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Investigating cadmium accumulation in wheat and barley cultivars from acidic soil of Central Turkey

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Abstract

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Cadmium (Cd) excess in soil represents an important problem for cereal productivity and food-chain contamination. Limited information is available on the Cd concentration in the grain of cereals, grown in acidic soils of Turkey. The objective of the study was to investigate the response of the cereal cultivars (bread wheat, durum wheat and barley) to increasing rates of cadmium (Cd) application in acidic soil using the pot experiment. In the first stage (in 2006-2007), 10 cultivars of each crop were examined for grain Cd accumulation at two application rate of Cd salt (0 and 5 mg kg^{-1}), and nine varieties were selected for their lowest, medium and highest level of grain Cd. In the second stage (in 2007-2008), Cd accumulation in the grain and stem of the selected nine crop varieties were studied at four-application rate of Cd salt (i.e., 0, 1, 3, 9 mg kg^{-1}). Results showed that (i) crop, cultivar and Cd application rate and their interaction had significant ($p < 0.05$) effect on grain or stem Cd concentration, (ii) increasing rate of Cd applications linearly (proportionally) increased Cd concentration in the stem and grain of the crops, and (iii) durum wheat genotype accumulated 2-3 fold more Cd in the grain or stem than bread wheat or barley (i.e. durum wheat > bread wheat >barley). The differences between Cd concentrations of the crops, and their cultivars were mostly considerably at higher Cd application rates (3 and 9 mg kg^{-1}). Grains of Ekiz (bread wheat), Meram-2002 (durum wheat) and Bulbul (barley) cultivars accumulated lowest amount of Cd. In all Cd treatments grains Cd concentration of the cultivars were higher (0.3-8.7 mg kg^{-1}) than acceptable level. Cadmium proportional bioavailability to crops can be associated with the soil characteristics (e.g. moderate acid reaction, low clay and organic matter content) and Cd application rate.

*Keywords: w*heat; barley; cultivars; cadmium accumulation; acidic soil

Introduction

Most of agricultural soils all over the world have been contaminated by cadmium (Cd) with various degrees due to natural and anthropogenic activities. Excessive amount of Cd in soil (> 1-3 mg kg^{-1}) directly or indirectly can (i) impede plant physiological processes, such as respiration, photosynthesis, plant-water relationships, nitrogen and carbohydrate metabolism, by altering the permeability of plasma membranes, resulting in reduction of root and shoot growth, and crop yield, (ii) damage soil biota and environment by erosion and bioturbation, (iii) adversely influence public health by accumulation in the food chain, initiating mostly from cereals and vegetables (Smolders, 2001; Kabata-Pendias, 2010; Lux et al., 2011; Roberts, 2014).

Uptake of Cd from soil and distribution within the various plants parts is a complex and dynamic process and can be controlled by several processes, including uptake from the soil solution, root-to-shoot and root-to-grain translocation during growing and maturation. Consequently, Cd concentrations in cereal crops and their cultivars can vary greatly among plant varieties and geographical locations (Gray et al., 2001; Kabata-Pendias, 2010; Liu et al., 2015; Yanardag et al., 2016; Vergine et al., 2017). Therefore, along with plant factor, agricultural management and soil properties and condition are considered an important feature in controlling the Cd concentrations in cereals. Although Cd concentration in the grain of cereals tends to be higher in soils with low pH and organic matter, and high soil Cd content, yet greater grain Cd concentration could not be explained merely by soil acidification, texture or management (Adams et al., 2004; Wang et al., 2012; Liu et al., 2015). Moreover, grain of cereals may accumulate Cd to an extent that may exceed the permissible level (0.1-0.2 mg kg^{-1}) for human use (Codex Alimentarius Commission, 2009) without adverse effects on crop growth (Li et al., 2011; Vergine et al., 2017).

Studies in different agricultural regions of Turkey displayed that long-term cultivation, application of fertilizer, sewage sludge and manures, and irrigation with waste water and saline water, soil salinization and acidification could increase Cd phyto-availability and accumulation in crops, including cereals (Koleli et al., 2004; Saltali et al., 2004; Demirezen & Aksoy, 2006; Kiziloglu et al., 2008;Eker et al., 2013). Nevertheless, Yanardag et al. (2016), who investigated Cd contents of numerous soils and wheats in Harran Plain, Turkey, long-term treated with several phosphorus fertilizer (containing >2 mg kg^{-1} Cd), stressed that (i) although the amounts of bioavailable Cd in bread wheat were lower than those in durum wheat, in both wheat grains Cd<0.05 mg kg^{-1}, and (ii) the lower bioavailable Cd concentration in wheat grains was related to the presence of high amounts of soil carbonates (> 20%), clay soil texture, and mineralogy.

Large amounts of commercial fertilizers have been used in arid and semi-arid regions of Turkey for last decades, where many of the applied fertilizers contained exceeding level of plant available Cd concentrations (Yanardag et al., 2016).Most published research findings on cereals nutrition and grain quality wererelated to the Zn and Cd balancing in Zn deficient Turkey soils with alkaline (pH > 8) reaction (Adiloglu, 2002; Koleli et al., 2004; Sozubek et al., 2015). There is a need in the Turkish farming industry to control Cd levels in cereals, either by agricultural management practices, breeding or using low Cd-accumulating cultivars (e.g. Eker et al., 2013; Yanardag et al., 2016; Clemens et al., 2013; Rizwan et al., 2016). However, limited information is available on the Cd status of cereals grain from acidic agricultural soils of Turkey. In addition, the inconsistent literature outcomes require a global, regional and local scale or site-specific assessment. The objective of this study was to investigate the accumulation of Cd in wheat and barley varieties grown in the acidic soil of semi-arid area of Central Turkey.

Material and Methods

Soil properties

Soil samples were taken before fertilization and sowing from cultivated layer (0-20 cm) of semi-arid sandy loam soil of

Table 1

Selected properties of the soil used in the greenhouse pot experiments

Parameters	Units	Values	Notes
pH (1:2.5 s:w)	-	4.7	Moderately acidic
EC (1:5 s:w) 25 ºC	μS cm^{-1}	260	non-saline (~ 2 dS m^{-1})
Lime (Total $CaCO_3$)	%	2.36	Low
Organic matter	%	1.58	Low
Clay	%	9.0	-
Silt	%	8.1	-
Sand	%	82.9	-
Saturation	%	35	Sandy loam texture
Field capacity	%	14.2	-
Wilting point	%	5.7	-
P (Available)	mg kg^{-1}	25.23	Much
K (Exchangeable)	mg kg^{-1}	298	Much
Fe (Available)	mg kg^{-1}	17.98	Much
Zn (Available)	mg kg^{-1}	0.42	Low
Mn (Available)	mg kg^{-1}	6.04	Low
Cu (Available)	mg kg^{-1}	0.76	Sufficient
Zn (Total)	mg kg^{-1}	86.6	-
Cd (Total)	mg kg^{-1}	0.29	-

Nevsehir Province, Turkey. Soil and plant analysis determined by standard analytical methods (Klute, 1986; Page et al., 1986). Total P, K, Zn, Cd were determined by ICP-AES (Soltanpour, Workman, 1981). Soil was characterized as moderate acidic with non-saline condition and low organic matter and carbonate content, and high available P, K and Fe content (Table 1).

Experimental setup

Soil samples were air-dried and mixed carefully and passed via 4 mm sieve and were packed in each pot (2 kg). Crops were grown in pots arranged in randomized complete block design with four replications. Drip irrigation was applied using deionized water throughout the season to maintain soil moisture upto 60-80% of field capacity. In the first stage of experiment (in 2006-2007), Cd accumulation was determined in the grains of 10 varieties of bread wheat (*Triticum aestivum*), durum wheat (*Triticum durum*), and barley (*Hordeum vulgare*) at the rate of 0 (control) and 5 mg kg^{-1} (Table 2). From each crop, three cultivars were selected with lowest, medium and highest level of grain Cd accumulation. In the second stage (in 2007-2008), Cd accumulation in the stem and grain of the selected nine varieties (3 crop x 3 cultivar) was determined at Cd application rate of 0, 1, 3, and 9 mg kg^{-1}. In both stages of the experiment, $CdCl_2.H_2O$ salts in the form of solution were used. Application of fertilizers to the soils in the pot was based on soil properties, pot surface area, and soil weight.

In the first stage of experiment, 0.082g DAPpot^{-1} (7.4 mg N kg^{-1}, and 19 mg P_2O_5 kg^{-1}) and 0.127 g ammonium nitrate (33% N) pot^{-1} (21 mg N kg^{-1}) were applied. Ten seeds were sown in each pot. In the second stage, solution of the mixed fertilizers (60 mg N kg^{-1}, 50 mg Mg kg^{-1}, 10 mg Fe kg^{-1}, 5 mg Zn kg^{-1}, 10 mg Mn kg^{-1}, and 1 mg Cu kg^{-1}), were applied to the soil in each pot. As fertilizer sources $5Ca(NO_3)_2{\bullet}NH_4NO_3{\bullet}10H_2O$, $MgSO_4{\bullet}7H_2O$, $FeSO_4{\bullet}7H_2O$, $ZnSO_4{\bullet}7H_2O$, $MnSO_4{\bullet}H_2O$ and $CuSO_4{\bullet}5H_2O$ were used. Initially 13 seeds were sown in each pot. After two weeks of seedling emergence, number of plants was reduced to four. During harvest time, plants shoot were collected (cut from above soil surface with steel scalpel), and was transported to the laboratory in paper bags. The ears (grains) of the plants were separated from the stem. The stems and grains weight were measured. The stem and grain samples were prepared using stainless steel grinder and placed in the oven to dry for 2 days at 70°C before laboratory analysis.

Statistical analysis

Data were subjected to a one-way or multifactor ANOVA (SAS, 2008). Interactions among crops, cultivars and Cd treatments were determined. Differences among Cd accumulation in stem and grain of crops were determined using a Turkey HSD test at ($P < 0.05$).

Results and Discussion

Selecting cultivars on the base of grain Cd concentration (first stage)

Results of the first experiment showed higher variation of grain Cd concentration of the cereals cultivars. With Cd

Table 2

An effect of Cd application rate (5 mg kg^{-1}) on the grain Cd concentrations of cereals

Bread wheat	Cd concentration mg kg^{-1}		Durum wheat	Cd concentration mg kg^{-1}		Barley	Cd concentration mg kg^{-1}	
Ekiz	0.833	a	Selcukl	2.035	a	Avci	0.445	a
Bezosta	0.422	b	Kiziltan	1.075	b	Kalayci	0.315	b
Kinaci-	0.312	cd	Meram-	0.566	c	Bulbul	0.092	de
Goksu-	0.481	b	Kumbet	1.737	a	Ince	0.211	c
Gerek-	0.447	b	Altintas	1.639	a	Konevi-	0.198	c
Bagci-	0.431	b	Yilmaz-	0.896	b	Kral-97	0.158	cd
Sultan-	0.361	bc	Kundur	0.684	c	Tarm	0.150	cd
Konya-	0.355	bc	Ankara-	0.469	c	Tokat-	0.113	d
Gun-91	0.329	bc	C-1252	0.439	c	Aydan	0.056	e
Yildiz-	0.247	d	Yelken-	0.243	d	Beysehi	0.009	f

within each columns the means labelled with same latter are not significantly different at *p<0.05* level application at the rate of 5 mg kg^{1}, the accumulation of Cd in crop grains was found as durum wheat > bread wheat > barley. With exception of six barley cultivars, accumulation of Cd in grains of all treated cultivars was ≥ 0.2 mg kg^{-1}. The selected cultivars for the subsequent experiment were (i) Kinaci-79, Bezostaja-1, and Ekiz for bread wheat, (ii) Meram-2002, Kiziltan-91, and Selcuklu-97 for durum wheat, and (iii) Bulbul, Kalayci, and Avci for barley, with low, medium and high Cd accumulation potential accordingly (Table 2).

Effect of Cd application on stem and grain weight (second stage)

Results of ANOVA test and an effect of treatments on grain and stem Cd concentration and Cd uptake of crops are given in Tables 3 and 4. Outcomes of ANOVA indicated that crop, cultivar, and Cd application rate and their interaction significantly affected grain and stem Cd accumulation, and grain and stem dry weight. However, cultivar and crop x cultivar interaction effect on grain weigh, and Cd rates x cultivar effect on grain and stem weigh, and correlation between Cd application rate and stem or grain weigh were not significant (Tables 3 - 5).

Generally increase in Cd application rate decreased crops or cultivars grain and stem weight; however, effect was inconsistent and crop or cultivar connected (Tables 3 and 5). In arid or semi-arid region of Turkey, it was shown that effect of Cd application on cereals growth, dry matter production of plants, and their Cd concentration depend on soil properties, Cd application rate and Zn deficiency (Adiloglu,2002; Koleli et al., 2004; Eker et al., 2013). Effect of increasing rate of Zn and Cd fertilizers on shoot dry weight and Zn or Cd concentrations of bread and durum wheat cultivars grown in calcareous clay soils (pH > 8) was studied by Koleli et al. (2004). Au-

Table 3

Significance of effects of crops, cultivars and Cd application rate on grain, stem Cd concentration and weight, and total uptake by the grain, and stem

Sources	df	Cd, mg kg^{-1}		Weight, kg		Uptake, µg pot^{-1}	
		Grain	Stem	Grain	Stem	Grain	Stem
Crop	2	***	***	***	***	***	***
Cultivar	2	***	***	ns	*	***	**
Crop × Cultivar	4	***	***	ns	**	***	***
Cd rate	3	***	***	***	*	***	***
Crop × Cd rate	6	***	***	ns	ns	***	***
Cultivar × Cd rate	6	***	***	***	*	***	ns
Crop × Cd rate × Cultivar	12	***	***	***	**	***	*

* *P<0.05, **P<0.01, *** P<0.001; ns,* not significant

Table 4

Effect of treatments (ANOVA) on crops' grain and stem Cd concentration, and Cd uptake

Factors	Cd concentration, mg kg^{-1}		Cd uptake, µg pot^{-1}	
	Grain	Stem	Grain	Stem
Crops				
Barley	0.88 b	5.39 b	9.21 c	126.34 b
Bread wheat	1.02 b	5.41 b	11.43 b	127.97 b
Durum wheat	2.71 a	13.58 a	17.9 a	242.12 a
Cultivars (grain Cd level)				
Low	1.05 c	6.49 b	10.05 b	147.67 b
Medium	1.24 b	7.52 b	11.22 b	170.16 ab
High	2.30 a	10.36 a	17.27 a	178.59 a
Cd application rate (mg kg^{-1})				
0	0.04 d	0.09 d	0.34 d	1.8 d
1	0.87 c	3.07 c	8.59 c	66.19 c
3	1.89 b	8.04 b	16.38 b	175.29 b
9	3.34 a	21.3 a	26.07 a	418.62 a

within each factor crop (crops, cultivars, Cd application), columns labeled with same letter are not significantly different at $p < 0.05$.

Table 5

Pairwise correlation between crop grain and stem Cd concentration and uptake

Indices	Cd conc. mg kg^{-1}		Weight, kg		Cd uptake, µg pot^{-1}		Cd rate mg kg^{-1}
	grain	stem	grain	stem	grain	stem	
Grain Cd	1	0.92*[1]	-0.59*	-0.5*	0.91*	0.83*	0.63*
Stem Cd		1	-0.55*	-0.44 *	0.82*	0.92*	0.75*
Grain weight			1	0.65*	-0.34 (ns)	-0.46*	-0.26 (ns)
Stem weight				1	-0.34 (ns)	-0.2 (ns)	-0.13(ns)
Grain Cd uptake					1	0.84*	0.75*
Stem Cd uptake						1	0.87*
Cd rate							1

* significant at $p < 0.05$; *ns*, non-significant

thors stressed that (i) growing plants without Zn fertilization caused significant decrease in shoot growth, especially at high Cd rate treatments, (ii) in comparing with bread wheat, durum wheat is more sensitive to Zn deficiency and Cd toxicity, and (ii) the impact was not related to higher Cd concentration in the plants. In clay loam soil with slight alkaline reaction, increase in Cd application rates (0 to 25 mg kg^{-1}) increased Cd concentration in shoot and decreased their nutrient content (N, P, K, Ca, Mg), and declined root and shoot growth of bread and durum wheat, being more actual in the latter (Eker et al., 2013). In our experiment, crops were grown in the pot (~ 2 kg soil) with sufficient nutrient (e.g. N, P, K, Ca, Mg and Zn), but limited photosynthesis rate, and under acidic condition which were considerable below the optimal level (pH 6.2-7.2) for crop growth. Such condition associated with high Cd application rate may slightly to moderately limit nutrients availability and soil microbial activity, hence alter or diminish contribution of Cd application on stem and grain weight and differences between the treatments, depending on Cd application rate and crops species (e.g. Gray et al., 2001, Smolders, 2001; Koleli et al., 2004; Li et al., 2011).

Cd accumulation in grains and stems of cereals

Contribution of crop variety, cultivar and Cd rate on Cd accumulation in the grain and stem are presented in Figures 1 - 4 and Tables 4 and 5.

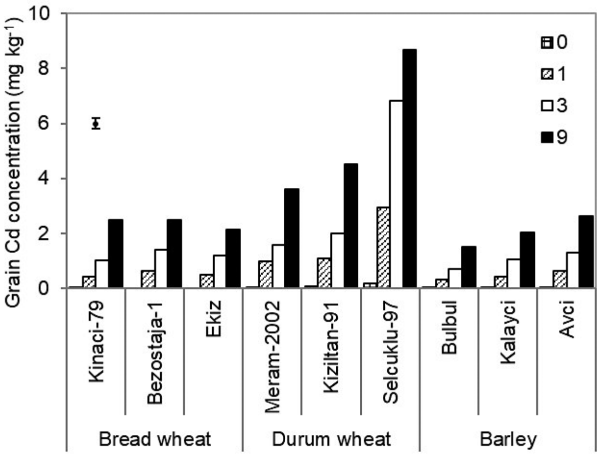

Fig. 1. Effect of Cd application rate (0, 1, 3, 9 mg kg^{-1}) on the grain Cd concentration (mg kg^{-1}) of cereal cultivars. Bar indicates a single confidence interval value (P < 0.05)

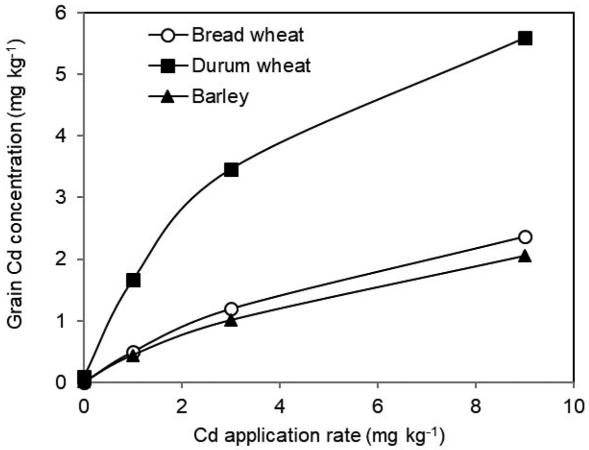

Fig. 2. Grain Cd concentration of crops as a function of Cd application rate

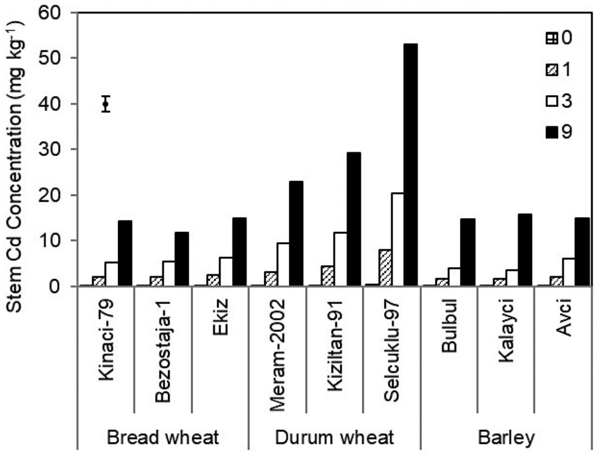

Fig. 3. Effect of Cd application rate (0, 1, 3, 9 mg kg^{-1}) on the stem Cd concentration (mg kg^{-1}) of cereal cultivars. Bar indicates a single confidence interval value (P < 0.05)

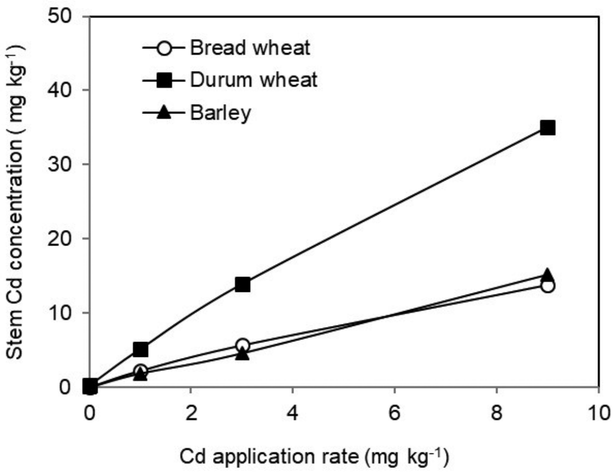

Fig. 4. Stem Cd concentration of crops as a function of Cd application rate

There was a significant correlation (Table 5) between (i) the Cd application rate and Cd concentration values of grains or stem(r=0.63-0.87), and (ii) the Cd concentration and Cd uptake values of grain or stem (r=0.84-0.92) (Figures 2 and 4, Table 5). A strong proportional or linear e.g. bread wheat and barley) or exponential (e.g. durum wheat) relationship between applied Cd rates and grain or stem Cd concentration was noted (Table 6, Figures 2 and 4). Like to results of numerous papers, grain Cd concentration widely varied (e.g. Gray et al.,2001; Greger & Lofstedt, 2004; Liu et al., 2015) between 0.02 and 2.49 mg kg^{-1} (bread wheat), 0.05 and 8.68 mg kg^{-1} (durum wheat), and 0.00 and 2.61 mg kg^{-1} (barley). Averaged stem Cd concentration by crops was 5.0-6.0fold higher than grain Cd concentration, and varied between 0.20 and 14.96 mg kg^{-1} (bread wheat), 0.09 and 53.13 mg kg^{-1} (durum wheat), and 0.00 and 15.80 mg kg^{-1} (barley) (Figures 2 and 4). The grain or stem Cd concentration of crops were in the following order: durum wheat > bread wheat > barley (e.g. Eker et al., 2013). Durum wheat was found more sensitive to Cd application, and accumulated 2-3 fold more Cd in the grain or stem than bread wheat or barley cereals with comparable grain or stem Cd concentrations (Figures 2 and 4). Such trend could be related to higher sensitivity of durum wheat against Cd toxicity than bread wheat or barley (e.g. Smolder, 2001; Eker et al., 2013).

Generally, Cd concentration in the grain or stem of the bread wheat, durum wheat and barley increased significantly (Table 4), by proportional (linear) or exponential (growth) way, with increase in the Cd application rate, which could be tracked using coefficient or exponent of regression (Table 6) equations (e.g. coefficient *a* and exponent *b* for grain Cd concentration: barley<bread wheat<durum wheat). The differences between grain or stem Cd concentrations of the crops mostly increased with an increase in Cd rate (Figures 2 and 4). The variance between the grain or stem Cd concentration of the cultivars of each crop group with low, medium and high accumulation ability was essential, but it was also found crop dependent (Figures 1and 3, Table 4). Although Bezostaja-1 had the highest and Kinaci-79 achieved the lowest grain Cd concentration, at the same Cd rates, the differences between Cd concentrations of the bread wheat cultivars was mostly not significant (Figure1). Barley cultivars, namely Avci and Bulbul, had the highest and lowest concentration of Cd (0.02-2.61 and 0.00-1.52 mg kg^{-1} accordingly); the differences between grain Cd concentration of these cultivars were only significant at two higher Cd application rate (3 and 9 mg kg^{-1}) (Figure 1). Meram-2002 and Selcuku-97 cultivars got lowest and highest grain Cd concentration (0.05-3.59 and 0.18-8.68 mg kg^{-1} accordingly) within durum wheat group, and the differences between Cd concentrations of the cultivars were considerably in all applied Cd rates (1 - 9 mg kg^{-1}) (Figure 1, Table 4).

Highest Cd concentrations noticed in the stem of the Ekiz (bread wheat), Selcuku-97 (durum wheat), and Avci (barley) varied between 0.20 to 14.96 to 0.38 to 53.13 g kg^{-1} and 0.01 to 14.86 mg kg^{-1} respectively. At the same Cd rates, in bread wheat or barley, the differences between stem Cd concentration of the three cultivars were comparable or insignificant; however in durum wheat the difference between the Cd concentrations of cultivars were significant at higher Cd application rates (3 and 9 mg kg^{-1}) (Figures 3 and 4, Table 4).

Table 6

Proportional linear and exponential (growth) relationship between grain or stem Cd concentration (y, mg kg^{-1}) and Cd application rate (x, mg kg^{-1})

Crops	Cd concentration in grain or stem	$y = ax$		$y = ax+b$			$y = a(1\text{-}exp\ (-bx))$		
		a	R^2	a	b	R^2	a	b	R^2
Bread wheat	grain	0.28	0.94	0.25	0.21	0.97	3.01	0.17	0.99
Durum wheat	grain	0.69	0.81	0.56	0.89	0.91	5.91	0.28	0.99
Barley	grain	0.24	0.94	0.22	0.18	0.97	2.69	0.15	0.99
Bread wheat	stem	1.57	0.98	1.49	0.58	0.99	27.44	0.07	0.99
Durum wheat	stem	3.98	0.99	3.81	1.20	0.99	85.40	0.05	0.99
Barley	stem	1.67	0.99	1.67	-0.05	0.99	58.52	0.03	0.99

Cd uptake by the grain and stem of the crops

Contribution of treatments on Cd uptake by crop grain and stem are presented in Figures 5 and 6, and Table 4. Grain or stem Cd uptake among the crops differed in the following order: durum wheat > bread wheat > barley. The general trend in Cd uptake by grain andstem of crops was almost similar to Cd concentration of the grain and stem, since there was higher correlation between Cd concentration and Cd uptake (Table 5). Uptake of Cd by the grain of the bread wheat, durum wheat and barley increased significantly with the increasing rate of Cd application and varied between 0.58 and 347.71, 1.69 and 658.30, and 0.0 and 318.84 mg pot^{-1}, correspondingly. In response to Cd treatments, grain Cd uptake 10-15 times was lower than stem Cd uptake (e.g. Koleli et al., 2004).

Influence of factors

The differential response of crop varieties and cultivars to environmental changes along with soil processes contributes to differences in their Cd uptake from soils (Smolders, 2001). Under the used experimental conditions, the interaction between soil properties and cereal genotypes resulted in elevated levels of Cd in the grain and stem, with the Cd values exceeding the permitted level. Increasing Cd application rate, significantly altered the Cd concentrations in cereals grain or stem, which could be associated with the favorable soil condition for Cd mobility and accumulation, such as acidic soil reaction (pH < 5), sandy loam texture (clay content < 9%) and low organic matter (< 1.6 %). Uptake of soil Cd by plant roots can be affected mostly by soil properties and condition, controlling Cd bioavailability, than by total soil

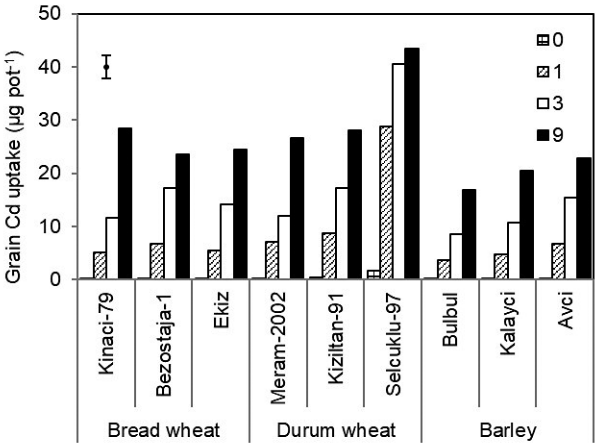

Fig. 5. Effect of Cd application rate (0, 1, 3, 9 mg kg^{-1}) on the grain Cd uptake (µg pot^{-1}) of cereal cultivars. Bar indicates a single confidence interval value (P <0.05)

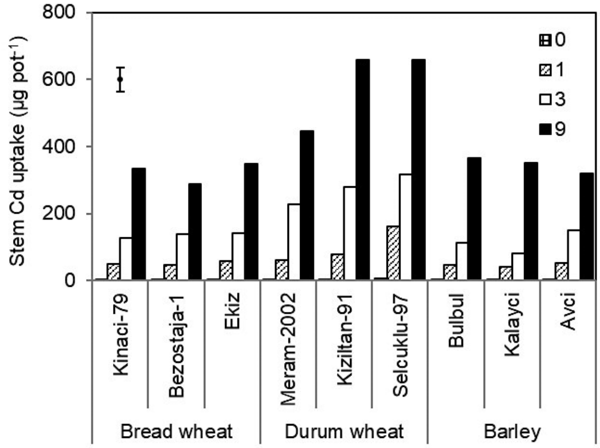

Fig. 6. Effect of Cd application rate (0, 1, 3, 9 mg kg^{-1}) on the stem Cd uptake (µg pot^{-1}) of cereal cultivars. Bar indicates a single confidence interval value (P < 0.05)

Cd (Smolders 2001). Soil had low lime content (< 3%) and low salinity (EC ~2 dS m^{-1}), and adequate level of nutrients (N, P, K, Zn, Fe, Mn, Cu, etc.) due to fertilizer application. Therefore, Cd application rate and bioavailability of Cd from soil solution could be considered the main regulating factor to increase in crop Cd concentration and Cd uptake, since (i) for each crop there was strong proportional relationship between the grain or stem Cd concentrations of the crops and Cd application rate ($R^2 > 0.9$), and (ii) same acidic loamy sand soil, fertilizer an soil condition were used in all treatments (Tables 5 and 6). The Cd transfer factor, which is the slope of the proportional regression (*a* in Table 6) between soil and crop Cd (*a*: 0.24-0.69 for grains, and 1.57-3.98 for stem of crops), suggesting that crop Cd concentration can be predicted appropriately from soil Cd concentration (e.g. Cd application rate) (Smolders, 2001). Exponential growth relationship between grain Cd concentration and Cd application rate (Figures 2 and 6, Table 6), particularly for durum wheat, exposed to the limitation of grain Cd uptake rate with an increase in Cd application rate in the pot experiments (Smolders, 2001).

Considerable variations, and difference in the grains or stem Cd concentration between the crop, and cultivars within each crop, agreed well with other published workindicatingto1-4 fold range in the abilities of different wheat cultivars to accumulate Cd in grains (e.g. Gray et al., 2001; Li et al., 2011; Liu et al., 2015; Vergine et al., 2017). Chaudri et al. (2007) investigated the effect of the sludge and metal salts on accumulation of Cd in wheat grain, and reported that soil pH, organic matter, and soil total Cd concentration are important variables affecting grain Cd concentration, which was generally in agreement with other studies (e.g. review paper by Smolders, 2001 and references therein; Liu et al., 2015; Dudkaet al., 2004).

Although soil pH was considered most important factor contributing to Cd uptake by wheat cultivars (Adams et al., 2004;Liu et al., 2015), yet influence of soil acidification (change in soil pH) on cereal Cd uptake could be less consistent than its effect on Cd mobility in the soil. Results of eight long-term field experiments, mostly in acidic soils with coarse texture, showed that reduction in soil pH (6.2 to 4.9) increased wheat grain Cd concentrations about ~4 times, and no trend was noticed below the moderate acidic pH < 4.9 condition (Oliver et al., 1994), which is similar to our soil experimental condition (pH = 4.7, sandy loam soil).Increasing the soil pH amplified the removal a portion of carboxyl and hydroxyl groups, and hence negative charge density in the soil solution was greater at lower pH. Therefore, in opposite to clay soils, in sandy soils the Cd ion has much less chance to bond with soil colloids, and thus increase the sorption by soil, decreasing the availability by the crop (Koleli et al., 2004; Yanardag et al., 2016).

Fertilizer additions (e.g. N, P, K and Zn) to soil can alter or increase Cd concentration and mobility in the soil solution, even if the fertilizer contains no Cd, through the influence of fertilizer application on soil pH, and ionic strength of the soil solution, solubility of Cd, improved root interception and enhanced mass flow, and hence elevated availability to plants (Koleli et al., 2004; Lux et al., 2011).Concentration of Cd in durum wheat at several locations of Canada was increased after application of P fertilizer; however, the increase was not directly related to the concentration of Cd present in the fertilizer, showing that fertilizer applications may increase Cd concentration in soils and modify their bioavailability (Cakmak et al., 2010).

Variation in Cd accumulation among cereal or wheat types could be associated with root-soil interaction and rhizosphere mechanisms. Roots of several wheat or barley varieties may have different capacities to release metal from soil colloids and to receive metals from soil solution, which may affect the plant Cd uptake rate and amount. Higher Cd accumulation in durum wheat than bread wheat or barley were also related to the difference of Cd translocation from root zone to root, from root to shoot and stem (Greger & Lofstedt, 2004; Yanardag et al., 2016; Liang et al., 2017; Vergine et al., 2017).

In acidic sandy soil with low organic matter, the plants can receive higher level of Cd, but the magnitude will be depended on crop varieties and genotype (Senn & Mihalm, 2000). Regarding to the transport of Cd from root to stem or shoot, there were differences between the various types of the cultivars, and within varieties of the same cultivars. Grains of durum wheat can accumulate high concentration of Cd (> 0.2 mg kg^{-1}) in soil with low Cd content (< 0.5 mg kg^{-1}) (Vergine et al., 2017). In our experiment in non-treated control soil (Cd = 0.29 mg kg^{-1}) durum wheat grain and stem Cd concentration was highest among the crops and varied between 0.05 and 0.18 m kg^{-1} and 0.09 and 0.38 mg kg^{-1}accordingly.The soils contaminated with various level of Cd may not visible influence on cereals growth or present notable phytotoxicity signs, and hence may not require to analyze grains Cd content (Vergine et al., 2017). Therefore planting these crops in the similar field (e.g. in Cd contaminated acidic sandy soils) should be avoided. Cultivars with low Cd accumulating can be used at sites where the Cd concentration in grain exceeds the maximum permissible concentration. Using cultivars with low Cd accumulating, amending the soil chemical conditions (e.g. increasing pH, soluble Ca and organic carbon) to minimize phytoavailability of Cd, and applying fertilizers and amendments with low level of Cd could be useful approach (Rizwan et al., 2016). Several fundamental processes governing the flow in the system of soil-root-stem-shoot-grain, and multiple mechanisms behind the process affected Cd accumulation in cereals. Therefore the mechanism preventing or negatively affecting to Cd accumulating by grain or stem of varieties was not fully defined and thus experimental approaches in the field for the agricultural regions are necessary (Greger & Lofstedt, 2004; Rizwan et al., 2016; Liang et al., 2017).

Conclusions

The accumulation of Cd in local cereals (e.g. bioavailability of the Cd and plant uptake) considerable depended on the Cd application rate, crop species, and soil chemical and physical properties involving Cd mobility. Applications of Cd salts in this acidic sandy loam soil with low organic matter considerably and proportionally (coefficient a = 0.24, 0.28, 0.69 for barley, bread wheat and durum wheat accordingly) increased Cd concentration and Cd uptake by grain and stem of cereals signifying that crop Cd concentration can be predicted properly from soil Cd content or Cd application rate. Cd concentration in grain and stem of the crops differed as durum wheat >bread wheat > barley. Compared to other crops, grains of durum wheat accumulated more than twice higher level of Cd (even at low rate of Cd application), and could pose much risk to human health. With exception of control, grain Cd concentrations in all treatments were higher ($\geq$ 0.3 mg kg^{-1}) than acceptable level. Grain of Ekiz (Bread wheat), Meram-2002 (Durum wheat) and Bulbul (barley) accumulated lowest Cd amount, whereas Kinaci (Bread wheat), Selcuklu-97 (Durum wheat) and Avci (barley) accumulated higher amount of Cd. Planting these crops (e.g. local tested cultivars) in the similar field (e.g. in Cd contaminated acidic sandy soils) should be avoided. Cultivars with low Cd accumulating can be used at sites where the soil Cd concentration does not exceed the maximum permissible level (< 0.5-0.8 mg kg^{-1}). Long-term studies on Cd accumulation in crops are suggested to elaborate the results under field management system.

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