



# Evaluation of Cadmium Concentration in Wheat Crop Affected by Cropping System

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## Abstract

**Background:** Cadmium accumulation is a growing problem for foodstuff and the environment; it has negative impacts on humans including the damage to kidneys and liver tissue, as well as carcinogenesis, and emphysema.

**Objectives:** The current research aimed at evaluating the effect of planting systems of agricultural products and different growth stages on cadmium concentration in wheat seed.

**Methods:** The study was carried out as a split plot experiment based a randomized complete-block design with 3 replications in the seasonal year of 2014 - 2015. The main factor included 2 cropping systems (wheat-rice, fallow-wheat) and the subfactor were the growth stages (tillering, flowering, and maturity). Comparison of the amount of wheat seed cadmium concentrations between the 2 cropping systems was performed by t test.

**Results:** The difference in seed cadmium concentration between the 2 cropping systems was significant ( $P < 0.01$ ), and seed cadmium concentration in rice-wheat cropping system with an average of 0.31 mg/kg was higher than that of the fallow-wheat planting system (0.27 mg/kg) as well as the world health organization (WHO) standard (0.20 mg/kg). The ANOVA results showed the significant effect of cropping systems and different growth stages on the cadmium concentration of plant, root, stem, and soil phosphorus content ( $P < 0.01$ ). Rice-wheat cropping system, due to high consumption of non-standard phosphate fertilizers (such as cadmium), higher soil phosphorus concentrations (9.03 mg/kg), and residues of the previous products had high cadmium concentration in plant (1.83 mg/kg), root (1.09 mg/kg) and stem (0.73 mg/kg) than those of the fallow-wheat cropping system.

**Conclusions:** Due to high accumulation of cadmium in wheat yield, management of phosphate consumption based the standards of Soil and Water Research Institute is recommended.

**Keywords:** Cadmium Monitoring, Pollution, Seed, Wheat

## 1. Background

Cadmium (Cd) is a heavy metal, which is known today as a major cause of environmental pollution with very high toxicity for animals and plants. The high half-life of the element in the human body (10 to 30 years) has caused cadmium as the most susceptible metal to accumulation in the body (1). About 75% of cadmium in the human food chain comes through seeds and vegetables (2). Due to the consumption of cadmium in different industries and releasing the wastes in wastewaters, as well as the indiscriminate use of pesticides and chemical fertilizers, particularly phosphate compounds in arable lands, the accumulation of cadmium increased. On the other hand, as a result of its consumption in various industries such as paint, plastics, pesticides, fungicides, batteries, photography, and metal

coating and melting, cadmium is distributed in the environment. The maximum cadmium tolerable to humans is 70  $\mu\text{g}$  per day, based on the food and agricultural organization (FAO) (3).

Cadmium is not essential for plants growth, but it would be toxic in leaves by 5 - 30 mg/kg (4). Another study reported the toxic effects of Cd > 5 - 10 mg/kg on growth and yield of plants (5). Previous studies showed that among seeds, wheat (especially durum varieties) can absorb higher amounts of Cd compared with other cereal (rye, barley, and oats). Cadmium uptake in durum wheat varieties is more than that of the bread varieties, which is probably due to apoplastic transports across the roots of such plants. Increased cadmium accumulation in durum wheat may be due to its higher transition by the phloem

vessels. Although the amount of Cd in durum wheat seed is higher than the bread wheat, this trend may be due to genetic differences between the bread and durum wheat (6).

Nitrogen fertilizers may increase Cd concentration in plants, even if the fertilizers do not contain significant amounts of Cd. Phosphate fertilizers application in agricultural lands may increase the level of Cd, As, Cr, and Pb in soil and dramatically decrease soil pH that results in desorption of heavy metals from the soil matrix. Pb is one of the heavy metals investigated in the current study. Atmospheric deposition, manures, and sludge are the main sources of lead in the agricultural lands (7).

Malakooti reported that the continuous use of non-standard phosphate fertilizers (containing Cd higher than the permitted limits) increased the amount of Cd in soil and plant tissue. In fact, Cd is accumulated in soil and plants following the use of phosphate fertilizers during the last 3 decades without any control over their importation, distribution, and consumption in Iran (8).

Atafar et al., investigated the concentration of heavy metals (Cd, Pb, and As) in wheat-cultivated soils. Their results indicated that Cd, Pb, and As increased in the cultivated soils due to the use of fertilizers. Although the statistical analysis indicated the significant increase of heavy metals in lands and plants ( $P < 0.05$ ), the lead and arsenic concentrations increased dramatically compared with that of Cd. It can be attributed to the overapplication of fertilizers as well as pesticides for replanting purposes, as well as controlling pests, herbs, and rats (9).

Durum wheat (*Triticum durum* L.) is of particular concern because it accumulates more Cd than other commonly grown cereal with the accumulation increase in the order of rye < barley < oats < bread wheat < durum wheat. Cadmium concentration in durum wheat grain harvested on Canadian prairies ranged < 50 to > 300  $\mu\text{g}/\text{kg}$ , which exceeded the 200  $\mu\text{g}/\text{kg}$  permitted limit set by the Codex Alimentarius Commission. In addition, approximately  $2.1 \times 10^6$  ha durum wheat, constituting 10% of worldwide durum production area, is grown in the Western prairie region of Canada (10, 11).

In a study on lettuce and spinach, adding zinc to soil decreased cadmium accumulation in young leaves, but had no impact on older leaves. It seems that zinc interferes with the transfer of Cd from the roots to the young leaves and improves the maintenance of cadmium absorbed by the roots. Due to different competitive mechanisms vs. cadmium and zinc, the ultimate effect of zinc increase in soil and planting systems is different depending on the relative concentrations of cadmium and zinc and the characteristics of soil and plant (12).

Cadmium has a high mobility and if it appears in the

root zone, it is easily absorbed by the plant and transported into the aboveground parts of it. Plant species and cultivars are greatly different in terms of ability to absorb, accumulate, and tolerate cadmium. Based on the amount of cadmium in plants cultivated commercially, sunflower, cotton, rice, and durum wheat are also highly capable of accumulating cadmium in their tissue and often have over 0.1 cadmium mg/kg in dry mass (13).

In Iran, reports indicated the concentration of cadmium in some crops, especially rice and potatoes. In peanut, the rate of cadmium in testa (seed coat) is 10 times higher than that of the seed itself. Cadmium content in spring wheat, barley, oat and corn is typically less than 0.1 mg/kg (14). Arduini et al., reported that the number of chloroplasts and thylakoids in wheat crop decreased by 100 mg/L of cadmium compared with the control treatment; they also reported structural changes and abnormalities in the organelles in higher concentrations of Cd, indicating the decrease of dry mass (15).

Arduini et al., evaluated 2 durum wheat varieties in low and high grain-Cd accumulating situations and showed that Cd did not affect plant growth and grain yield, but grain-Cd concentration always exceeded the permitted limit of 0.2 mg/kg, and was approximately doubled in low concentrations than that of the high grain-Cd accumulating. They suggested that reduced height, high root to shoot biomass ratio during vegetative growth, and elevated post-heading dry mass can promote Cd accumulation into grain (16).

Cadmium is rather mobile in soil and contaminates foodstuff and fodder crops even at low concentrations in soil. Since prolonged exposure to Cd causes renal dysfunction and bone demineralization, and increases the risk of lung cancer in human, the European Food Safety Authority reduced the tolerable weekly intake of Cd from 7 to 2.5  $\mu\text{g}/\text{kg}$  body weight. Cereal products are estimated to account for approximately 40% of alimentary Cd in Europe, and figures showed the increasing rate due to rising pasta consumption. Indeed, durum wheat, from which pasta is prepared, accumulates higher amounts of Cd than bread wheat. The codex alimentarius commission proposed a permitted limit of 0.2 mg/kg for Cd in wheat grain products, but higher Cd concentrations were recorded in wheat crops grown worldwide (17).

## 2. Objectives

Evaluation of the concentration of cadmium in soil-water-plant systems is of great importance, due to quantitative and qualitative impacts of this element on agricultural products as well as the food chain and human health;

therefore, the current study aimed at evaluating the accumulation of cadmium in different organs of wheat plant under conventional planting systems and agricultural production in Khuzestan Province, Iran.

### 3. Methods

#### 3.1. Field and Treatment Information

The study was conducted in Shavoor Research Station to investigate cadmium concentration in wheat plant in 2 conventional cropping systems at Khuzestan Province via a split plot experiment based on randomized complete-block design with 3 replications during the seasonal year of 2014-2015. The main factor included 2 cropping systems (wheat-rice, fallow-wheat) and the subfactor was different growth stages (tillering, flowering, and maturity). Shavoor Research Station is located in 70 km North of Ahvaz at longitude 48° 27' 33" E and latitude 32° 0' 37" N in Khuzestan Province, Southwest Iran. The average annual rainfall, temperature, and evaporation in the region are 240 mm, 22°C and 3000 mm, respectively. Soil properties of the land under study are listed in [Table 1](#).

#### 3.2. Measurements

##### 3.2.1. Method of Measuring Cadmium Concentration in Plant

To measure the concentration of cadmium in wheat plant, first, the plant seeds were washed 3 times with distilled water in order to remove dirt, dust, and pollution, and then, the samples were dried in an oven at 75°C for 72 hours. The seeds were crushed into powder using a mill. The same process was carried out for the stems and roots. The powder samples of each organ of the plant were stored in paper bags in refrigerator at 4°C until use. In order to determine cadmium concentration, the plant samples were digested via wet digestion (70% nitric acid, perchloric acid, and sulfuric acid). After the extraction and reaching the desired volume, the optical density of prepared samples was measured using graphite furnace atomic absorption spectrometry (Perkin Elmer 600) (18).

##### 3.2.2. Transfer Coefficient

The index is the ratio of the concentration of the metallic element in shoot to the total concentration of the same element in soil or growing medium (19) that is known as one of the indicators to assess the efficiency of plant purification. Due to the potential toxicity of cadmium to humans, livestock and poultry, it is very crucial to remove it from the environment. To treat the polluted sites, the excavation, leaching, and mechanical remediation methods

are usually used and to assess the ability of plants to transfer metal elements from root to shoot, the transfer coefficient (translocation factor) is calculated using the following formula (20):

$$TC = \frac{\text{Cadmium concentration in stem (mg/kg)}}{\text{Cadmium concentration in root (mg/kg)}} \quad (1)$$

##### 3.2.3. Bioaccumulation Factor

As mentioned earlier, bioaccumulation and TC indicate the ability of the plant to tolerate and accumulate heavy metals in its organs; these parameters are calculated using the following ratios:

Metal concentration in root/amount of metal in soil (roots bioaccumulation coefficient)

Metal concentration in shoots/metal content in soil (shoots bioaccumulation coefficient)

Metal concentration in shoots/ metal concentration in root (transfer coefficient) (20)

#### 3.3. Statistical Analysis

Descriptive statistics such as mean, variance, maximum elongation, skewness, and standard error of the measured traits were measured by Minitab software version 14. Analysis of variance and mean comparisons by the Duncan test were performed with SAS software version 8 ( $P < 0.05$ ). The amount of cadmium in wheat seed in 2 cultivation systems (rice-wheat and fallow-wheat) were compared using t test with Minitab software version 14.

### 4. Results

#### 4.1. Wheat Seed Cadmium Concentration

According to the results of [Table 2](#), there was a significant difference in the mean concentration of seed cadmium between rice-wheat and fallow-wheat cropping systems ( $P < 0.05$ ); in other words, the mean of rice-wheat cropping system (0.31 mg/kg) was higher than that of the fallow-wheat cropping system (0.27 mg/kg).

It is noteworthy that durum wheat has higher potential than bread wheat to accumulate cadmium. The results of a research by Valinejad showed that the mean cadmium concentration in 11% of the rice products in the studied regions was higher than the permitted limits (0.1 mg/kg) (21). In Fars Province 4% and in Isfahan Province about 12% of rice products had the cadmium concentrations higher than the permitted limits, this trend can be due to the use of sewage sludge and composts, as well as excessive consumption of non-standard phosphorus fertilizers in Iran. With regard to the aforementioned problems, American food and drug administration (FDA) announced the permitted level of cadmium absorbed by human body

**Table 1.** Soil Properties of the Under Study Site<sup>a</sup>

EC, ds/m	pH	Pb, g/cm <sup>3</sup>	OC, %	P, ppm	K, ppm	Fe, ppm	Cu, ppm	Mn, ppm	Zn, ppm
2.8	7.8	1.35	0.7	10.9	239	9.6	1.3	8.5	0.6

<sup>a</sup>Depth: 0 - 30 cm**Table 2.** Result of t Test for Compare Wheat Seed Cadmium Concentration in Different Planting System

Treatment (Planting System)	No. Observation	Mean, mg/kg	Standard Deviation	t
Rice-wheat	3	0.31	0.01527	5.01 <sup>a</sup>
Fallow-wheat	3	0.27	0.0109	

<sup>a</sup>P < 0.05.

as 75 mg/day. In Europe, the permitted amount of cadmium in wheat seed is 0.2 mg/kg of seed (22). FAO and the world health organization (WHO) announced the permitted amount of cadmium enters the human body as 70 µg/day. American Society of Aging announced 20% of the permitted amount, while in Europe it ranges 30% to 40% of the permitted limits (23). Some reports from Iran showed that in some paddy fields the rate of cadmium in rice seed exceeds the permitted limit. Long-term changes in planting systems of agricultural products may affect the availability of cadmium to plants. The highest rate of cadmium was obtained in wheat seeds in rotation with legumes and the lowest rate in wheat seeds in rotation with seed. Moreover, in areas where much tillage is done during wheat cultivation, cadmium concentration in wheat seed is higher than that of traditional planting methods with little tillage (24). In a study on the effect of zinc consumption to reduce cadmium concentration in seed, results showed that zinc residual reduced the cadmium concentration in seed. The decreasing effect of zinc on seed cadmium concentration may be associated with the inhibitory effect of zinc on the transfer of cadmium from straw into seed and the competitive effect of zinc vs. cadmium absorption. In a study on the relationship between cadmium concentration in seed, chemical properties of soil, and varieties of rice, it was found that about 80% of the total cadmium accumulated in seed was attributed to the total cadmium and organic carbon in soil (25). The cadmium of wheat seed in soil had a positive relationship with lime changes, total cadmium, and seed yield, but a negative relationship with soil pH, ammonium lactate-extractable phosphorus (P-AL), and nitric acid-extractable zinc. However, the relationship between seed cadmium and soil properties was significantly weaker in wheat grown on calcareous soils. In a study, the presence of cadmium significantly reduced seed yield, total yield, and total protein content of wheat seed, but adding zinc improved the quantitative and qualitative characteristics of the wheat (26).

Wheat (especially durum varieties) can accumulate Cd in its tissue more than other currently grown cereal. Based on the announcements of European Union, the permitted limit of Cd in wheat grain is 0.2 mg/kg. Soil is the main Cd source for plants. Cadmium phyto-availability in soil is related to soil properties such as concentration and form of metal, pH, organic matter, clay content, cation exchange capacity (CEC), soluble chlorine (Cl), sulfur (S), and sodium (Na) (27).

#### 4.2. Cadmium Accumulation in Plant

According to ANOVA results, the effect of cropping systems on cadmium concentration in wheat plant was significant (P < 0.01), but the effect of growth stages on the mentioned traits was not significant (Table 3).

The rice-wheat cropping system had higher amounts of cadmium accumulation in wheat plant tissue (1.83 mg/kg) in comparison with fallow-wheat cropping system (1.32 mg/kg) (Table 4); it can be attributed to the higher consumption of phosphate fertilizer in lands with rice-wheat cropping system than that of the fallow-wheat cropping system. Further studies on the accumulation of cadmium along with phosphate fertilizer in lands with rice cultivation history are suggested. In this regard, the wheat in fields with rice-wheat planting system can absorb higher amounts of cadmium from the soil and proportionally enjoy higher cadmium amounts in wheat plant before which the rice has been planted. According to the Duncan test, there was not a significant difference between different growth stages, but generally there was an increasing trend in cadmium accumulation in plants from tillering to maturity (Table 4).

The data analysis results such as the mean of the studied traits showed that the total cadmium concentration in the studied wheat plant was 1.57 mg/kg (Table 5) indicating the risk of cadmium contamination in the area. Therefore, larger amounts of cadmium are accumulated in the wheat plant. The normal amount of cadmium in the plant is 0.1-

**Table 3.** The ANOVA Results of the Measured Traits

S.O.V	df.	Cadmium Concentration in Plant	Cadmium Concentration in Stem	Cadmium Concentration in Root	Transfer Coefficient	Bioaccumulation Factor
Replication	2	0.000038 <sup>a</sup>	0.00027 <sup>a</sup>	0.00015 <sup>a</sup>	0.00015 <sup>a</sup>	0.0089 <sup>a</sup>
Planting system	1	1.1755 <sup>b</sup>	0.2403 <sup>b</sup>	0.3528 <sup>b</sup>	0.0162 <sup>b</sup>	0.02067 <sup>b</sup>
Error 1	2	0.0125	0.00073	0.0016	0.001	0.0113
Growth stages	2	0.2337 <sup>c</sup>	0.0064 <sup>c</sup>	0.0053 <sup>c</sup>	0.0108 <sup>c</sup>	0.00545 <sup>c</sup>
Planting system × growth stages	2	0.0029 <sup>c</sup>	0.0005 <sup>c</sup>	0.0010 <sup>c</sup>	0.00005 <sup>c</sup>	0.00027 <sup>c</sup>
Block × growth stages	4	0.0001 <sup>c</sup>	0.00015 <sup>c</sup>	0.0000055 <sup>c</sup>	0.00029 <sup>c</sup>	0.0010 <sup>c</sup>
Error 2	4	0.00048	0.00055	0.000066	0.00016	0.0029
CV.	-	16.65	19.35	14.73	12.54	9.26

<sup>a</sup>Significant at P < 0.05.<sup>b</sup>Significant at P < 0.01.<sup>c</sup>Non-significant.**Table 4.** Comparison of Planting System and Growth Stage on the Measured Traits<sup>a</sup>

Treatment	Cadmium Concentration in Plant, ppm	Cadmium Concentration in Stem, ppm	Cadmium Concentration in Root, ppm	Transfer Coefficient, ppm	Bioaccumulation Factor, ppm
<b>Planting system</b>					
Rice-wheat	1.83 <sup>a</sup>	0.73 <sup>a</sup>	1.09 <sup>a</sup>	0.41 <sup>a</sup>	1.05 <sup>a</sup>
Fallow-wheat	1.32 <sup>b</sup>	0.50 <sup>b</sup>	0.81 <sup>b</sup>	0.36 <sup>b</sup>	0.99 <sup>b</sup>
<b>Growth stage</b>					
Tillering	1.51 <sup>a</sup>	0.58 <sup>a</sup>	0.92 <sup>a</sup>	0.35 <sup>b</sup>	0.91 <sup>b</sup>
Flowering	1.59 <sup>a</sup>	0.62 <sup>a</sup>	0.96 <sup>a</sup>	0.39 <sup>ab</sup>	1.05 <sup>a</sup>
Ripening	1.63 <sup>a</sup>	0.65 <sup>a</sup>	0.98 <sup>a</sup>	0.43 <sup>a</sup>	1.14 <sup>a</sup>

<sup>a</sup>Similar letters in each column show insignificant difference at P < 0.05 using the Duncan multiple rang test.

1 mg/kg and a large amount of absorbed cadmium is accumulated in the roots (28).

Pampana studied samples of soil and wheat in France and reported that the concentration of cadmium in seed is not influenced by the total concentration of cadmium in soil, but it is correlated with the cadmium extracted from 0.1 M cadmium nitrate, and to a lower extent, the soil pH, and the soil CEC (29). They measured the highest concentrations of seed cadmium in plants with shortage of zinc and copper in their shoots. In their study, the concentration factor (the ratio of cadmium concentration in plant to its concentration in soil) ranged 0.1 to 1. Among different varieties of wheat, there might be 2.5 times difference in terms of cadmium accumulation. They believed that selecting wheat cultivars with low potential of cadmium accumulation and setting the chemical state of the soil is useful to reduce cadmium absorption and its entrance into the human foodstuff chain. Khuzestan Province is one

of Iran's agricultural hubs with special position in terms of the variety of products such as wheat, rice, corn, and vegetables. Therefore, the use of phosphorus fertilizers in some areas with extensive agricultural activities is very high (30).

Wheat is the main crop in Khuzestan Province and farmers make excessive use of phosphate fertilizers containing high levels of cadmium (7 - 170 mg/kg), so the amount of cadmium available to the plant is also high (31, 32).

According to Table 4, the mean phosphorus in the studied lands was 8.18 mg/kg, a relatively high level.

Cadmium is transported from soil to plant roots by convection, diffusion, and interception. Cd accumulation in wheat grain is significantly affected by soil chemical characteristics and cultivar (33).

**Table 5.** Descriptive Statistics of Measured Traits

Variable	Cadmium Concentration in Plant, mg/kg	Cadmium Concentration in Stem, mg/kg	Cadmium Concentration in Root, mg/kg	Soil Phosphorus, mg/kg	Transfer Coefficient	Bioaccumulation Factor
Mean	1.57889	0.621111	0.957778	8.18889	0.395556	1.03611
Standard deviation	0.269485	0.123044	0.147391	0.889077	0.0496129	0.0963534
Variance	0.0726222	0.0151399	0.0217242	0.790458	0.0024614	0.009284
Mode	1.545	0.605	0.94	8.25	0.395	1.02
Max.	1.92	0.79	1.16	9.3	0.48	1.2
Skewness	0.0829709	0.104726	0.0964403	-0.04784	-0.003519	-0.246392
Kurtosis	-2.0448	-1.94775	-2.04521	-2.02873	-0.717353	-0.0090208

#### 4.3. Cadmium Accumulation in Stem

The ANOVA results showed that the effect of cropping systems on cadmium accumulation in wheat stem was significant ( $P < 0.01$ ), but the effect of growth stages on its accumulation was not significant (Table 3). Rice-wheat cropping system had higher amounts of stem cadmium (0.73 mg/kg) in comparison with fallow-wheat cropping system (0.50 mg/kg) (Table 4).

Cadmium within the membrane is absorbed by plant cells through the channels or carriers of divalent cations. It is absorbed through the root parenchyma, and then, through the pathways enters the xylems and is combined with several ligands such as organic acids or phytochelatins (34).

Cadmium also enters the plants through the calcium channels, but its transferring rate is very low. Cadmium is transferred from the roots to the shoots through the xylems and is stimulated by transpiration of the leaves. Cadmium accumulation is different in plant species. Spinach, wallflower, potato, and sunflower are greatly potential to store cadmium. The concentration of cadmium in old leaves is more than young leaves in lettuce, spinach, and tobacco (35).

According to the Duncan test, there was not a significant difference between different growth stages, but generally there was an increasing trend in the cadmium accumulation in stem tissue from tillering to maturity (Table 4). In other words, cadmium concentration in plant has an ascending trend during growth stages and as the plants get closer to the last stages of growth and maturity, the cadmium accumulation also increases, which is exactly opposite to the descending trend of total concentration of absorbable cadmium in soil. It may be due to invariability of cadmium accumulation in the stem of wheat from planting to harvest. Descriptive statistics of the mentioned traits showed the mean concentration of cadmium in stem as 0.62 mg/kg (Table 5).

Sohrabi Yourtchi and Bayat evaluated the effect of cadmium treatment on growth, Cd accumulation, and macronutrient content of durum wheat (Dena CV.); they concluded that Cd treatment had significant effects on the studied traits ( $P < 0.01$ ). Their findings indicated that cadmium treatment declined the shoot length, shoot dry weight, and N, P, K, Ca contents in shoot of durum wheat. The maximum decrease was observed at 30 mg/kg Cd treatment. On the other hand, Cd accumulation in root and shoot of the plant increased with increasing Cd concentration in soil. The results suggested that Cd toxicity in durum wheat can suppress the growth development by inhibiting cell division and damping the secretion of some growth enzymes. Besides, cadmium may have antagonistic interactions, especially at high concentrations, with macronutrient content in plant, which leads to decrease in macronutrient content in durum wheat (36).

#### 4.4. Cadmium Accumulation in Roots

The effects of cropping systems and growth stages on the abovementioned traits were significant ( $P < 0.01$ ) and insignificant, respectively (Table 3). Rice-wheat cultivation system had higher concentration of root cadmium (1.09 mg/kg), while fallow-wheat cultivation system had a lower concentration (0.81 mg/kg) (Table 4).

Masoni reported that the concentration of cadmium in the roots was higher than that of the shoots, due to the use of sewage sludge (37).

Cadmium transfer from roots to shoots is very limited and only about 3% of the total absorbed Cd is transferred by this mechanism. Cadmium is absorbed by root and transferred to the shoots very slowly. Kubo stated that although cadmium is not highly soluble in soil, it is mainly attracted by vacuum cords and is significantly stored in root cell walls (38).

Greger stated that further accumulation of metals such as chromium, copper, lead, and zinc in roots rather

than shoots indicates wheat tolerance mechanism at higher concentrations of the metals in the soil (39).

On the other hand, due to the accumulation of heavy metals such as cadmium in plants roots, the use of compounds containing such elements (such as sewage sludge and phosphate fertilizers) is not recommended to cultivate plants with edible roots. According to the results, there was no significant difference between growth stages in terms of cadmium accumulation in roots, but there was a descending trend in the studied traits from the beginning of tillering to maturity (Table 4).

Thawornchaisit and Polprasert attributed the accumulation of heavy metals in roots to the complexes of these metals with sulfhydryl groups, which prevent the transmission of metals to shoots (40). Further accumulation of cadmium in the roots (compared with shoots) can be considered as a positive point, because it probably prevents further transmission of the elements to the seeds, and accordingly, human food chain. On the other hand, since the roots are not being harvested (except for edible roots) at the time of harvest, leaving the roots in the soil can lead to the accumulation of these elements in the soil and their absorption by the plants that results in entering the cropping system gradually. So, it is recommended to remove plantar roots from soil as much as possible during the harvest (41). At lower levels of cadmium, the amount of this element in the roots is higher than the shoots, but since the amount of this element increases in medium concentrations, a greater amount of cadmium is transferred to the shoots and accumulates in the upper parts of wheat seedlings, which indicates the inability of wheat seedlings to inhibit the transfer of cadmium into upper parts (42). Rodda reported 3 different stages for the uptake and transfer of cadmium from soil solution to plant; in the first phase that cadmium was supplied within a few hours, the element affected the growth and metabolism of the root (43). The mean of the studied traits in the current study showed the mean cadmium concentration in wheat root as 0.95 mg/kg (Table 5).

In bread wheat, high grain-Cd was associated with elevated Cd uptake during the early growth stages and with high root to shoot translocation, while in durum wheat it was associated with high translocation to the shoot, but not with high uptake (38). Gao and Grant determined the effect of crop rotation, phosphorus fertilization and tillage on grain yield, and grain concentrations of Cd and Zn in durum wheat (*Triticum durum* L.). Their results showed that reduced tillage management decreased grain-Cd and increased grain yield and grain Zn in half of the site-years. Rate and timing of P application had little impact on grain-Cd, but the increased P rate could decrease grain-Zn. There was no correlation between grain-Zn and grain-Cd, but it

positively correlated with other nutrients such as Fe, Mn, P, Ca, K, and Mg (44).

#### 4.5. Transfer Coefficient

According to the ANOVA results, the effect of cropping systems on TC was significant ( $P < 0.01$ ), but the effect of growth stages on TC was insignificant (Table 3).

Phytoremediation of heavy metals is divided into 3 major groups:

1- Phytoextraction: Heavy metals are removed from the soil and accumulated in the upper parts of the plants (stems and leaves).

2- Phytostabilization: Heavy metals are stored in the roots of plants.

3- Rhizofiltration: Plants' roots are used for absorption, concentration, and deposition of elements from contaminated aqueous environments (45, 46).

In the environments with high concentrations of heavy metals, plants respond in 2 ways: the first mechanism is avoidance in which the plants avoid absorbing the metals and transferring them between the organs; these plants are called non-accumulators. The second mechanism is to accumulating and encoding metals; the plants using this mechanism have very high capacity to absorb metals by roots and transfer and store them in shoots. These plants are called excessive accumulators. They can be used to remove heavy materials and remediate contaminated soils through the phytoremediation process (47). The percentage of the metal accumulated in dry leaves is the criterion to select a plant as an excessive accumulator of heavy metals. In the case of cadmium, a plant with the capability of concentrating more than 100 mg of cadmium per kg of leaf dry mass is regarded as the excessive accumulator of cadmium. In most of plant species, cadmium concentration is less than 3 mg/kg, but in the soils rich in cadmium, the concentration might be increased even up to 20 mg/kg. However, the plants with more than 100 mg/kg of Cd in shoots are rarely found (48). Rice-wheat cropping system had higher amounts of cadmium accumulation in wheat plant tissue (0.41 mg/kg) than the fallow-wheat planting system (0.36 mg/kg) (Table 4). The results are consistent with those of Wang and Zhou (49).

Totally, with regard to the studies on the accumulation of cadmium in wheat in both planting systems, wheat is not classified as a plant with soil treatment capability, since based on the data analysis results, the mean transfer coefficient was 0.39 (Table 5). It should be noted that if the transfer coefficient is less than 1, the plant is not identified with soil treatment capability. The results were consistent with those of Rafati et al. (50). To the authors' best knowledge, most of the ions in the environment are in close contact

with the roots that are the first place for absorption; therefore, some ions are absorbed by the cell wall and cannot be transferred into the stem. In addition, the ions might be linked with various combinations and be captured within different cellular organelles such as vacuoles, so they are also unavailable to be transferred into the stem (51).

Moreover, there are some other special mechanisms to restrict metal transfer; therefore, a lot of ions are absorbed by the roots, but the possibility of transmission into the stem is restricted. Despite the restriction of metal ions transfer into the shoots, the transfer of the desired metals from the root to the shoot is essential for the plant. The movement of the sap containing metal from root to stem is controlled by 2 processes: root pressure and leaf transpiration. Cadmium is also able to pass through the root cell membranes and enter the xylem, and then, pass through the stem and be absorbed by the leaf cells (19).

Among different growth stages, there was a significant difference between the mid tillering and flowering stages, and the maturity stage in terms of TC; in addition, an increasing trend was observed in cadmium TC from the early stage of growth to maturity on the whole because despite the increasing trends of cadmium accumulation in plant tissue during the growth, the TC also increased gradually from the mid tillering to maturity (Table 4). Excessive accumulating plants are also identified based on TC and absorption of ions by the shoots; therefore, by calculating TC the capability of plants is clarified. Cadmium TC in licorice is 27.3 - 50.7. The coefficient for the 2 excessive accumulating plants, *Eriochloa polystachya* and *A. haller* are 52.5 and 23.8, respectively. Therefore, licorice can accumulate a significant amount of cadmium ions in its shoots (52).

A major problem in phytoremediation process is that heavy metals in high concentrations may prevent plant growth and biomass production. Additional heavy metals can affect plant growth in different ways and may disrupt physiological and morphological features of the plant. Cadmium also reduces seed germination and plant growth (53).

Cadmium may inhibits the activity of some enzymes, sediment of essential elements or metabolites, and thereby may induce cell damage; cadmium toxicity symptoms in the leaves appear as jaundice and burn, and by inhibiting the elongation of growing cells reduces the growth of roots and stems (54).

#### 4.6. Bioaccumulation Factor

According to ANOVA results, the effect of cropping systems on bioaccumulation coefficient (the ratio of metal concentration in plant to metal concentration in soil) was significant ( $P < 0.01$ ), but the effect of growth stages on bioaccumulation coefficient was insignificant (Table

3). Rice-wheat cropping system had higher amounts of cadmium accumulation in wheat tissue (1.05 mg/kg) in comparison with the fallow-wheat cropping system (0.99 mg/kg) (Table 4).

Among different growth stages, there was a significant difference between the mid tillering and flowering stages, and the maturity stage in terms of bioaccumulation coefficient, and an increasing trend was observed in bioaccumulation coefficient from the early stage of growth to maturity on the whole (Table 4). The results of data analysis such as the means of the studied traits showed that the mean bioaccumulation coefficient in the studied soils was 1.03 (Table 5) indicating that wheat plant has lower bioaccumulation coefficient than other crops such as sunflower, barley, and rapeseed and is not identified with as soil treatment ability.

## 5. Discussion

It is noteworthy that the seed mean concentration of cadmium in both cropping systems was above the standard limits of WHO (2 mg/kg) (FAO/WHO, 1984). The high seed cadmium concentration in Eastern part of Khuzestan Province mainly depends on the type of cultivated wheat since in this region durum wheat is the dominant cultivar. The evaluation cadmium accumulation in plants showed that the accumulation of cadmium in plant has an ascending trend during the growth stages and as the plants get closer to the last stages of growth and maturity, cadmium accumulation also increases in the plant, which is exactly against the descending trend of the total concentration of cadmium in soil. Due to the high consumption of phosphate fertilizers (according soil test data), the soil Cd concentration in rice-wheat cropping system was higher than that of the fallow-wheat cropping system. The cadmium concentration in stem depends on the plant species, organs, or tissue of the same plant; also, the difference in cadmium accumulation is not merely associated with plant species, but with plant cultivar, leaf age, and growth stage of the plant. It seems that due to further accumulation of cadmium concentration in lands with rice-wheat planting system, the root of wheat faces more availability of cadmium in soil in the mentioned rotation and higher concentration of cadmium is accumulated in the plant. As a result, TC, which indicates the capability of transferring the element from soil to plant in rice-wheat cropping system, is higher in the rice-wheat planting system than the fallow-wheat cropping system because the availability of cadmium is higher in the rice-wheat planting system. It seems that more availability of cadmium in both lands and different plant tissue in rice-wheat planting system leads to higher bioaccumulation coefficient in the rice-wheat



planting system rather than the fallow-wheat planting system.

### 5.1. Conclusion

The results of data analysis showed that the mean concentration of cadmium in seed, stem, and root was 0.29, 0.62, and 0.95 mg/kg respectively, which indicates wheat plant mechanism to resist against cadmium transfer and more accumulation of the element in root, stem, and seed, respectively. Therefore, cadmium accumulation trend in plant and root and stem had an increasing trend during the growth stages from early tillering to maturity, which is probably due to the transfer of cadmium from soil to plant over the time. Although this process and wheat plant mechanism in the accumulation of cadmium seem desirable, wheat is not identified with soil treatment capabilities (according to the mean TC of 0.39 and bioaccumulation coefficient of 1.03) and its seed is directly used for human nutrition. Moreover, with regard to the available standards and the threshold of 2 mg/kg as the maximum permitted rate for cadmium accumulation in wheat seeds, the management of factors involving in the increase of cadmium concentration, such as non-standard phosphate fertilizers, which is mainly imported without any monitoring (high concentrations of phosphorus, 8.18 mg/kg in soil, indicate excessive use of phosphate fertilizers in the studied lands), sewage sludge (for irrigating farms), and the volume of crop residues in soil (from the plant cultivated before the current plant), is very important and essential to the planting pattern of crops.

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### Footnotes

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