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Composition of some trace elements in wheat plant and soil

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Buğday bitkisi ve toprağındaki bazı eser elementlerin bileşimi

Abstract: Zinc, copper, nickel, and manganese are essential nutrients for plants. However, excessive accumulation in the plant can lead to significant risks and problems in terms of human health after consumption. Also, the accumulation of chromium, cadmium and lead elements in plants can have a toxic effect on human health. This study aimed to determine the concentrations of copper (Cu), chromium (Cr), cadmium (Cd), nickel (Ni), manganese (Mn), zinc (Zn), and lead (Pb) trace elements in wheat plants and soil. Mean trace element levels in soil samples taken from the city center Mn 556.9 mg kg^{-1}, Ni 62.45 mg kg^{-1}, Cr 24.98 mg kg^{-1}, Zn 40.75 mg kg^{-1}, Cu 17.25 mg kg^{-1}, Pb 7.65 mg kg^{-1}, Cd as 1.63 mg kg^{-1} and the average trace element levels in soil samples taken from villages Mn 418.7 mg kg^{-1}, Zn 48.53 mg kg^{-1}, Ni 32.34 mg kg^{-1}, Cu 15.93 mg kg^{-1}, Cr 13.7 mg kg^{-1}, Cd 1.033 mg kg^{-1} was determined. Cd, Cr, and Pb concentrations were not detected in wheat samples. Average Cu (4.462 mg kg^{-1}), Mn (30.03 mg kg^{-1}), and Zn (20.39 mg kg^{-1}) concentrations in wheat samples were determined at lower levels compared to soil samples. In the process of transporting trace elements from the soil to the plant, even if the plants are grown under the same conditions, the trace element levels accumulated in the plant may differ.

Key words: Mineral content, wheat, soil, ICP-OES

Özet: Çinko, bakır, nikel ve mangan bitkiler için temel besin maddelerindendir. Ancak, bitkide aşırı birikmeleri tüketim sonrasında insan sağlığı açısından önemli risklere ve sorunlara yol açabilmektedir. Ayrıca, bitkilerde krom, kadmiyum ve kurşun elementlerinin birikmesi insan sağlığı üzerinde toksik etkiye sahip olabilir. Bu çalışmada, buğday bitkilerinde ve toprakta Cu, Cr, Cd, Ni, Mn, Zn, ve Pb eser elementlerinin konsantrasyonlarının belirlenmesi amaçlanmıştır. Şehir merkezinden alınan toprak örneklerinde ortalama eser element seviyeleri Mn 556.9 mg kg^{-1}, Ni 62.45 mg kg^{-1}, Cr 24.98 mg kg^{-1}, Zn 40.75 mg kg^{-1}, Cu 17.25 mg kg^{-1}, Pb 7.65 mg kg^{-1}, Cd 1.63 mg kg^{-1} olarak ve köylerden alınan toprak örneklerinde ortalama eser element seviyeleri Mn 418.7 mg kg^{-1}, Zn 48.53 mg kg^{-1}, Ni 32.34 mg kg^{-1}, Cu 15.93 mg kg^{-1}, Cr 13.7 mg kg^{-1}, Cd 1.033 mg kg^{-1} olarak belirlenmiştir. Buğday örneklerinde Cd, Cr ve Pb konsantrasyonları tespit edilmemiştir. Buğday örneklerindeki ortalama Cu (4.462 mg kg^{-1}), Mn (30.03 mg kg^{-1}) ve Zn (20.39 mg kg^{-1}) konsantrasyonları ise toprak örneklerine göre düşük seviyelerde belirlenmiştir. Topraktan bitkiye eser elementlerin taşınması sürecinde, bitkiler aynı koşullarda yetiştirilse bile bitkide biriken eser element seviyelerinde farklılık gösterebilmektedir.

Anahtar Kelimeler: Mineral içerik, buğday, toprak, ICP-OES

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1. Introduction

One of the most important economic sectors in the world, especially in developing nations, is agriculture, and agricultural practices have a direct impact on food safety (Tudi et al., 2021). Considering various soil pollutants, trace elements and heavy metals pose a serious danger to human and animal health due to their toxicity and persistence. While some trace elements like Cu, Zn, and Ni are necessary for the human body and plant growth, the accumulation of toxic elements like Cd, arsenic (As), Pb, and Cr is harmful to biological systems (Rana, 2008; Järup, 2003).

The bioaccumulation and persistence of trace elements in agricultural soil systems are becoming a serious global health and environmental problem (Wang et al., 2016). Trace and toxic elements accumulate in agricultural soils due to natural sources, urbanization, industrial activities, or atmospheric transport, and the products grown in these soils are affected by these trace elements. The accumulation of these trace elements has often been studied (Rezapour et al., 2019; Zhang et al., 2019).

Through the food chain, the movement and bioaccumulation of trace elements in soils and crops not only have a detrimental impact on the environment and the safety of food but also negatively affect the reproductive, nervous, and immune systems of people and other animals (Khan et al., 2019). For instance, continued consumption of little amounts of Cd can cause the metal to build up in the body, weakening bones or affecting kidney function (Wiggenhauser et al., 2016). Relevant research also revealed that endocrine disruption in both people and animals can be caused by a combination of trace elements, even at low concentrations (Ma et al., 2016).

Among the cereals, wheat is very popular in many countries in terms of being an important food source. Wheat accounts for approximately 30% of the world's grain production (Giraldo et al., 2019). Wheat is a member of the family *Triticeae* and belongs to the genus *Triticum* (Hussain et al., 2022). Like many other plants, wheat is vulnerable to trace elements. The wheat plant is an important source of various trace elements such as Zn, Cu, Mn, and Ni that are important to humans. The wheat plant can also contain various toxic elements like Cd, Pb, and Cr.

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According to the findings, mercury and arsenic uptake was maximum for wheat grown in a petri dish. Due to cadmium, nickel, mercury, and copper adsorption on soil phases, the wheat grown in a pot had high levels of manganese and iron while the wheat produced in a petri dish had considerable quantities of nickel, copper, and cadmium. A decrease in the intake of trace elements was observed after the addition of liquid fertilizers in wheat, except for manganese (Stanisić Stojić et al., 2016).

Trace elements stress plants, which results in a range of reactions from germination to growth to metabolic reactions and, in the case of wheat, yield reductions. For instance, it has been demonstrated that Pb is incredibly detrimental to wheat, causing stunted growth and raised membrane permeability, which ultimately results in the production of ROS (Gang et al., 2013). The accumulation of ROS in plant tissues causes electrolyte leakage and threatens the integrity of cell membranes (Emamverdian et al., 2015). Higher lead concentrations during the *Eruca sativa* planting stage, the researchers found, decreased germination. The quantity of soluble protein rose along with the concentration of Pb (Faheed, 2005). As Pb concentration rose, so did the amount of soluble protein. The germination of seeds was hindered when silver (Ag) (10 mM) was applied, and it was completely prevented when the Ag concentrations were increased. High Zn concentrations promote seed germination, whereas Pb treatment prevents seed sprouting (Ashraf et al., 2008).

The bioavailability of trace elements in the soil is a process that needs to be monitored as they are not degraded by microorganisms, chemicals, or other means. Trace element levels in the soil can affect the growing conditions, photosynthesis, yield, and nutritional value of wheat (Rizwan et al., 2018). This process changes the quality of wheat. Wheat is one of the most important staple foods all over the world. Trace elements and their toxicity in crops, particularly wheat, have become a regular concern. This study aimed to determine the concentrations of Cd, Cu, Cr, Mn, Ni, Pb, and Zn trace elements in wheat plants and soil.

2. Materials and Method

2.1. Materials

The wheat and soil samples were collected from Karaman city center (No:1) and 4 different villages (Lale (No:2), Kızılyaka (No:3), Sudurağı (No:4), Yollarbası (No:5)). It is important to collect the samples to be analyzed. Soil samples were taken from the fields at a depth of 10-15 cm using a Cr-Ni spatula. Wheat samples were selected from ears that were ripe and ready to be harvested before harvest time. Soil and wheat samples were collected at the same place and at the same time. The samples were kept in transparent bags. Three separate samples were taken from each selected region.

Pre-drying was done by laying the collected wheat and soil samples in a dust-free environment in the open air. It was then ground into powder by grinding in a porcelain mortar. The powdered samples were sieved through 100 and 150 mesh sieves, respectively. The sieved samples were dried in an oven at 80-90 ^{o}C for 2 hours.

2.2. Wheat and soil sampling

1 g of wheat sample was put into the beaker (50 ml) and 20 ml of HNO_3 (w/w, 65%) was added. After waiting for 10 hours, 7 ml of $HClO_4$ (w/w, 70%) was added. It was heated slowly for 6-7 hours in a fume hood. The heating was cut off and cooled near the end of the acid. 7 ml of H_2O_2 (w/w, 30%) was added and heating continued until a clear liquid was obtained. The volume was made up to 10 ml with ultrapure water (Milli-Q Direct 8, Water Purification System, Merck) by filtration through the blue band filter paper and made ready for analysis (Karapınar et al., 2017; Kaya et al., 2017; Karapınar and Kılıçel, 2020).

1 g of soil sample was placed in the beaker (50 ml) and 16 ml of HNO_3/HCl (w/w, 1/3) was added. It was kept for 7 hours. After it was heated to dryness in a fume hood, 15 ml of 2 M HNO_3 was added and after waiting for 4 hours, it was filtered through a blue band filter paper and made ready for analysis by making it up to 20 ml with ultrapure water (Türkdoğan et al., 2003; Bermudez et al., 2012).

2.3. Analytical technique trace elements detection

Inductively Coupled Plasma Optic Emission Spectroscopy (ICP-OES) was used to analyze the samples at room temperature.

Merck provided the ultra-high purity reagents (certified >99.99%). To create working solutions, 1000 mg l^{-1} standard solutions (CRM, Merck) were diluted in 0.5% HNO_3. Working standards were used for calibration curves with a six-point range (including zero).

Accelerating Inductively Coupled Plasma Optic Emission Spectroscopy with Axially Observed Plasma (Agilent 720 Series, Santa Clara, ABD) was employed for this work (Table 1).

Table 1. Analytical conditions for trace elements analysis using ICP-OES

Apparatus	Agilent Technologies 720
RF forward power	1.0 kW
Plasma gas (Ar) flow	15 l min^{-1}
Auxiliary gas (Ar) flow	1.5 l min^{-1}
Nebulizer gas (Ar) flow	0.75 l min^{-1}
Replicates	3
Pump rate	2.0 ml min^{-1} (peristaltic pump)
Plasma position	Axial
Rinse time	15 sec
Total sample usage	2 ml
Torch	Standard one piece quartz axial
Spray chamber type	Glass cyclonic (single-pass)
Nebulizer type	Sea Spray

A specially created CCD detector is included with the Agilent 720, enabling true simultaneous measurements and complete wavelength coverage from 167 to 785 nm (Table 2). The two-dimensional image from the echelle lenses is ideal for the continuous angled arrays in the CCD detector. The thermally stabilized optical system has no moving parts, which provides excellent long-term stability.

The method of selecting the trace elements has been validated by repeated studies of certified reference material. For every six measurements, the specified components were examined in six blank control samples and certified standards. A computerized laboratory data management system was utilized to perform calibration measurements on standards, control standards, and blank samples.

Table 2. The studied wavelength and LOD values of the elements

Elements	Studien wavelength (nm)	Detection limit (μg/l)
Cd	228.802	0.01
Cr	206.158	0.005
Cu	327.395	0.01
Mn	259.372	0.005
Ni	216.555	0.005
Pb	182.143	0.005
Zn	213.857	0.02

The data (mean, standard deviation) from all samples were assessed three times using IBM SPSS Statistics version 20 software and the Student *t*-test. The significance level was set as $p < 0.05$.

3. Results

The World Health Organization Expert Committee (WHO, 1996) examines trace elements, Pb and Cd potentially toxic elements, Co and Ni elements that may be necessary, Zn, Cu, and Cr basic elements in terms of their nutritional importance in humans.

Cd, Cr, Cu, Ni, Mn, Zn, and Pb trace elements concentrations in wheat and soil samples are given in Tables 3 and 4.

Trace element concentrations in soil samples taken from the city center were determined as Mn> Ni> Zn> Cr> Cu> Pb> Cd. Trace element concentrations in soil samples taken from villages were generally determined as Mn> Zn> Ni> Cu> Cr> Cd.

According to the reported reports, the average trace element levels in the surface soil of arable lands were determined as 20 mg kg^{-1} for Ni, 900 mg kg^{-1} for Mn, 70 mg kg^{-1} for Zn, 0.1 mg kg^{-1} for Cd, 55 mg kg^{-1} for Cu, 14 mg kg^{-1} for Pb, and 100 mg kg^{-1} for Cr (Kabata-Pendias and Mukherjee, 2007; Kabata-Pendias, 2011). According to previous reports, it was determined that Zn, Mn, Pb, Cu, and Cr in wheat soil were below the values given, but above the values given for Ni and Cd.

Although the concentration of Ni and Cd in soil samples was higher than in previous reports, the concentration of Cd and Ni in wheat samples could not be determined. Ni trace element was detected at low levels only in the samples taken from the city center. It is thought that the Ni concentration in the samples taken from the city center is due to urbanization and industrialization.

According to the international legislation on wheat grains and foodstuffs (FAO/WHO) and the Turkish food codex communiqué (28157/2011), the average concentrations of Mn, Cu, Zn, and Ni were below the permissible limits (Berg and Licht, 2002; Joint FAO, 2017).

In our study, the amounts of Pb and Cd in wheat were lower than in previous studies (Nan et al., 2002; Lavado et al., 2007; Chandra et al., 2009; Douay et al., 2008). Ni, Zn, and Cu concentrations in wheat samples are in agreement with previous studies (Nan et al., 2002; Lavado et al., 2007; Kirchmann et al., 2009; Singh et al., 2010).

Zn is one of the trace elements that are part of a few bioactive enzymes in plants. Many plant oxidases include copper, which can encourage redox reactions. Also, plants have a lot of copper in their chloroplasts, which helps the chlorophyll stay stable (Zhang et al., 2018). Trace element concentrations can vary between various crop tissues and between different locations of the same crop. Wheat's ability to bioabsorb and transfer elements from the soil to it is influenced by a variety of factors, including cation exchange capacity, soil pH, plant species, organic matter content, plant species, and age (Abdelhafez and Li, 2015). Based on their physiological mechanisms, many plants have an innate capacity to metabolize a variety of heavy metals (Ran et al., 2016).

In addition, values similar to Cu and Zn concentrations were observed in grain samples grown in an industrial town (Huang et al., 2008). Cr concentrations in wheat samples were lower than in India, China, and previous studies (Balaji et al., 2000; Al-Dayel and Al-Kahtani, 2002; Huang et al., 2008; Singh et al., 2010).

Table 3. Average concentrations ± SD of trace elements in soil (mg kg^{-1}) (SD: Standard Deviation)

Soil	Cd	Cu	Cr	Mn	Ni	Pb	Zn
1	1.63 ±0.08	17.25 ±1.23	24.98 ±1.78	556.9 ±23.3	62.45 ±3.54	7.65 ±0.9	40.75 ±3.12
2	1.11 ±0.05	28.45 ±2.56	12.67 ±0.13	560.7 ±22.4	27.56 ±1.45	*	65.01 ±5.45
3	0.83 ±0.02	14.70 ±1.67	12.34 ±0.56	356.9 ±18.1	31.67 ±1.34	*	42.37 ±3.55
4	0.87 ±0.07	11.52 ±0.89	17.23 ±1.01	468.5 ±20.2	35.89 ±2.02	*	57.70 ±6.67
5	1.32 ±0.13	9.061 ±1.12	12.56 ±0.78	288.7 ±17.1	34.23 ±2.78	*	29.03 ±2.03

*Not determined

Table 4. Average concentrations ± SD of trace elements in wheat (mg kg^{-1}) (SD: Standard Deviation)

Soil	Cd	Cu	Cr	Mn	Ni	Pb	Zn
1	*	1.15 ±0.33	*	15.91 ±2.33	2.44 ±0.54	*	7.85 ±1.11
2	*	2.65 ±0.26	*	23.71 ±2.41	*	*	15.01 ±1.44
3	*	4.56 ±0.88	*	35.51 ±4.12	*	*	12.33 ±1.05
4	*	3.87 ±0.65	*	46.42 ±2.54	*	*	17.71 ±1.47
5	*	10.08 ±1.34	*	28.62 ±1.54	*	*	49.03 ±2.56

*Not determined

Table 5. Average trace element concentrations in previous studies in wheat (W) and soil (S) samples (mg kg^{-1})

Soil	Cd	Cu	Cr	Mn	Ni	Pb	Zn	Reference
W	0.038	3.510	0.022	33.26	0.240	-	27.35	Kirchmann et al., 2009
W	0.097	9.023	41.72	87.20	5.956	13.76	13.49	Tudi et al., 2021
W	0.055	5.229	0.108	-	0.148	0.177	27.78	Huang et al., 2008
W	1.43	14.7	9.21	34.5	1.42	21	34.2	Setia et al., 2023
W	0.1	10.7	4.0	51.4	1.6	1.3	62.6	Özturk and Arici, 2021
W	0.05	25	0.6	100	5.0	6.0	70	Kacar and Inal, 2008
W	-	4.462	-	30.03	2.44	-	20.39	This study
S	0.732	22.65	44.48	641.8	25.95	33.74	69.30	Tudi et al., 2021
S	-	7.94	-	395	8.38	10	-	Bermudez et al., 2012
S	0.16	26	67.41	-	35.84	28.63	98.58	Huang et al., 2008
S	2.42	26.3	28.9	324	28.4	36.8	55.9	Setia et al., 2023
S	0.15	14.5	24.98	352	34.29	20.4	35.98	Ozturk and Arici, 2021
S	0.41	38.9	60	488	29	27	70	Kabata-Pendias, 2011
S	1.152	16.2	15.96	446.3	38.36	7.65	46.97	This study

Cu ($p<0.03$), Mn ($p=0.004$), and Zn ($p<0.002$) levels were significantly different between wheat and soil samples. Ni ($p<0.002$) levels in the samples taken from the city center differed significantly between wheat and soil samples.

The average trace element concentrations of previous studies from similar and different regions are given in Table 5. Cd, Cr, and Pb elements were not detected in wheat samples. It was determined that the average Cu, Mn, Ni, and Zn concentrations in wheat were at lower levels compared to previous studies. Also, It was determined that the average Cu, Cr, and Pb levels in the soil were lower than in previous studies and that Cd, Mn, and Zn were at average levels.

4. Discussions

The present study demonstrates the importance of bioaccumulation and the transfer of trace elements between wheat and soil. The Pb concentration was determined only in the soil samples taken from the city center. Trace element concentrations of Cd, Cr, and Pb were not detected in wheat samples. Cu, Mn, and Zn concentrations in wheat samples were determined at very low levels compared to soil samples. It has been determined that the process of element transport from soil to plant may differ in trace element concentrations even if the plants are grown under the same conditions.

Conflict of Interest

There is no conflict of interest with any institution or person.

References

Abdelhafez AA, Li J (2015). Environmental monitoring of heavy metal status and human health risk assessment in the agricultural soils of the Jinxi River area, China. Human and Ecological Risk Assessment: An International Journal 21(4): 952-971.

Al-Dayel OAF, Al-Kahtani SA (2002). Elemental content in wheat products of Al-Qusim region, Saudi Arabia using the INAA technique. Journal of Radioanalytical and Nuclear Chemistry 252: 605-609.

Ashraf M, Athar HR, Harris PJC, Kwon TR (2008). Some prospective strategies for improving crop salt tolerance. Advances in Agronomy 97: 45-110.

Balaji T, Acharya RN, Nair AGC, Reddy AVR, Rao KS, Naidu GRK, Manohar, SB (2000). Multielement analysis in cereals and pulses by k0 instrumental neutron activation analysis. Science of the Total Environment 253(1-3): 75-79.

Berg T, Licht D (2002). International legislation on trace elements as contaminants in food: a review. Food Additives & Contaminants 19(10): 916-927.

Bermudez GM, Jasan R, Plá R, Pignata ML (2012). Heavy metals and trace elements in atmospheric fall-out: their relationship with topsoil and wheat element composition. Journal of Hazardous Materials 213: 447-456.

Chandra R, Bharagava RN, Yadav S, Mohan D (2009). Accumulation and distribution of toxic metals in wheat (Triticum aestivum L.) and Indian mustard (Brassica campestris L.) irrigated with distillery and tannery effluents. Journal of Hazardous Materials 162(2-3): 1514-1521.

Douay F, Roussel H, Pruvot C, Waterlot C (2008). Impact of a smelter closedown on metal contents of wheat cultivated in the neighbourhood. Environmental Science and Pollution Research 15: 162-169.

Emamverdian A, Ding Y, Mokhberdoran F, Xie Y (2015). Heavy metal stress and some mechanisms of plant defense response. The Scientific World Journal. 756120.

Faheed FA (2005). Effect of lead stress on the growth and metabolism of Eruca sativa M. seedlings. Acta Agronomica Hungarica 53(3): 319-327.

Gang A, Vyas A, Vyas H (2013). Toxic effect of heavy metals on germination and seedling growth of wheat. Journal of Environmental Research and Development 8(2): 206-213.

Giraldo P, Benavente E, Manzano-Agugliaro F, Gimenez E (2019). Worldwide research trends on wheat and barley: A bibliometric comparative analysis. Agronomy *9*(7): 352.

Huang M, Zhou S, Sun B, Zhao Q (2008). Heavy metals in wheat grain: assessment of potential health risk for inhabitants in Kunshan, China. Science of the Total Environment 405(1-3): 54-61.

Hussain I, Afzal S, Ashraf MA, Rasheed R, Saleem MH, Alatawi A, Fahad S (2022). Effect of metals or trace elements on wheat growth and its remediation in contaminated soil. Journal of Plant Growth Regulation 1-25.

Järup L (2003). Hazards of heavy metal contamination. British Medical Bulletin 68(1): 167-182.

Joint FAO, World Health Organization, & WHO Expert Committee on Food Additives (2017). Evaluation of certain contaminants in food: eighty-third report of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization.

Kabata-Pendias A, Mukherjee AB (2007). Trace elements from soil to human. Berlin: Springer Science & Business Media.

Kabata-Pendias A (2011). Trace elements in soils and plants/fourth editions. Boca Raton: CRC Taylor and Francis Group.

Kacar B, Inal A (2008). Bitki Analizi. Ankara: Nobel Publication.

Karapınar HS, Uzun Y, Kılıçel F (2017). Mineral contents of two wild morels. Anatolian Journal of Botany 1(2): 32-36.

Karapınar HS, Kılıçel F (2020). Determination of Some Toxic Element (Cr, Cd, Cu and Pb) Levels in Cumin and Cinnamon Aromatic Plants Frequently Used as Foodstuff. Bursa Uludağ Üniversitesi Ziraat Fakültesi Dergisi 34(Özel Sayı): 1-8.

Kaya A, Kılıçel F, Karapınar HS, Uzun Y (2017). Mineral contents of some wild edible mushrooms. The Journal of Fungus 8(2): 178-183.

Khan Z, Iqbal S, Ahmad K, Ashfaq A, Bashir H, Dogan Y (2019). Assessment of heavy metal content of wheat irrigated with wastewater in Sargodha, Pakistan: Implications for human health. Trace Elements and Electrolytes 36(2): 82-92.

Kirchmann H, Mattsson L, Eriksson J (2009). Trace element concentration in wheat grain: results from the Swedish long-term soil fertility experiments and national monitoring program. Environmental Geochemistry and Health 31: 561-571.

Koehler P, Wieser H (2012). Chemistry of cereal grains. In Gobbetti M, Ganzle M (eds.). Handbook on sourdough biotechnology, New York: Springer.

Lavado RS, Rodríguez M, Alvarez R, Taboada MA, Zubillaga MS (2007). Transfer of potentially toxic elements from biosolid-treated soils to maize and wheat crops. Agriculture, Ecosystems & Environment 118(1-4): 312-318.

Ma L, Wang L, Jia Y, Yang Z (2016). Arsenic speciation in locally grown rice grains from Hunan Province, China: Spatial distribution and potential health risk. Science of the Total Environment 557: 438-444.

Nan Z, Zhao C, Li J, Chen F, Sun W (2002). Relations between soil properties and selected heavy metal concentrations in spring wheat (Triticum aestivum L.) grown in contaminated soils. Water, Air, and Soil Pollution 133: 205-213.

Ozturk A, Arici OK (2021). Carcinogenic-potential ecological risk assessment of soils and wheat in the eastern region of Konya (Turkey). Environmental Science and Pollution Research 28(12): 15471-15484.

Ran J, Wang D, Wang C, Zhang G, Zhang H (2016). Heavy metal contents, distribution, and prediction in a regional soil–wheat system. Science of The Total Environment 544: 422-431.

Rana SVS (2008). Metals and apoptosis: recent developments. Journal of Trace Elements in Medicine and Biology 22(4): 262-284.

Rezapour S, Atashpaz B, Moghaddam SS, Kalavrouziotis IK, Damalas CA (2019). Cadmium accumulation, translocation factor, and health risk potential in a wastewater-irrigated soil-wheat (*Triticum aestivum* L.) system. Chemosphere 231: 579-587.

Rizwan M, Ali S, Rehman MZU, Javed MR, Bashir A (2018). Lead toxicity in cereals and its management strategies: a critical review. Water, Air, & Soil Pollution 229: 1-16.

Setia R, Dhaliwal SS, Singh R, Singh B, Kukal SS, Pateriya B (2023). Ecological and human health risk assessment of metals in soils and wheat along Sutlej river (India). Chemosphere 312: 137331.

Singh A, Sharma RK, Agrawal M, Marshall FM (2010). Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. Food and Chemical Toxicology 48(2): 611-619.

Stanisˇić Stojić SM, Ignjatović LM, Popov S, Škrivanj S, Đorđević AR, Stojić A (2016). Heavy metal accumulation in wheat and barley: the effects of soil presence and liquid manure amendment. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology 150(1): 104-110.

Turkish Food Codex (2011). The Communique on Microbiological Criteria. Ankara: Official Gazette 29.12.2011-28157.

Tudi M, Ruan HD, Yu Y, Wang L, Wei B, Tong S, Yang LS (2021). Bioaccumulation and translocation of trace elements in soil-irrigation water-wheat in arid agricultural areas of Xin Jiang, China. Ecotoxicology 30: 1290-1302.

Türkdoğan MK, Kilicel F, Kara K, Tuncer I, Uygan I (2003). Heavy metals in soil, vegetables and fruits in the endemic upper gastrointestinal cancer region of Turkey. Environmental toxicology and pharmacology 13(3): 175-179.

Wang S, Nan Z, Prete D, Ma J, Liao Q, Zhang Q (2016). Accumulation, transfer, and potential sources of mercury in the soil-wheat system under field conditions over the Loess Plateau, northwest China. Science of the Total Environment 568: 245-252.

Wiggenhauser M, Bigalke M, Imseng M, Muller M, Keller A, Murphy K, Frossard E. (2016). Cadmium isotope fractionation in soil–wheat systems. Environmental Science & Technology 50(17): 9223-9231.

World Health Organization (1996). Trace elements in human nutrition and health. Geneva: World Health Organization.

Zhang W, Chen Y, Qi Y, Hong C (2018). Seasonal variations of mercury levels and human health risk in vegetables from Arid Oasis (Shihezi city), Xinjiang, Northwest China. Human and Ecological Risk Assessment: An International Journal 24(1): 122-136.

Zhang WP, Qian J, Xu GJ, Zhang DM, Kang C, Feng DX, Zhang CS (2019). Characterization and evaluation of heavy metal pollution in soil-wheat system around coal mines in Pingdingshan, China. Applied Ecology Environmental Research 17: 5435-5447.