RESEARCH ARTICLE

International Journal of Agriculture, Environment and Food Sciences 2023; 7(4): 785-791

DOI: https://doi.org/10.31015/jaefs.2023.4.8

The effect of zinc application on growth and alleviating shoot concentration of cadmium in durum wheat plant growth under conditions of salt and cadmium stress

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Abstract

A study was conducted in a greenhouse to investigate the effect of the combination of cadmium (Cd) and salinity (NaCl) stress in zinc (Zn) deficiency on growth, Cd accumulation in durum wheat (*Triticum turgidum* L. durum, cv. Balcali-2000), and micro (Zn, Fe, Cu, Mn) minerals differing in salt tolerance. The negative effects of Cd and NaCl stress on plant growth and Cd accumulation detected to alleviate Cd uptake on wheat growth increasing zinc application. The results revealed that Cd, NaCl and their combined stresses reduced shoots dry matter and Cd concentration in shoots increased compared to control pots. In increasing Cd and NaCl treatments, increasing Zn application significantly decreased the Cd concentration in shoot. In particularly, the decrease in Cd concentration was more noticeable with the improvement of Zn nutrition of plants at low doses of NaCl and Cd. The effect of increasing zinc treatments on reducing Cd accumulation decreased to slightly at high doses of Cd and NaCl. According to the results it can be suggested that Zn application to soils with low Cd content and medium salinity can be reduce Cd uptake by durum wheat.

Keywords: NaCl stressed, Cd reduced, Micro nutrient, Cd accumulation

Citation: Ozkutlu, F. (2023). The effect of zinc application on growth and alleviating shoot concentration of cadmium in durum wheat plant growth under conditions of salt and cadmium stress. International Journal of Agriculture, Environment and Food Sciences, 7 (4), 785-791

Received: *September 25, 2023*

Accepted: *December 6, 2023*

Published Online: *December 17, 2023*

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Available online at
https://jaefs.com/
https://dergipark.org.tr/jaefs

INTRODUCTION

Heavy metal contamination of agricultural soils has developed into an important problem for the environment. In addition to the natural decomposition heavy metals are also entering soils from anthropogenic sources due to increased human activities. Therefore, heavy metal pollution of agricultural soils creates a risk to crop production globally. (Rizvan et al., 2016). Among heavy metals, Cd is the most toxic and can be to humans, animals, and plants even at very low concentrations. Cd levels in soils are typically around 0.1 mg kg^{-1}, and the acceptable Cd content in agricultural soils is 3 mg kg^{-1}. (Alloway, 1995). It has been reported that the average Cd concentration of the world's agricultural soils is 0.53 mg kg^{-1} and Cd concentration in soils ranges from a minimum of 0.01 to a maximum of 2.7 mg kg^{-1} (Kabata-Pendias and Pendias 1992; Szolnoki, et al., 2013). Although Cd concentrations in soils are low, high Cd accumulation can be observed in cereals such as wheat, maize and rice, which play an important role in human nutrition. Toxic effects of Cd are observed in humans who regularly consume plants containing more than 3 mg kg^{-1} Cd in their tissues (Alloway, 1995). More than half of the world's population receives their basic food needs from wheat (Triticum aestivum L.), the third-most significant cereal crop in the world after rice and maize (FAO, 2012). Cereal crops can easily uptake Cd from the soil and compared to other cereals, wheat can easily uptake Cd through its roots and accumulate high concentrations in its grains even when Cd is at very low concentrations in the soil (Jafarnejadi et al., 2011). Cd accumulated in wheat grain enters humans through the food chain and causes serious health problems (Järup et al., 1998; Du et al., 2020). Therefore, FAO/WHO (2010) reported that the maximum permissible limit of Cd in wheat grain is 0.1 mg kg^{-1}. The capacity of wheats to accumulate Cd in grain is different and it has been explained that durum wheat varieties accumulate higher Cd compared to bread wheat varieties (Gao et al.,2011; Naeem et al., 2016). In recent years, various strategies to minimize Cd risks to human health and to reduce Cd bioaccumulation have been investigated. For this, it is very important to know the factors that increase or decrease Cd transport in wheat. Cd addition to the soil solution and bioavailability depend on factors such as Cd content of the soil, different metals in the soil, cation exchange capacity (CEC), pH and soil salinity (Gallego et al., 2012). In various studies, it has been explained that soil salinity increases Cd uptake by plants (Norvell et al., 2000; Özkutlu et al., 2007). One of the most significant abiotic stresses influencing crop yield is salinity. Salinity lowers nutrient uptake and accumulation and reduces the plant's ability to absorb nutrients, according to a number of studies. (Essa, 2002; Fernández-García et al., 2004; Aydemir et al., 2023). Additionally, salinity causes a number of problems for plant growth, such as nutrient deficiencies and diseases. (Santos et al., 2002). The effect of Cd stress on nutrient uptake and distribution is related with the way it affects plant growth. There have been reports of Cd stress affecting the uptake of minerals including Fe, Zn, Cu, and Mn in crops as wheat. (Zhang et al., 2002) and barley (Wu and Zhang, 2002; Wu et al., 2003). It is widely recognized that NaCl and Cd stress together can promote Cd uptake and accumulation in plants grown in Cd-contaminated soils (Smolders et al., 1998; Ghallab and Usman, 2007; Özkutlu et al., 2007; Ondrasek, 2013; Özkutlu, 2020). Zn is an essential element in the nutrition of plants, animals, and humans while Cd, which enter soils from a variety of sources and is a significant environmental pollution, is not. Zinc (Zn) is crucial for plant and human metabolism, in addition to being a cofactor for more than 300 enzymes, including DNA and RNA polymerases. One of the sustainable strategies to reduce Cd accumulation in plants is to increase the supply of beneficial nutrients to plants (Hussain et al., 2019; Wu et al., 2019). As many researchers have shown that due to the chemically similar properties of Zn and Zn application can efficiently reduce plant Cd uptake is a good alternative (Özkutlu and Erdem, 2018; Khan et al., 2019; Rizwan et al., 2017; Wu et al., 2019). Although salinity increases Cd uptake by plants, Cd uptake may decrease with Zn application. In this research, Cd and Zn, Fe, Mn, Cu accumulation durum wheat were investigated grown under different Cd, Zn and NaCl treatments.

MATERIALS AND METHODS

Pot soil preparation

For studying, a Zn deficient soil of Central Anatolian taken from wheat field in Eskişehir-Sultanönü region origin was used in the experiment. The soil was sieved using a 4 mm sieve after initially being air dried. Table 1 shows some of the soil's chemical and physical properties.

Table 1. Physicochemical Characteristics of the Soil Used in the Experiment

Soil properties	Measurue	Methods
Sand, %	8.6	Bouyoucous, 1952
Silt, %	30.8	
Clay, %	60.6	
Texture	Clay (C)	
pH (1/2.5)	8.08	Jackson, 1959
Organic matter (%)	0.70	Jackson, 1959
$CaCO_3$ (%)	14.2	Scheibler Calcimeter
DTPA-Zn (mg kg^{-1})	0.1 0	Lindsay and Norvell, 1978
DTPA-Cd (mg kg^{-1})	0.005	Lindsay and Norvell, 1978
Total Zn (mg kg^{-1})	51	Schlichting and Blume, 1966
Total Cd (mg kg^{-1})	0.27	Schlichting and Blume, 1966
EC (mmhos/cm)	0.22	U.S. Salinity Loboratory Staff, 1954

Plant growth conditions and cadmium, salt and zinc treatments

Pots in experiment were filled with 1.65 kg of soil. Before sowing the seeds, the basic fertilizers and application doses were added to each pot as solutions and mixed thoroughly and homogeneously mixed into the soil. Basal fertilizers and Cadmium (Cd), Salt (NaCl), Zinc (Zn) doses applications: 200 mg N in the form of $Ca(NO_3)_2 4H_2O$; 100 mg P and 125 mg K in the form of KH_2PO_4 and as the application doses of the experiment; increasing Cd doses (0, 0.2 and 1.0 mg Cd) in the form of $(CdS0_4)_3.8H_20$; increasing NaCl doses (0, 250, 2500 mg NaCl) and increasing Zn (0, 0.05, 0.5, 5.0 mg Zn) in the form of $ZnSO_4.7H_2O$. The pots in the greenhouse were completely random during the experiment's random plots trial design, which included four pot replicates for each treatment. In plastic pots, durum wheat seeds (*Triticum turgidum* L. durum, cv. Balcali-2000) were planted. In each pot, six plants were grown. The pots were watered everyday with deionized water during the experiment. Plants were grown until differences occurred of shoot, and at harvested on the 30th day. After determining the dry weight of each plant's shoots, the concentrations of Cd, Zn, Fe, Mn, and Cu in the shoots were determined using inductively coupled argon plasma optical emission spectrometry (Jobin-Yvon, JY138-Ultrace), which was used to digest the shoot samples in 65% (w/w) nitric acid using a closed microwave system (Milestone, 1200-Mega).

Statistical analysis

All data used the means among treatments were compared with excell . Results were given in the form of mean±std.

RESULTS

Shoot Dry Matter Weights (DW)

This research was carried out to determine the effect of increasing Zn doses on the decrease in Cd uptake of durum (Balcali-2000) wheat under Cd and NaCl stress. Since the soil used in the experiment was a Zn-deficient soil, increasing Zn doses applied to the soil increased the shoot dry matter yield of the plant at different doses of both NaCl and Cd, as expected (Table 2). For example, when NaCl 0 and Cd (1.0 mg kg^{-1}) were applied, the shoot dry matter yield was at the level of 122 mg $plant^{-1}$, but with increasing Zn application, this value increased to 124, 155 and 171 mg $plant^{-1}$, respectively (Table 2). On the other hand, with increasing amounts of NaCl (0, 0.025% and 0.25% NaCl) doses application and 1.0 mg kg^{-1} of Cd, the dry matter yield of the plants decreased from 122 mg $plant^{-1}$ to 106 and 89 mg $plant^{-1}$ as 37%. These results show that dry matter yield decreases significantly with increasing NaCl stress in Cd 1.0 mg kg^{-1} contaminated soil. In the results, by applying high 5.0 mg Zn kg^{-1} dose had increased by 37% compared to the control an improving effect on shoot dry matter yield in the plant growing under 1.0 mg Cd kg^{-1} and NaCl 0.25% stress (Table 2).

Shoot Cd and Zn, Fe, Mn, Cu Concentration

In each NaCl treatment, increasing Zn application had a decreasing effect on Cd concentration in shoot. Under Zn0 and NaCl0 conditions, when 5 mg Zn kg^{-1} application, the average Cd concentration was 19.1 mg kg^{-1} in the application of 1.0 mg Cd kg^{-1}, while it decreased to 15.9 mg kg^{-1} when 5 mg Zn kg^{-1} application, control Cd concentration decreased by 20% from 19.1 mg kg^{-1} to 15.9 mg kg^{-1} (Table 3). Especially, at low doses of NaCl and Cd, shoot Cd concentration decreased more significantly with improved Zn nutrition of the plants. For example, under at the nil NaCl and Zn0 conditions, when Cd was applied at 0.2 mg kg^{-1}, the Cd concentration of the control plant was 3.8 mg kg^{-1}, whereas this value decreased by 52% to 2.5 mg kg^{-1} with 5.0 mg Zn kg^{-1} application. But, in the case of 1 mg Cd kg^{-1} and 2.5% NaCl applications at the highest doses, this reduced in shoot Cd concentration was not found (Table 3). These results showed that Zn had no significant effect on the reduction of Cd uptake at high Cd dose and high saline conditions.

Zn, Fe, Mn, Cu concentrations of shoot are given in Table 4. It was found that there were differences in Zn, Fe, Mn, Cu concentrations of durum wheat under Cd and NaCl stress. Zn concentration decreased with the increase in Cd concentration shoot. The antagonistic interaction between Cd and Zn is what causes this result.

DISCUSSION

Due to the fact that it is not an essential component of living things, cadmium is extremely hazardous to plants and animals even at very low doses. The primary means by which Cd enters humans through the food chain is through contaminated food. For wheat grain intended for human consumption, the FAO/World Health Organization (FAO, 2007) has established a concentration limit of 0.1 mg Cd kg^{-1}. Therefore, research has focused on a strategy to reduce Cd uptake and accumulation in wheat. The Cd concentration, pH, organic matter content, salinity and Zn concentration in the soil affect how much Cd the roots can take up from the soil. These distinctive characteristics of the soil not only influence the soil's chemical availability by limiting cadmium uptake in the roots or by enhancing the plant with nutrients, cadmium accumulation and toxicity in wheat can be decreased or increased. Salinity can alter Cd speciation, which can affect Cd translocation in plants. For instance, studies by Norvell et al. 2000, Özkutlu et al. (2007) and Lo'pez-Chuken et al. (2010) demonstrated examples of the relationship between elevated Cd content in food crops (wheat, maize, and sunflower) and chloride salinity in soils. According to the results of our research, the applications of Cd or NaCl, and their combination, significantly affected to decline on the plants growth. At the highest doses of Cd and NaCl %0.25 treatments, the Zn deficiency-induced reduction in shoot growth became more pronounced. Increasing Cd and low doses of NaCl 0.025% with increasing Zn applications were found to improve shoot growth. wheat plants can readily uptake Cd from the soil through their roots (Black et al., 2014). Cadmium uptake varies among wheat species and Cd uptake varies among wheat cultivars. Research has shown that, both durum wheat and bread wheat can accumulate cadmium (Cd) in their grains, but durum wheat tends to accumulate more Cd than bread wheat (Hart et al., 1998; Vergine, M., 2017). The accumulation and distribution of Cd in durum wheat plants can differ depending on the expression of genes involved in Cd uptake, and translocation from root to shoot. Another study investigated into the relationship between durum wheat's tolerance for Cd contamination and how resistant it is to NaCl salt. The results showed that the degree of salinity resistance was positively correlated with Cd accumulation in the grain (Pastuszak et al., 2020). In our research, at increasing doses of Cd and NaCl treatments in Zn deficiency, durum wheat growth decreased and Cd uptake increased. In this case, soil chloride and chelate-extractable soil cadmium can be associated with Cd uptake in durum wheat. Dahlin et al. (2016) found that chloride can mobilize Cd in soil, increasing its uptake by wheat. Our research results showed that with increasing salinity, Cd concentrations in wheat can increase, and Zn concentrations can decrease. This

Table 2. Shoot Dry Weights (DW) of Durum Wheat (*Triticum turgidum* L. *durum*, cv. Balcali-2000) Grown Under Greenhouse Condition (mg bitki^{-1}).

Treatments		Shoot Dry Matter Weight (DW) Cd Treatments, mg kg^{-1}		
NaCl	Zn	0	0.2	1.0
0%	0.00	124±8	119±36	122±8
	0.05	136±4	142±3.3	124±31
	0.50	179±15	164±33	155±25
	5.00	191±13	179±6.3	171±17
	mean	158	151	143
0.025%	0.00	121±26	124±18	106±12
	0.05	124±5	140±4	116±1
	0.50	167±9	156±13	137±14
	5.00	197±19	171±7	148±11
	mean	152	148	127
0.25%	0.00	115±6	119±8	89±9
	0.05	125±13	121±8	101±11
	0.50	127±7	123±4	134±4
	5.00	122±22	129±3	122±15
	mean	122	123	111

Table 3. Shoot Cd Concentration of Durum Wheat (*Triticum turgidum L. durum*, cv. Balcali-2000)) Grown Under Greenhouse Conditions.

Treatments		Shoot Cd Concentration, mg kg^{-1} Cd treatments, mg kg^{-1}		
NaCl	Zn, mg kg^{-1}	0	0.2	1.0
0%	0.00	0.25±0.12	3.8±0.8	19.1±1.1
	0.05	0.28±0.06	3.8±0.5	20.2±1.2
	0.50	0.20±0.01	3.6±0.0	18.4±0.7
	5.00	0.14±0.02	2.5±0.5	15.9±1.8
	mean	0.22	3.4	18.4
0.025%	0.00	0.31±0.03	4.5±0.6	21.5±3.5
	0.05	0.29±0.06	5.4±0.4	22.2±1.6
	0.50	0.21±0.03	4.8±0.4	23.2±1.5
	5.00	0.17±0.05	4.0±1.6	19.5±1.2
	mean	0.24	4.7	21.6
0.25%	0.00	0.34±0.02	6.3±1.0	26.2±2.9
	0.05	0.32±0.14	7.9±2.2	27.2±0.8
	0.50	0.36±0.19	6.2±0.5	24.8±3.3
	5.00	0.20±0.16	5.6±0.2	26.6±2.5
	mean	0.30	6.5	26.2

Table4. Shoot Zn, Fe, Mn and Cu Concentration of Durum Wheat (*Triticum turgidum* L. *durum*, cv. Balcali-2000) Grown Under Greenhouse Condition (mg kg^{-1}).

Treatments		Zn			Fe			Mn			Cu		
		Cd treatments, mg kg^{-1}											
NaCl	Zn,mg kg^{-1}	0	0.2	1.0	0	0.2	1.0	0	0.2	1.0	0	0.2	1.0
0%	0.00	8.5	6.5	6.1	60	68	70	121	111	115	6.9	6.4	7.2
	0.05	8.8	6.6	6.2	63	71	69	115	120	109	7.4	6.8	6.8
	0.50	20	19	19	62	69	66	127	133	127	7.9	7.4	7.8
	5.00	72	68	63	66	66	61	108	109	111	8.7	7.7	7.4
	mean	27.3	25.0	23.6	63	69	67	118	118	116	7.7	7.1	7.3
0.025%	0.00	7.6	5.80	7.1	64	63	66	132	114	111	6.8	6.7	6.8
	0.05	7.1	6.00	7.7	60	62	61	127	124	117	7.2	6.5	5.9
	0.50	17	19.00	17	59	66	58	124	126	114	7.5	6.4	6.2
	5.00	75	75.00	72	61	72	64	126	133	122	7.9	6.2	6.6
	mean	26.7	26.5	26.0	61	66	62	127	124	116	7.4	6.5	6.4
0.25%	0.00	7.5	7.5	7.6	55	58	64	117	114	124	8.4	6.1	5.7
	0.05	8.2	8.2	7.7	58	55	66	124	125	125	9.4	5.9	5.8
	0.50	19	19	18	64	54	68	127	114	127	9.7	6	6.4
	5.00	84	77	68	69	53	62	133	136	134	9.5	6.2	5.3
	mean	29.7	27.9	25.3	62	55	65	125	122	128	9.3	6.1	5.8

effect zinc a micronutrient for plants that competes with Cd for binding sites on root surfaces and in the soil due to its physical and chemical similarities. In accordance with several research (Hart et al., 2005; Liu et al., 2007; Zhao et al., 2011; Erdem et al., 2012; Li and Zhou, 2012; Singh and Shivay, 2013), Zn treatment decreased wheat's Cd concentration. Due to their physical and chemical similarities, zinc and cadmium may compete for binding sites on the root surfaces of plants as well as in the soil. In agreement with several research (Liu et al., 2007, Zhao et al., 2011, Erdem et al., 2012, Singh and Shivay, 2013, and Özkutlu and Kara., 2018), Zn application reduced the concentration of Cd in wheat. Increased Cd and NaCl and their combined stresses had no significant effect on the concentrations of micronutrients Cu, Fe and Mn.

CONCLUSION

The shoot growth of durum wheat plant were negatively affected by increasing of Cd and NaCl. Cadmium accumulation in shoots of durum increased with increasing soil Cd concentrations. Increased Cd and NaCl combined stress in Zn deficiency, Cd concentration in shoot increased more with the effect of salt. In increasing NaCl applications, increasing Zn application had a decreasing effect on Cd concentration in shoot. At low doses of NaCl and Cd, Cd concentration of shoot decreased more significantly with improved Zn nutrition of the durum wheat. But it was determined that Zn had no significant effect on Cd uptake at high Cd dose and under high saline conditions. As a result, Cd concentration in wheat can be reduced by improving Zn nutrition of plants in low saline soils.

COMPLIANCE WITH ETHICAL STANDARDS

Peer-review

Externally peer-reviewed.

Conflict of interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author contribution

The author read and approved the final manuscript. The author verifies that the Text, Figures, and Tables are original and that they have not been published before.

Ethics committee approval

Ethics committee approval is not required.

Funding

No financial support was received for this study.

Data availability

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

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