil may cause toxicity when these concentrations are over 1 mg L^{-1} for Cd, 10 mg L^{-1} for Co, 0.1 mg L^{-1} for Cu, 10 mg L^{-1} for Se, 0.5-1 mg L^{-1} for Va and 100 mg L^{-1} for Ni (Yildiz, 2001).

The uptake mechanism for Cd^{2+} by plants is not known. Recent results of Gonzalez *et al.*, (1999) suggest that Cd^{2+} like Ca^{2+} and Zn^{2+} is translocated across the tonoplast by a proton antiport.

The objective of this study was to determine the response of tomato and corn against increasing Cd levels in nutrient culture and to what extent Cd is accumulated in these two crops.

Material and Methods

The study was conducted to determine Cd toxicity on tomato and corn plants under the greenhouse conditions during April and May of 2001 in Erzurum, Turkey. Tomato (*Lycopersicon esculentum* L. cv. Kaya f1) and corn (*Zea mays.* L. cv. TMP.1 Akpınar) cultivars were grown and Arnon (1938) nutrient solution was used as growth medium. Tomato and corn seeds were germinated in soil + sand mixture (1+3) for 2 weeks after which the seedlings were transferred to containers (3 liters per pot) having nutrient solution (stable water culture technique). $CdSO_4$ (as a Cd source) was added to the standard nutrient solutions to give concentrations of 0, 0.05, 0.1, 1, 2, 5, 10 and 20 µg mL^{-1} Cd, after one week in the standard nutrient solution.

The experiment was carried out in greenhouse conditions for a period of two months. The test plants were harvested just before flowering. All nutrient solutions were aerated with an air compressor every day and renewed once for every 2 weeks. Before flowering, the plants were photographed and harvested for evaluation of their mineral content and yield (Kacar, 1972).

The leaf and stem samples were dried at 70°C for 48 h and then grounded. Total macro and microelement concentrations of plants were determined in the dry ashed solutions of the samples. N was determined by N-analyser, K by flame emission atomic absorption spectrophotometry (Ca, Fe, Cu, Zn, Mn) and spectrophotometry: (P) and Cd content of plants were determined by graphite oven attached Atomic absorption spectrophotometry (Kacar, 1972).

Results and Discussion

The results showed that yield and mineral composition of tomato and corn plants varied significantly ($p \leq 0.01$) depending on treatments (Table 1). The highest yield was obtained in the control. Dry matter production decreased dramatically with increasing concentrations of Cd (Table 2, 3). Decrease in yield of both crops was observed at 0.1 mg L^{-1} Cd and reached to acute toxicity (leaf chlorosis and termination of growth) at 2 mg L^{-1}.

Nitrogen content of tomato was not affected until 0.1 mg L^{-1} Cd but it was decreased with 1 mg L^{-1} Cd. Phosphate content of tomato between 0 and 0.05 mg L^{-1} Cd level was in the normal range, but it decreased at higher Cd levels. Potassium content of tomato was not stable and did not show a clear trend. Calcium content of the tomato was not affected by Cd. Mg content of tomato was low in all treatments, except the control. Fe and Zn contents of plants were in adequate level. Mn contents of tomato decreased with increase in external Cd level.

In corn, the N contents decreased generally to insufficient level. Phosphorus content of corn plant decreased starting from 2 mg L^{-1} Cd level. Potassium and calcium contents were not at sufficiency level except at the control K and Ca contents of corn decreased with increase in Cd regimes. Mg content of plant was reduced and insufficient for plant growth after 0.1 mg L^{-1} Cd level. Fe content of plant was insufficient from 1 mg L^{-1} Cd to onwards. Zn content of corn plant was not much affected. Mn contents of corn plant decreased to insufficient level based on the criteria reported by Walsh & Beaton (1973). Cd contents of corn and tomato plant increased with increasing Cd application.

As reported in Table 3 and 4, dry matter content of tomato plant decreased 21 and 32% with 0.05 and 0.1 mg L^{-1} Cd applications, respectively. Decrease in the relative dry matter production changed gradually with increasing Cd doses and reached up to 92% at 20 mg L^{-1}. However, dry matter of corn decreased 32 and 44% at 0.05 and 0.1 mg L^{-1} Cd application and reached to 82% at the highest Cd application. Cd tolerance indices were calculated following Das *et al*., (1999) and presented in Table 4.

$$\text{Tolerance indexes} = \frac{\text{Growth (dry matter) increase in Cd level}}{\text{Growth (dry matter) in nutrient solution without Cd}} \times 100$$

The results of the present study showed that yield reduction of tomato and corn plants with tolerance index of 79.2 and 68.6 were approximately 20.8 and 31.4% at 0.05 mg L^{-1} Cd, respectively (Table 4). However, yield reduction of tomato and corn were 92.2% and 82% at 20 mg L^{-1} Cd, respectively.

In the both tomato and corn plants uptake of macro- and micronutrients was below the critical levels. The level of nutrients absorbed by plants is related to the amount of available nutrients in the growth medium. Meanwhile, uptake of nutrients increases for some nutrients or decreases for the others depending on antagonistic or synergistic (interactions) effects among plant nutrients.

Duncan's Multiple Range Comparison Test indicated that the effect of doses on the dry matter except the 10 and 20 mg L^{-1} Cd applications were significantly different in both plants (Table 2, 3). The chemistry of Cd and Zn are similar to each other. Therefore, a special importance has been given for both elements. Cd concentrations of both plants increased with increasing concentrations of Cd in the growth medium, and differences among the means for Cd doses were significant (Table 2, 3). Zn concentrations of tomato

Table 1. The results of analyses of variance in relation to increasing Cd levels.

Cd levels	Dry matter g kg^{-1}	N g kg^{-1}	P g kg^{-1}	K g kg^{-1}	Ca g kg^{-1}	Mg g kg^{-1}	Fe µg g^{-1}	Zn µg g^{-1}	M µg g^{-1}	Cd µg mg^{-1}
					Tomato					
F values	830***	586***	12**	27**	23***	302***	105***	50.8***	329***	263***
					Corn					
F values	99.5***	99.5***	18.2***	20.5***	55.9***	1.06^{ns}	62.6***	847***	159***	164***

, * = Significant at 0.01 and 0.001 levels, respectively
ns= not significant

Table 2. Duncan test results for the mean values of effect of the increased Cd concentration on dry matter and mineral content of tomato plant grown in nutrient culture.

Cd . level µg mL^{-1}	Dry matter g kg^{-1}	N g kg^{-1}	P g kg^{-1}	K g kg^{-1}	Ca g kg^{-1}	Mg g kg^{-1}	Fe µg g^{-1}	Zn µg g^{-1}	Mn µg g^{-1}	Cd µg mg^{-1}
0	3.85a	3.45a	0.55a	0.65 cd	1.85ab	0.395a	115b	82c	172a	2.8g
0.05	3.05b	3.25ab	0.45abc	0.55 d	1.75bc	0.18b	147a	71d	162a	12g
0.1	2.65c	3.15b	0.40abcd	0.9 bc	2.05a	0.175b	142a	65d	140b	32f
1	1.35d	2.15c	0.50ab	1.25 a	1.95ab	0.185b	92de	87bc	97c	57e
2	1.05e	1.95c	0.35bcde	1.2 a	1.9ab	0.17ab	111bc	92b	68d	75d
5	0.55f	0.95d	0.3cde	1.15 ab	2.0ab	0.135c	100cd	102a	55de	95c
10	0.45fg	0.85de	0.25de	0.8 cd	1.55c	0.105d	84ef	66d	54de	115b
20	0.30g	0.55e	0.20e	0.65 cd	1.25d	0.105d	75f	72d	53e	145a

Table 3. Estimates of Duncan test for the mean values of the effect of increased Cd concentration on dry matter and mineral content of corn plant.

Cd level. $\mu g\ mL^{-1}$	Dry matter $g\ kg^{-1}$	N $g\ kg^{-1}$	P $g\ kg^{-1}$	K $g\ kg^{-1}$	Ca $g\ kg^{-1}$	Mg $g\ kg^{-1}$	Fe $\mu g\ g^{-1}$	Zn $\mu g\ g^{-1}$	Mn $\mu g\ g^{-1}$	Cd $\mu g\ mg^{-1}$
0	4.15a	2.70a	0.65ab	2.25ab	1.6a	0.23a	117ab	185a	375a	2.1h
0.05	2.85b	1.55b	0.55ab	1.30b	1.25c	0.25a	137a	177a	366a	27g
0.1	2.35c	1.35bc	0.55a	1.1cd	1.2c	0.185a	127a	163b	371a	54f
1	2.05d	1.15c	0.50ab	0.95de	1.55a	0.180a	101bc	113c	125b	82e
2	1.65e	0.80d	0.4bc	1.25ab	1.6a	0.69a	120ab	97d	98c	98d
5	1.15f	0.55de	0.25c	1.1cd	0.9d	0.175a	87c	68e	77d	105c
10	0.85g	0.40e	0.25c	1.0de	1.15c	0.145a	61d	60e	62de	147b
20	0.75g	0.35e	0.20c	0.85e	1.4b	0.135a	47d	60e	58e	163a

Table 4. Tolerance indexes of tomato and corn plants*.

Cd level (μg mL^{-1})	Tomato	Corn
0.05	79.2	68.6
0.1	68.8	56.6
1.0	35.0	49.3
2.0	27.2	39.7
5.0	14.2	27.7
10.0	11.6	20.5
20.0	7.8	18.0

* Calculated by tolerance index equation (Das *et al*., 1999)

plant decreased with increasing Cd in the growth medium until 0.1 mg L^{-1}, but it was unstable thereafter. However, Zn concentrations of corn decreased with increasing Cd doses in the growth medium. On the other hand, tolerance indexes of tomato and corn plants changed in the range of 79.2-7.8 and 68.6-18 in response to (0.05-20 μg mL^{-1} Cd), respectively. Our results confirmed the data of previous studies indicating that increased Cd dose in nutrient culture up to 10 mg L^{-1} causes yield reduction at 75 % for bean, 65 % for sugar beet, 60 % for turnip and 40 % for corn (Haktanır & Arcak, 1978).

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