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ORIGINAL PAPER

Mineral content of some bread wheat cultivars

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Abstract
There are not enough studies in which agronomic studies on wheat are evaluated in terms of mineral content. This research was carried out to determine the differences in mineral content of 42 bread wheat varieties. Ground grains of bread wheat varieties were used as material. Average Cu, Fe, Mn, Se, Zn, As, Cd, Co, Cr, Ni and Pb contents of the wheat varieties were 1.38, 15.6, 31.1, 0.066, 2.19, 0.041, 0.0064, 0.052, 0.147, 1.20 and 0.185 ppm, respectively. The data obtained from present study indicate that mineral nutrient content of bread wheat genotypes were different to each other. Differences in grain mineral element contents among varieties could be associated with differences in adaptation ability of genotypes, genotypic structure and reaction to different soil and climate conditions. The intake of plant nutrients and their interaction with each other is one of the issues that should be carefully considered. The tested wheat varieties showed significant differences in terms of mineral content. However, there is a need for more detailed studies using fewer varieties (such as Sultan-95, Uzunyayla and Dogu-88, which are prominent in this study) in order to make more accurate recommendations about the mineral content of wheat.

Keywords Bread wheat · Genotypes · Mineral content

Introduction

The nutritional value of wheat is extremely important as it takes an important place among the few crop species being extensively grown as staple food sources. The importance of wheat is mainly due to the fact that its seed can be ground into flour, semolina, etc., which form the basic ingredients of bread and other bakery products, as well as pastas, and thus it presents the main source of nutrients for most of the world population. Wheat consumption can provide 30% of the daily calorie intake (WHO 2020). A huge increase in demand for cereals is predicted if the food needs for the estimated world population growth are to be met. But there is another potentially great benefit to these communities and that is the possibility to ensure such staple crops are nutritionally-balanced and help remove the millions of cases of nutritionally-related deficiency disease that afflict them. It should be emphasized that in the past there has not been a single instance where plants have been bred to improve their nutritional content. Due to the rapid increase in the world population, it is necessary to increase the yield in crop production, where it is aimed to increase the amount and quality of the products obtained from the unit area and to avoid applications that may affect human health. Today, heavy metals, which have started to accumulate widely in soil, water and air, are one of the most important environmental problems that threaten the life of all organisms on the Earth's surface (Masindi and Muedi 2018). While heavy metals such as zinc, manganese, cobalt, copper, nickel and molybdenum reaching the ecosphere are essential for plant growth, aluminum, vanadium, arsenic, mercury, lead, cadmium and selenium are toxic to the plant. Excessive accumulation of heavy metals in plant tissues and organs, whether it is an essential element for plant growth or not, negatively affects the development of vegetative and generative organs of plants (Aprile and De Bellis 2020). It is also possible for people to take these elements into their bodies. An excess of these elements causes toxic effects, while their deficiency causes various disorders.

Microelements play an important role in the biochemical and physiological functions of any biological system. It is estimated that more than three billion people worldwide are suffering from microelement malnutrition, often called

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'hidden hunger' (FAO 2013). Microelement malnutrition can result in low working efficiency, high rate of premature death of infants, permanent impairment of cognitive abilities and increased healthcare costs (Welch and Graham 2004). The populations in developing countries are particularly at risk because many cannot afford to buy foods such as meat, poultry, fish, fruits and vegetables, all of which have high amounts of micronutrients (Welch and Graham 1999). Wheat grain and its products are considered an important source of minerals for both humans and animals (Iskander and Murad 1986; Gupta et al. 2015). Wheat grain contains 1.6% minerals (Fujino et al. 1996). The amounts of essential elements vary between different milling fractions of the wheat grain. The amounts of K, P and Se in wheat grain are high, while S, Mg and Ca are present in lower concentrations. Wheat bran has been found to have high amounts of P, K and Mg and low amounts of Se, S, Ca and Fe (Dikeman et al. 1982; Hussain 2009; Hussain et al. 2012; Saleh et al. 2019).

The amounts of these microelements ingested by humans with food, whether they are within the tolerance limits, and the possible harms, if any, should be researched. The aim of this study is to determine whether mineral contents of different wheat varieties are within tolerance limits or not for human consumption.

Materials and methods

Field experiments were performed on the land (left for fallow for the previous year) of Experimental Farm of Erciyes University, Kayseri, Turkey under dry farming conditions during the cropping seasons of 2010–11 and 2011–12. The experiments were carried out in a Lattice experimental design with three replications. A total of 42 bread wheat (*T. aestivum*) cultivars were grown in experiments. As a mineral fertilizer, N was applied in the form of ammonium sulfate at 60 kg ha^{-1} and P was applied in the form of triple superphosphate at 50 kg ha^{-1}. Half of the N and all P were applied at sowing; the second half of N was applied at the beginning of stem elongation. Soils of the experimental fields are slightly alkaline with sandy-loam texture, low organic material and lime, moderate phosphorus and high potassium contents (Topbas 1987; Ergene 1993). Climate conditions were more favorable for wheat farming in the second year than the first year. Following the harvest, the spikes were threshed and grains were stored at −20 °C. Dried seed samples were ground and digested in a microwave (Berghof Speedwave, Germany) using 2 mL of 35% H_2O_2 and 5 mL of 65% HNO_3. Following the digestions, Copper (Cu), Iron (Fe), Manganese (Mn), Selenium (Se), Zinc (Zn), Arsenic (As), Cadmium (Cd), Cobalt (Co), Chrome (Cr), Nickel (Ni) and Lead (Pb) were analyzed in an Inductively Coupled Plasma Mass Spectrometry (ICP-MS; Agilent 7500a). To check related elemental measurements, reference leaf samples from the National Institute of Standards and Technology (Gaithersburg, MD, USA) were used.

Statistical analysis

The significance of treatment means was evaluated with standard analysis of variance techniques. Mean values of each treatment were presented in tables. The DUNCAN test was used to compare the differences among treatment means at the 0.05 probability level. The statistical analyses were performed with SAS.

Results

In the current study, mineral nutrient contents of wheat varieties, growing years and variety x year interactions were significant for all of the tested elements (Tables 1, 2). Differences in grain mineral element contents among varieties could be associated with differences in the adaptation of genotypes, genetic make up and different reactions of genotypes to soil and climate conditions. The influence of genotype and environmental conditions on the mineral composition of wheat has been studied by different authors (Vignola et al. 2016; Ciudad-Mulero et al. 2021). Similarly, to our current findings, in the previous studies, it was emphasized that wheat mineral content varies according to wheat varieties, environmental conditions, agronomic practices (Stefanovic et al. 2008, Jalskulska et al. 2018) and environment x variety interactions (Zhang et al. 2014).

Copper (Cu)

Copper concentrations varied between 0.88 and 2.77 ppm and the average of cropping years and cultivars was 1.38 ppm (Table 1). The highest Cu concentrations were observed in Sultan 95, Tosunbey and Uzunyayla cultivars, respectively, with 2.77, 1.88 and 1.79 ppm; the lowest Cu concentrations were observed in Cetinel 2000, Bayraktar 2000 and Demir 2000 with 0.88, 1.00 and 1.01 ppm, respectively.

Iron (Fe)

Iron concentrations varied between 5.7 and 33.5 ppm and the average Fe for cropping years and cultivars was 15.6 ppm (Table 1). The highest Fe concentrations for Uzunyayla, Palandoken 97, Aytin 98 and Dogu 88 were 33.5, 32.8, 31.3 and 24.0 ppm, respectively. The lowest Fe concentrations were observed in Ikizce 96, Altay 2000 and Bezostaja-1 were 5.7, 6.2 and 7.1 ppm, respectively.

Table 1 Copper (Cu), Iron (Fe), Manganese (Mn), Selenium (Se) and Zinc (Zn) concentrations of wheat cultivars (ppm)

	Cu (ppm)		Fe (ppm)		Mn (ppm)		Se (ppm)		Zn (ppm)	
Years										
2010–2011	1.49	A	16.7	A	32.7	A	0.071	A	2.35	A
2011–2012	1.27	B	14.5	B	29.5	B	0.061	B	2.03	B
Average	1.38		15.6		31.1		0.066		2.19	
Cultivars										
Aksel 2000	1.34	f-m	17.2	e-j	32.4	d-ı	0.062	c-m	2.08	j-l
Alparslan	1.39	e-k	16.6	e-k	32.9	c-g	0.050	h-m	1.77	l-o
Altay 2000	1.66	b-e	6.2	q	32.5	d-h	0.050	h-m	1.49	n-p
Atli 2002	1.60	b-g	11.0	k-q	31.6	e-l	0.112	a	1.48	n-p
Aytin 98	1.31	g-m	31.3	a	32.9	c-g	0.041	lm	1.47	n-p
Bagci 2002	1.57	c-h	19.2	b-h	32.4	d-ı	0.048	ı-m	1.48	n-p
Bayraktar 2000	1.00	on	20.8	b-f	28.8	n-q	0.053	f-m	1.14	pq
Bezostaja-1	1.30	h-n	7.1	pq	34.3	b-d	0.053	f-m	1.28	o-q
Bolal 2973	1.13	k–o	14.0	h-n	27.0	rq	0.058	e-m	3.21	c-e
Cetinel 2000	0.88	o	17.6	d-j	27.8	p-r	0.092	a-d	1.66	l-o
Dagdas 94	1.11	k–o	15.4	f-k	31.4	e-m	0.079	b-j	2.02	j-m
Demir 2000	1.01	on	8.7	n-q	29.7	l-p	0.059	d-m	2.38	h–k
Dogu 88	1.08	l-o	24.0	b	31.3	e-m	0.053	f-m	0.29	r
Gerek 79	1.06	m–o	9.3	m-q	26.0	r	0.045	j-m	1.71	l-o
Gun 91	1.70	b-d	9.0	m-q	30.7	h-n	0.050	h-m	0.93	q
Ikizce 96	1.16	j-o	5.7	q	27.3	rq	0.047	j-m	0.97	q
Izgi 2001	1.26	ı-n	18.1	c-ı	30.3	ı-o	0.058	e-m	0.31	r
Karahan 99	1.41	d-k	16.7	e-k	30.3	ı-o	0.040	m	2.09	j-l
Karasu-90	1.32	f-m	13.0	ı-o	27.8	p-r	0.053	f-m	2.76	d-ı
Kate A-1	1.08	l-o	12.3	j-p	33.3	c-e	0.097	ab	2.10	j-l
Kirac 66	1.55	c-ı	14.3	g-n	36.7	a	0.083	b-h	2.94	d-g
Kirgiz 95	1.15	k–o	10.5	ı-q	32.0	e-j	0.051	g-m	1.55	m-p
Kirik	1.26	ı-n	12.6	ı-p	28.7	o-q	0.091	a-e	2.31	ı-k
Kirkpinar 79	1.32	f-m	22.8	b-d	31.9	e-k	0.056	f-m	1.92	j-n
Kutluk 94	1.19	j-n	23.5	bc	30.8	g-o	0.062	c-m	3.04	c-g
Mizrak	1.18	j-n	13.8	h-n	30.2	j-o	0.094	a-c	2.66	f-ı
Mufitbey	1.54	c-ı	9.2	m-q	30.1	j-o	0.069	b-m	2.74	e-ı
Nenehatun	1.50	d-ı	19.8	b-g	31.5	e-l	0.044	k-m	2.82	d-h
Palandoken 97	1.70	b-d	32.8	a	34.9	a-c	0.043	k-m	1.62	l-p
Pehlivan	1.39	e-k	9.3	m-q	30.3	ı-o	0.042	k-m	1.47	n-p
Prostor	1.16	j-o	23.0	b-d	31.9	e-k	0.046	j-m	2.05	j-l
Seri 82	1.38	e-l	7.3	o-q	29.8	k-p	0.067	b-m	3.24	cd
Sonmez 2001	1.40	e-k	14.8	g-m	30.9	f-n	0.095	a-c	3.48	c
Soyer 02	1.27	h-n	15.3	f-l	29.3	m-p	0.076	b-k	1.90	k-n
Sultan 95	2.77	a	11.0	k-q	32.6	d-h	0.095	a-c	5.11	a
Suzen 97	1.62	b-f	21.0	b-e	31.2	e-m	0.097	ab	2.58	g-ı
Tosunbey	1.88	b	11.1	k-q	30.1	j-o	0.073	b-m	3.13	c-f
Turkmen	1.38	e-k	12.2	j-p	33.1	c-e	0.085	b-g	2.08	j-l
Uzunyayla	1.79	cb	33.5	a	35.9	ab	0.085	b-g	4.10	b
Yakar 99	1.45	d-j	12.7	ı-p	31.7	e-l	0.074	b-m	2.42	h-j
Zencirci 2002	1.31	g-m	13.8	h-n	33.0	c-f	0.082	b-ı	2.29	I-k
Zerin	1.37	e-l	16.0	e-l	28.9	n-q	0.075	b-l	4.09	b
Var. Sources	F Değerleri									
Year (Y)	8527.43**		975.00**		983.96**		729.02**		3610.64**	
Genotype (G)	13.08**		16.15**		13.28**		4.06**		43.17**	
Y x G	9.86**		16.68**		14.14**		5.48**		23.20**	
LSD (G)	0.0532		1.029		0.3834		0.0059		0.0910	
C.V. (%)	15.51		26.59		4.95		36.21		16.69	

The difference between means with the same letter is not significant ($P < 0.01$)

The difference between means with different letters is significant at $P < 0.01$ level

**significant at 0.01 level

Manganese (Mn)

Manganese concentrations varied between 26.0 and 36.7 ppm, and average Mn content forcropping years and cultivars was 31.1 ppm (Table 1). The highest Mn concentrations were obtained in Kirac 66, Uzunyayla, Palandoken 97, Bezostaja-1, Kate A-1 and Turkmen with 36.7, 35.9, 34.9, 34.3, 33.3 and 33.1 ppm, respectively. The lowest Mn concentrations were observed in Gerek 79, Bolal 2973, Ikizce 96, Cetinel 2000 and Karasu-90 with 26.0, 27.0, 27.3, 27.8 and 27.8 ppm, respectively.

Selenium (Se)

Selenium concentrations varied between 0.040 and 0.112 ppm, and the average Se value for cropping years and cultivars was 0.066 ppm (Table 1). The highest Se concentrations were obtained in Atli 2002, Kate A-1 and Suzen 97 with 0.112, 0.097 and 0.097 ppm, respectively. The lowest Se concentrations were observed in Karahan 99 and Aytin 98 with 0.040 and 0.041 ppm, respectively.

Zinc (Zn)

Zinc concentrations varied between 0.29 and 5.11 ppm, and the average Zn content of cropping years and cultivars was 2.19 ppm (Table 1). The highest Zn concentrations were observed in Sultan 95, Uzunyayla, Zerin and Sönmez 2001 with 5.11, 4.1, 4.09 and 3.48 ppm, respectively. The lowest Zn concentrations were observed in Doğu-88, İzgi 2001, Gün 91 and İkizce 96 with 0.29, 0.31, 0.93 and 0.97 ppm, respectively. Zinc contents of genotypes was ranged from 0.29 (Dogu-88) to 5.11 ppm (Sultan-95) in our study.

Arsenic (As)

Arsenic concentrations varied between 0.032 and 0.050 ppm, and the average as content for cropping years and cultivars was 0.041 ppm (Table 2). The highest as concentrations were observed in Mizrak, Bolal 2973 and Atli 2022 cultivars with 0.050, 0.048 and 0.048 ppm, respectively. The lowest as concentrations were observed in Nenehatun and Palandoken 97 cultivars with 0.032 and 0.033 ppm, respectively.

Cadmium (Cd)

Cadmium concentrations varied between 0.0023 and 0.0434 ppm and the average Cd content for cropping years and cultivars was 0.0064 ppm (Table 2). The highest Cd concentrations were observed in Izgi 2001, Gun 91 and Uzunyayla with 0.0434, 0.0214 and 0.0141 ppm, respectively. The lowest Cd concentrations were observed in Mufitbey, Gerek 79 and Kirac 66 with 0.0023, 0.0024 and 0.0025 ppm, respectively.

Cobalt (Co)

Cobalt concentrations varied between 0.014 and 0.121 ppm and the average Co content for cropping years and cultivars was 0.052 ppm (Table 2). The highest cobalt concentrations were observed in Aksel 2000, Bezostaja-1, Alparslan and Atlı 2002 with 0.121, 0.121, 0.110 and 0.100 ppm, respectively. The lowest Co concentrations were obtained in Tosunbey and Mizrak with 0.014 and 0.020 ppm, respectively.

Chrome (Cr)

Chrome concentrations varied between 0.057 and 0.471 ppm, and the average Cr content for cropping years and cultivars was 0.147 ppm (Table 2). The highest chrome concentrations were observed in Dogu 88, Kirkpinar 79, Kutluk 94, Mizrak, Bagci 2002, Kirgiz 95, Aytin 98 and Nenehatun with 0.471, 0.417, 0.326, 0.316, 0.310, 0.293, 0.219 and 0.172 ppm, respectively. The lowest Cr concentrations were observed in Kirik, Turkmen Yakar 99, Prostor, Zerin, Bayraktar 2000, Kate A-1 and Aksel 2000 with 0.057, 0.066, 0.068, 0.076, 0.076, 0.079, 0.080 and 0.080 ppm, respectively.

Nickel (Ni)

Nickel concentrations varied between 0.50 and 2.48 ppm and the average Ni content for cropping years and cultivars was 1.20 ppm (Table 2). The highest nickel concentrations were observed in Uzunyayla, Sultan 95 and Mufitbey with 2.48, 2.23 and 2.16 ppm, respectively. The lowest Ni concentrations were observed in Kirac 66 and Izgi 2001 with 0.50 and 0.56 ppm, respectively.

Lead (Pb)

Lead concentrations varied between 0.092 and 0.435 ppm and the average Pb value for cropping years and cultivars was 0.185 ppm (Table 2). The lowest Pb concentrations were observed in Izgi 2001, Aksel 2000, Bolal 2973, Kirgiz 95 and Alparslan with 0.435, 0.405, 0.349, 0.321 and 0.300 ppm, respectively. The lowest Pb concentration was observed in Bagci 2002 with 0.092 ppm.

Discussion

Research on microelement content of food crops showed that there are two approaches to increase microelement content (1) agronomic approach to improve microelement

Table 2 Arsenic (As), Cadmium (Cd), Cobalt (Co), Chrome (Cr), Nickel (Ni) and Lead (Pb) concentrations of wheat cultivars (ppm)

	As (ppm)		Cd (ppm)		Co (ppm)		Cr (ppm)		Ni (ppm)		Pb (ppm)	
Years												
2010–2011	0.044	A	0.0073	A	0.059	A	0.160	A	1.29	A	0.194	A
2011–2012	0.038	B	0.0055	B	0.045	B	0.134	B	1.11	B	0.176	B
Average	0.041		0.0064		0.052		0.147		1.20		0.185	
Cultivars												
Aksel 2000	0.034	k-m	0.0056	h–l	0.121	a	0.080	k-m	1.60	d-g	0.405	a
Alparslan	0.037	ı-m	0.0036	k-n	0.110	ab	0.142	e–h	1.82	cd	0.300	c
Altay 2000	0.038	h-m	0.0044	ı-n	0.054	e-j	0.090	ı-m	1.44	e–h	0.175	g-k
Atli 2002	0.048	a-c	0.0039	j-n	0.100	b	0.161	ef	1.67	de	0.158	h-n
Aytin 98	0.034	k-m	0.0093	ef	0.051	f-k	0.219	d	1.16	h–k	0.191	g-ı
Bagci 2002	0.039	f-m	0.0044	ı-n	0.058	d-g	0.310	c	1.63	d-f	0.092	r
Bayraktar 2000	0.041	b-k	0.0069	f-ı	0.043	ı-n	0.079	k-m	1.30	g-j	0.130	k-r
Bezostaja-1	0.039	f-m	0.0042	ı-n	0.121	a	0.096	h-m	0.88	k-r	0.102	qr
Bolal 2973	0.049	ab	0.0041	ı-n	0.058	d-g	0.086	ı-m	1.55	d-g	0.349	b
Cetinel 2000	0.047	a-f	0.0034	k-n	0.028	o-r	0.152	e–g	0.74	n-s	0.186	g-j
Dagdas 94	0.047	a-f	0.0044	ı-n	0.044	h-m	0.084	j-m	0.85	l-r	0.146	ı-q
Demir 2000	0.044	b-ı	0.0046	h-n	0.029	n-r	0.158	ef	1.01	ı-n	0.207	e–g
Dogu 88	0.039	f-m	0.0124	cd	0.073	c	0.471	a	1.32	f-j	0.251	de
Gerek 79	0.040	c-m	0.0024	mn	0.021	q-s	0.095	h-m	2.05	bc	0.197	f–h
Gun 91	0.044	b-ı	0.0214	b	0.038	k-p	0.094	h-m	0.95	k-p	0.153	h-p
Ikizce 96	0.048	a-c	0.0067	g-j	0.025	p-s	0.115	f-l	0.66	o-s	0.192	g-ı
Izgi 2001	0.046	a-h	0.0434	a	0.035	l-q	0.105	f-m	0.56	rs	0.435	a
Karahan 99	0.035	j-m	0.0074	f–h	0.050	g-k	0.088	ı-m	0.76	n-s	0.144	j-q
Karasu-90	0.038	h-m	0.0037	k-n	0.045	g-l	0.101	g-m	0.88	k-r	0.111	n-r
Kate A-1	0.047	a-e	0.0047	h-n	0.044	h-m	0.080	k-m	0.74	n-s	0.117	m-r
Kirac 66	0.040	c-m	0.0025	mn	0.044	h-m	0.138	e-j	0.50	s	0.106	p-r
Kirgiz 95	0.041	b-k	0.0049	h-n	0.069	cd	0.293	c	1.15	h-m	0.321	bc
Kirik	0.046	a-h	0.0039	j-n	0.028	o-r	0.057	m	1.56	d-g	0.236	ef
Kirkpinar 79	0.040	b-m	0.0051	h-n	0.045	g-l	0.417	b	1.39	e–h	0.282	cd
Kutluk 94	0.037	g-m	0.0057	h–k	0.074	c	0.326	c	0.96	k-p	0.236	ef
Mizrak	0.050	a	0.0026	l-n	0.020	rs	0.316	c	0.58	q-s	0.130	k-r
Mufitbey	0.042	b-k	0.0023	n	0.041	j-o	0.152	e–g	2.16	b	0.104	qr
Nenehatun	0.032	m	0.0109	ed	0.049	g-l	0.172	e	0.98	j-o	0.252	de
Palandoken 97	0.033	lm	0.0089	e–g	0.057	d-ı	0.126	e-k	0.90	k-q	0.195	f–h
Pehlivan	0.038	h-m	0.0036	k-n	0.045	g-l	0.084	j-m	1.22	h–k	0.156	h–o
Prostor	0.039	d-m	0.0056	h–l	0.041	j-o	0.076	k-m	0.88	k-r	0.110	o-r
Seri 82	0.037	g-m	0.0040	ı-n	0.037	k-p	0.108	f-m	0.81	m-s	0.241	de
Sonmez 2001	0.044	b-ı	0.0036	k-n	0.076	c	0.108	f-m	1.03	ı-n	0.101	qr
Soyer 02	0.045	a-ı	0.0050	h-n	0.047	g-l	0.138	e-j	1.17	h–l	0.123	m-r
Sultan 95	0.044	b-ı	0.0047	h-n	0.065	ce	0.095	h-m	2.23	ab	0.161	h-m
Suzen 97	0.047	a-e	0.0026	mn	0.045	g-l	0.139	e-j	1.31	g-j	0.170	g-l
Tosunbey	0.039	f-m	0.0037	k-n	0.014	s	0.108	f-m	0.63	p-s	0.113	n-r
Turkmen	0.039	f-m	0.0034	k-n	0.030	m-r	0.066	lm	0.95	k-p	0.241	de
Uzunyayla	0.040	b-m	0.0141	c	0.055	e-j	0.149	e–h	2.48	a	0.127	l-r
Yakar 99	0.041	b-k	0.0032	k-n	0.035	l-q	0.068	lm	1.64	de	0.103	qr
Zencirci 2002	0.042	b-k	0.0033	k-n	0.038	k-p	0.141	e–h	1.14	h-m	0.104	qr
Zerin	0.043	b-j	0.0052	h-m	0.064	c-f	0.076	k-m	1.06	ı-n	0.131	k-r
Var. Sources	F Değerleri											
Year (Y)	6641.12**		776.88**		1664.26**		2035.21**		616.53**		3374.01**	
Genotype (G)	3.56**		67.91**		34.78**		34.82**		23.01**		36.74**	
Y x G	4.05**		57.14**		17.88**		38.14**		10.39**		33.95**	
LSD (G)	0.0014		0.0005		0.0025		0.0098		0.0608		0.0084	
CV (%)	14.03		31.87		20.180		27.12		20.44		18.41	

Table 2 (continued)

The difference between means with the same letter is not significant ($P < 0.01$)

The difference between means with different letters is significant at $P < 0.01$ level

**significant at 0.01 level

content and (2) genotypic approach in uptake and accumulation of micronutrients (Khoshgoftarmanesh et al. 2010). Considering ecological concerns, cultivation and breeding of micronutrient-efficient genotypes in combination with proper agronomic management practices appear to be the most sustainable and cost effective solution for alleviating micronutrient deficiency. Micronutrient-efficient genotypes could provide a number of benefits such as reductions in the use of fertilizers, improvements in seedling vigor, and resistance to abiotic and biotic stresses (Khoshgoftarmanesh et al. 2010). Genotype and environmental factors affect the mineral content of wheat. The distribution of the nutrients in wheat grains depends largely on their morphology, the bran fraction being the richest in minerals, thus developing important functions related to human health (Ciudad-Mulero et al. 2021).

Some heavy metals are important for plant nutrition, but they are toxic at high concentrations. For example, Cu is one of them. Copper acts as a necessary element for the structure of proteins and enzymes that play an important role in the growth and development of plants (Steffens 1990; Teklic et al. 2013). The Cu content of 1.38 mg/kg obtained from present research is far below the limits that will cause toxic effects for health. Looking at the results of different studies on the wheat nutrient contents, in the study conducted with 12 bread wheat varieties in Eskişehir, 7.20 mg/kg Cu was detected as an average of the varieties (Olgun et al. 2017) and this value was five times higher than our values. On the other hand, the values obtained from the study conducted in Croatia were similar to our values (Kovacevic et al. 2013).

Increasing the Zn and Fe concentration of crop plants, resulting from better crop production techniques, is important for human health and it is an important global challenge (Sramkova et al. 2009). Zinc deficiency is currently listed as a major risk factor for human health and cause of death globally (Myers et al. 2014). Hotz and Brown (2004) reported that Zn deficiency affects, on average, one-third of world's population, ranging from 4 to 73% in different countries. As in our study, the differences among varieties in terms of Fe content were significant in wheat grown in different ecological conditions (Oktem and Oktem 2009; Szira et al. 2014; Chatrath et al. 2018; Kenzhebayeva et al. 2019). While there were significant genotype × environmental interactions obtained for Fe and Zn grain concentrations, there was still a strong genetic differences for Fe and Zn accumulation in the grain (Welch and Graham 2002; Maltzahn et al. 2020; Ciudad-Mulero et al. 2021).

Present Mn values were similar to the study of Kirchmann et al. (2009) and Maltzahn et al. (2020). However, it was four times higher than the values (9.01 mg/kg) obtained by Olgun et al. (2017). However, there are also researchers stating that differences among varieties were not important in terms of Mn content (Alam 2001). Differential uptake of Mn has also been reported for other researchers (Yang et al. 1998; Kirchmann et al. 2009; Pandey et al. 2016; Olgun et al. 2017; Maltzahn et al. 2020).

Selenium is an essential micronutrient for humans and animals, with antioxidant, anti-cancer and anti-viral effects (Arthur 1999). Published values range from 0.02 and 0.60 for most of the wheat. In the study conducted by Alfthan and Neve (1996), it was reported that the Se content of World's wheats (published values) varies was between 0.02 and 0.60 mg/kg^{-1}. Some found no evidence for genetic variability among wheat cultivars for Se density in grain (Grela 1996) and a study conducted in Russia suggested that commercial wheat cultivars may vary in their ability to accumulate Se (Seregina et al. 2001; Maltzahn et al. 2020). More research is needed to determine whether sufficient genetic variation in grain Se density in wheat exists to enable the selection of this trait for plant breeding purposes (Lyons et al. 2005; Maltzahn et al. 2020).

Differences in grain Zn contents among varieties could be associated with differences in adaptation ability of genotypes. In previous studies, the differences between wheat varieties in terms of Zn content were found to be significant (Alpaslan et al. 1998; Olgun et al. 2017; Chatrath et al. 2018; Khokhar et al. 2018; Kenzhebayeva et al. 2019; Maltzahn et al. 2020). In the other hand, Genotype and site effects were associated with 10% and 6% of the overall variation in grain Zn concentration, respectively (Khokhar et al. 2018). Grain Fe concentration was significantly and positively correlated with Zn concentration for both spring and winter wheat (Liu et al. 2014). The results regarding Zn obtained from some studies were found to be higher than our results; according to Liu et al. (2014) 13.9 to 56.3 mg kg^{-1} for spring wheat and 13.6 mg kg^{-1} to 56.6 mg kg^{-1} for winter wheat. In other studies, Zn contents of wheat was reported as varying from 16.5 to 32.6 mg kg^{-1} in the Harran Plain (Oktem and Oktem 2009). As in our study, the zinc content of wheat grown in different ecological conditions was found to be different from each other (Zhao et al. 2009). The data reported on the Zn content of winter wheat samples from different regions of the world varied between 21.9 and 38.5 mg/kg, values were the following for example: 26.3–38.5 in Germany, 28.0 in

Denmark and Sweden, 32.6 in Finland, 21.9–27 in the USA, 22.0 in Turkey and 26.0 mg/kg in India (Kent 1994). The data we obtained were found to be very low compared to previous studies. This may be due to various types of environmental interactions (significant genotype × environment interactions) as previously detected by researchers such as Welch and Graham (2002) and Ciudad-Mulero et al. (2021).

Food can be an important source of inorganic minerals for human intake. In a study conducted in Europe with 26 wheat varieties, it was found that the average arsenic (As) concentrations of wheat varieties (in ground white flour) were 69 ± 17 µg kg^{-1}. It has been determined that the As concentration was 3.8 and 4.7 times higher in the case that the obtained flour was milled as whole wheat (grain into bran) As a result, it was emphasized that using wheat flour by removing bran was important in terms of low As content. (Zhao et al. 2010). In the study conducted by Maltzahn et al. (2020) on wheat in Brazil, arsenic and cadmium were not determined in the wheat grain. Arsenic and cadmium accumulation were not detected in wheat grain (Maltzahn et al. 2020).

Cadmium (Cd), has a toxic effect on living organisms, is one of the most dangerous heavy metal pollutants in the ecosystem. Cadmium reaches the toxic level in the soil as a result of human activities such as industrial activities and phosphorus fertilizer applications. It has been reported that 54–58% of the Cd reaching the soil by human activities comes from phosphorus fertilizers, 39–41% from atmospheric storage, and 2–5% from waste sludge and farm manure applications (Yost and Miles 1979; Wang et al. 2015). As an average Cd content of 42 wheat varieties, 6.4 µg/kg Cd is well below the limit value (0.2 mg/kg) determined by the European Commission and does not pose a health risk. Kirchmann et al. (2009) in the Swiss study by 2.2 µg/kg Cd content is close to our results; According to Özkutlu and Erdem (2018), the Cd content (17–31 µg/kg) obtained in the study conducted in Adana province of Turkey was high in the present study. On the other hand, Tomas et al. (2012) it was also found to be almost 100 times higher than our results. The results of present study showed that the mineral content of wheat varieties varied depending on the year, variety and location (Anglani 1998; Wangstrand et al. 2007; Stefanovic et al. 2008; Zhang et al. 2014; Yigit et al., 2015; Atar 2019; Johansson et al. 2021) and Shewry (2018) and Olgun et al. (2018) stated that variety x environment interaction was important for mineral content differences in wheat. Özkutlu and Erdem (2018) pointed out that Cd intake to wheat grain was higher in case of Zc deficiency.

The present cobalt (Co) concentrations in wheat in this study were 10 times biger than those reported previously for Swedish wheat (Jorhem and Sundstrom 1993, Kirchmann et al. 2009) and Finnish wheat (Ekholm et al. 2007). On the other hand, Tomas et al. (2012) found Co content three times higher than our results, and six times higher than that of Kan (2015). However, the Co content obtained from the present study was close to the study conducted by Migliorini et al. (2016).

The lowest Cr concentration obtained from the present research was almost three times higher than the average value (0.022 mg/kg) obtained from the study conducted by Kirchmann et al. (2009). On the other hand, it was ranged between 0.40 and 0.80 mg/kg that was higher than our results (Tomas et al. 2012). Similar Cr content values were obtained in a study conducted in continental climatic conditions in Turkey (Kan 2015).

The mean Ni concentration obtained from the present research (1.20 mg/kg^{-1}); was almost five times higher than the average value (0.240 mg/kg) obtained from the study conducted by Kirchmann et al. (2009) and three times higher than the average value (0.40 mg/kg) obtained from the study conducted by Tomas et al. (2012). Nickel values obtained from current study were similar to findings of Hamner et al. (2013) in oats and Kan (2015) in wheat. On the other hand, in a study conducted with 122 bread wheat lines in 39 locations in Bingol, the average Ni content was 8.52 mg/kg, which was seven times higher than the present study (Ucar 2016).

Variations in mineral contents among different wheat genotypes may be closely related to differences in root morphological characteristics. In the current study, the average Pb concentration for 42 bread wheat varieties was 10 times higher than the values obtained in Sweden (Kirchmann et al. 2009). On the other hand, our results are close to the results obtained for wheat in Slovakia by Tomas et al. (2012). The Pb content differences for wheat varieties were due to different climate-soil conditions and caused by pollution from heavy industries (Kan 2015; Yigit et al. 2015).

The data obtained from present study indicate that mineral nutrient contents of bread wheat genotypes were different from each other. The mineral composition of cereal grain is determined by factors such as type of cereal, soil conditions and fertilizing practices. P and Ca contents increased with N fertilization, while Zn content decreased. In the grain, fertilizer P additions decreased Zn content but Mn increased (Syltie and Dahnke 1983). Differences in grain mineral element contents among varieties could be associated with differences in adaptation ability of genotypes, genotypic structure and different reactions to soil and climate conditions. Significant mineral nutrient content differences were found among wheat varieties and growing years. The significant differences could be attributed to the crop grown in different locations in two cropping years and genetic make up of wheat varieties. This variability was due to a variety of factors including environmental and genetic factors and their interactions.

In this study, which comprises the evaluation of agronomic practices on wheat mineral content, significant mineral element content differences were found. However, it was also observed that the results obtained in the study did not exceed the limit values determined in terms of human health. It will be possible to make healthier suggestions by conducting studies using varieties such as Sultan-95, Uzunyayla and Doğu-88, which have high mineral intake capacity, especially Fe, Zn and Cu, which are important for human nutrition.

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