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Seed Vigor of Maize Grown on the Contaminated Soils by Cadmium

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Abstract: Cadmium is one of the highly toxic heavy metals in the agricultural soils. The effects of cadmium on plant growth have been reported by many authors, but the effects of cadmium content of seeds on germination and seed vigor have not been reported in the literature. A cold test study was conducted to evaluate the effects of different levels of cadmium contamination of soils on seed vigor of maize grown on contaminated soils. The experiment was designed in a randomized complete block design with a split-plot arrangement. Soil series (Comba and Reyhanlı) were in the main plots and cadmium contamination levels (0, 10, 20, 40 and 60 mg kg^{-1}) were in the sub-plots. Four replications of 50 seeds from each treatments were planted in cold test for germination and seed vigor. Germination and strong seedling ratios of maize seeds significantly decreased with increases in cadmium contents of soils and the highest germination and strong seedling ratios (90.3, 84.3%, respectively) were observed at uncontaminated soils, whereas, the lowest ratios (79.8, 70.8%, respectively) were at the highest level of Cd contaminated soils.

Key words: Maize, germination, seedling, cold test, contamination

INTRODUCTION

Maize (*Zea mays* L.) is one of the important cereals grown in most countries in the world with total areas exceeding 160 million ha (FAO, 2010). Maize producers wants to buy quality seeds, because of it's profund influence on the yield of maize.

Cadmium (Cd) is one of the highly toxic heavy metals in the agricultural soils. Cadmium is released into the environment by power stations, heating systems, metal-working industries, phosphorus fertilizers and urban traffic (Benavides *et al*., 2005). Elevated Cd concentration of soils reduces plant growth, development and crop quality. It is a highly mobil element in the environment and plants can easily uptake cadmium and transfer it to aboveground organs (Ciécko *et al*., 2004). It is recognized as an extremely significant pollutant due to its high toxicity and large solubility in water (Pinto *et al*., 2004). Cadmium can alter the uptake of nutrient elements by plants through its effects on the availability of elements in the soil solution or through a reduction in the population of soil microbes (Moreno *et al*., 1999). Malekzadeh *et al*. (2007) reported that cadmium treatments, increased GPx (glutathione peroxidase) and APX (apical protein X) activities in root of maize seedlings in the presence of 0.25, 0.5, 0.75 mM $CdCl_2$ concentrations, but their activities were constant in 1, 3 and 5 mM. Increased concentrations of $CdCl_2$ from 0.25 to 5 mM decreased root length progressively. Chaffai *et al*. (2006) declined that after exposure to 100 μM Cu or Cd for 4 days, maize seedlings showed a significant decrease in root and shoot growth and increase in Cu and Cd content. Chaffai *et al*. (2007) examined the fatty acid composition and the polar lipid profiles in maize seedlings treated with 100 μM Cd. Their results showed that the phosphatidylglycerol (PG) and monogalactosyldiacylglycerol (MGDG) content in shoots were markedly decreased indicating that the cadmium toxicity caused severe damage to the structure and function of photosynthetic membranes. The increase of the malondialdehyde (MDA) content in roots indicates an oxidative stress, which can be involved in mediating compositional membrane alterations. Heavy metal stress cause changes in the lipid composition and the membranes become rigid thus resulting in changes in the activity of enzymes bound to membranes (Fodor *et al*., 1995). The Cd toxicity induce production of oxygen free radicals by decreasing enzymatic and non-enzymatic antioxidants. Reactive oxygen species are to change oxidative modification of proteins towards formation of reactive aldehydes that modified proteins show increased hydrophobicity (Reinheckel *et al*., 1998; Pacifici and Davies, 1990). Both the differences in membranes structure and protein structure reduces the germination ability of seed.

Iwai *et al*. (1975) reported that an increase of cadmium concentration in nutrient solution caused an increase of sodium and cadmium content in maize plant and a decrease of nitrogen, iron, manganese, zinc and total dry weight.

The effects of Cd on plant growth have been reported by many authors (Haghiri, 1973; Iwai *et al*., 1975;

Benavides *et al*., 2005; Yıldız, 2005; Pál *et al*., 2006), but the germination and vigor of seeds, obtained from the plants grown on soils contaminated by cadmium, have not been reported in the literature.

Seed vigor refers to both the ability and strength of a seed to germinate successfully and establish a normal seedling. Vigor is positively related to the ability of a seed population to establish and optimum plant stand, in both optimum and sub-optimum soil environments and therefore, to maximize yield (Dornbos, 1995). Seed vigor defined by AOSA (1983) as seed properties which determine the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions. Copeland and McDonald (1995) declained that vigor tests can have an important role in seed production and making decision of marketing.

Seed vigour testing has become vital to quality control and marketing for many commercial seed companies in the last decades. The cold test is one of the oldest methods of stressing seeds and is most often employed for evaluating seed vigor in corn and soybeans (Copeland and McDonald, 1995). The cold test is widely used in the hybrid corn industry as a means of determining seed vigor. Martin *et al*. (1988) reported that the cold test was a superior predictor of field emergence of corn. A research by Byrum and Copeland (1995) concluded that cold test was apropriate for vigour tests.

The objective of this study was to determine germination and seedling vigor of seeds obtained from maize plants grown on the contaminated soils with different levels of cadmium.

MATERIALS AND METHODS

Seed material: Seeds were harvested from maize plants grown in polyethilene pots which contained 10 kg dry soils of two different soil series which are contaminated by different cadmium levels (0, 10, 20, 40, 60 mg Cd kg^{-1}, as $CdCl_2$ 2.5 H_2O). The first (Comba) of soil series had high organic matter content (15%) and the second one (Reyhanlı) was poor in organic matter (1.9%).

Cadmium content of seeds were determined with ICP-AES (Varian, Liberty Series II) after wet digestion procedure with HNO_3-$HClO_4$ mixture (4/1, v/v). Cadmium contents of seeds significantly increased upon contamination degrees of soils and seed cadmium content varied from 0.38 to 0.987 mg kg^{-1} in Comba soil and from 0.044 to 1.008 mg kg^{-1} in Reyhanlı soil.

Vigor tests: Soil obtained from the top 5 cm of a corn field at the MKU Agricultural Faculty Experiment Station was used for the cold test. The soil was screened through a 5 mm sieve and 250 g dry soils were placed into 19×6×9.5 cm plastic containers. Four replications of 50 seeds from each treatments were planted in each plastic container and covered with 250 g dry soil. A calculated quantity of prechilled (10°C) distilled water was added to adjust the moisture content to 70% of water holding capacity. The containers were then covered and incubated at 10°C in darkness for 7 days. The containers then moved to a 25°C chamber with an altering light source (12 h light per day) for 4 day grow-out period and normal seedlings were counted for germination ratio. Seedlings classified as strong or weak after 7 days as described by Fiala (1987). The experiment was designed in a randomized complete block design with a split-plot arrangement with four replications in 2009. Soil series (Comba and Reyhanlı) were in the main plots and cadmium contamination levels (0, 10, 20, 40 and 60 mg kg^{-1}) were in the sub-plots.

Data were subjected to Analysis of Variance (ANOVA) using the statistical software package (MStat-C) and means were separated using Duncan's multiple range test ($p \leq 5\%$). Correlation coefficients were calculated between germination, seed vigor and seed cadmium contents.

RESULTS AND DISCUSSION

Vigor tests: Germination ratios of maize seeds in cold test significantly affected by contamination levels with cadmium (Table 1). Germination ratios slightly decreased in the lowest contamination level according to uncontaminated soil and differences were not statistically significant, but germination percentage significantly decreased with increasing contamination degrees in both soil series. The lowest germination (79.8%) observed at the seeds obtained from the plants grown on the soils contaminated by the highest cadmium level, when the highest germination (90.3%) observed at the seeds obtained from uncontaminated soils (Table 1). Strong seedling ratios significantly decreased with increase in cadmium contents of both soils (Table 2), when the weak

Table 1: Germination ratios (%) of maize seeds harvested from plants grown on contaminated soils by different levels of cadmium

	Cadmium contents of soils (mg kg^{-1})					
Soil series	0	10	20	40	60	Mean
Comba	90.5	89	84	81.5	80.5	85.1
Reyhanlı	90	88	86	83	79	85.2
Mean	90.3a*	88.5ab	85bc	82.3cd	79.8d	

LSD (5%) for comparisons of cadmium contents: 1.34. *Means with the same letter are not significantly different ($p \leq 0.05$) according to Duncan's multiple range test

Table 2: Strong seedling ratios (%) of maize seeds harvested from plants grown on contaminated soils by different levels of cadmium

	Cadmium contents of soils (mg kg^{-1})					
Soil series	0	10	20	40	60	Mean
Comba	85.3	85.5	76.5	72.5	72.3	78.4
Reyhanlı	83.3	81	78	75	69.5	77.4
Mean	84.3a*	83.3a	77.3b	73.8c	70.9d	

LSD (5%) for comparisons of cadmium contents: 2.7. *Means with the same letter are not significantly different ($p \le 0.05$) according to Duncan's multiple range test

Table 3: Weak seedling ratios (%) of maize seeds harvested from plants grown on contaminated soils by different levels of cadmium

	Cadmium contents of soils (mg kg^{-1})					
Soil series	0	10	20	40	60	Mean
Comba	5.3	3.5	7.5	9.0	8.3	6.7b
Reyhanlı	6.8	7.0	8.0	8.0	9.5	7.9a
Mean	6.0bc*	5.3c	7.8ab	8.5a	8.9a	

LSD (5%) for comparisons of cadmium contents: 2.0. *Means with the same letter are not significantly different ($p \le 0.05$) according to Duncan's multiple range test

seedlings increased (Table 3) and there were not statistically significant differences between uncontaminated soils and the lowest cadmium level containing soils. The strongest seedling ratio (84.3%) observed for the seeds of maize grown on uncontaminated soils and the lowest strong seedling ratio (70.9%) observed at the seeds of maize grown on the soils contaminated at the highest level of cadmium (Table 2).

Also weak seedling ratios were higher in the higher contaminations (Table 3).

Present results indicated that the seed quality of maize was significantly affected by cadmium contents of soils. Germination and strong seedling ratios of seeds of maize plants grown on the contaminated soils decreased with increases in the cadmium contents of soils (Table 1-3).

The level of Cd uptake in higher plants is determined by the Cd concentration of the soil and by its biological activity. Cadmium can cause toxicity to plants, such as the inhibition of growth and photosynthesis, the activation or inhibition of enzymes, disturbances in plant-water relationships, ion metabolism and the formation of free radicals. Heavy metals are also able to interact with essential macro and microelements, thus exerting a significant influence on plant nutrient uptake (Pál *et al*., 2006). The uptake of Cd ions seems to be in competition for the same transmembrane carrier with nutrients, such as K, Ca, Mg, Fe, Mn, Cu, Zn and Ni (Clarkson and Luttge, 1989; Rivetta *et al*., 1997). Increasing amounts of Cd concentration in growing media limits the nutrient transport to shots (Yıldız, 2005). On the other hand, cadmium inhibits germination processes and the development of seedlings (Rascio *et al*., 1993). Maize

Table 4: Correlations coefficients

	Seed cadmium content	Strong seedlings	Weak seedlings
Germination	-0.723**	0.922**	-0.159
Strong seedlings	-0.836**		-0.528**
Weak seedlings	0.548**		

**Significant at $p \le 0.01$

plants grown in the presence of 10 μM Cd^{2+} showed significant growth reduction of both roots and shots (Nocito *et al*., 2002). In addition, Cd has been reported to inhibit the activities of several other enzymes involved in nitrogen metabolism (Boussama *et al*., 1999; Kumar and Dubey, 1999), glycolysis and the pentose phosphate pathway (Chugh and Sawhney, 1999) and sulfate assimilation (Lee and Leustek, 1999). Modified proteins can undergo a change in their hydrophobicity producing protein aggregates, or giving rise to formation of peptide fragments (Pacifici and Davies, 1990). This change can inversely affect the germination and seedling growth.

Correlations: There were significant relations between cadmium content and seed vigor. Germination and strong seedling ratios were significantly and negatively correlated with the seed cadmium content, whereas, the weak seedlings positively correlated with Cd content. There were also significant positive correlations between germination and strong seedling ratios, whereas significantly negative correlations were observed between strong and weak seedling ratios (Table 4). This indicates that cadmium inhibits the germination processes and th development of seedlings (Rascio *et al*., 1993). The growth inhibition is positively related to Cd concentration by reduction in the viability of root cells (Siroka *et al*., 2004).

Consequently, these results indicated that seed production of maize should be made on uncontaminated soils to obtain high quality seeds.

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