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Quality and nutritional characteristics of durum wheats grown in Anatolia

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RESEARCH ARTICLE

Abstract

This study aimed to determine the quality and nutritional characteristics of durum wheat varieties commonly grown in Anatolia and detect changes in nutritional properties due to milling. There were significant differences in hectoliter weight, thousand kernel weight, hardness index, kernel size, ash, protein, beta-carotene contents, and SDS sedimentation values. The correlation between ash and phytic acid contents was significant (r=0.953). Over 60% reduction was observed in semolina samples' phytic acid content compared to wheat. There were significant correlations between TDF and phytic acid contents in the durum wheat and semolina samples. Although the Zn, Fe, P, Ca, and B concentrations of the wheat samples grown in Central Anatolia were higher than those grown in South-eastern Anatolia, there was an opposite trend in their semolina samples. The results might benefit breeders in improving durum wheat's technological and nutritional quality.

Keywords: durum wheat, phytic acid, dietary fiber, mineral content

Introduction

Durum wheat is a staple food in various parts of the world, supplying calories and nutrients. The largest durum wheat producers worldwide are Canada, Italy, and Turkey. In the 2020/21 growing period, the world durum wheat production was 33.8 million tons; 21% of the production was realized in EU countries, 20% in Canada, and 12% in Turkey, which ranked the 3rd in the world with 4 million tons of production. The climate in certain parts of Anatolia is quite suitable for growing high-quality durum wheat. South-eastern Anatolia (41%) and Central Anatolia (33%) regions are the major durum wheat growing areas (International Grains Council; TMO, 2020).

Durum wheat quality characteristics, such as protein content, protein quality, kernel hardness, kernel size, and vitreousness, are strongly related to end product quality (Yildirim *et al.*, 2019; Baljeet *et al.*, 2017). Especially vitreousness, kernel size, and hardness are important in the yield and appearance of semolina. Grain size and vitreousness vary depending on variety, weather, and growing conditions. As the grain size and hardness increase, the milling yield increase, but increasing yield negatively affects ash content and flour color in bread wheat (Acar *et al.*, 2019).

The Zn and Fe content of durum wheat is largely a function of available Zn and Fe in the soil and is also affected by the cultivar (Cakmak, 2008). Durum wheat is a significant source of Fe, Zn, Cu, Mg, and Mn, and most of the minerals are in bran and germ. Durum wheat also includes high dietary fiber, vitamins, and bioactive compounds (Liu *et al.*, 2007). Most of the P is in the form of phytate, which might reduce the bioavailability of Fe, Zn, and Ca (Sissons *et al.*, 2012). Although durum wheat is a good source of mineral elements, milling reduces their concentrations, especially Fe, Zn, and Mg, due to the lower concentrations in the endosperm (Sissons *et al.*, 2012).

Some studies investigate the quality or nutritional properties of durum wheat in the literature. However, the studies on the same material quality and nutritional properties (phytic acid, dietary fiber and mineral composition) are limited. Hence, this study is expected to contribute to the relevant literature.

The primary purposes of this study were to determine the phytic acid, dietary fiber, and mineral element contents of durum wheat varieties commonly grown in Anatolia (Central Anatolia and South-eastern Anatolia regions) and to detect changes in nutritional properties due to milling. Furthermore, physical, chemical, and physicochemical analyses were carried out to determine durum wheat cultivars' quality and nutritional characteristics.

Materials and method

Materials

Samples of eight durum wheat (*Triticum durum* L.) cultivars commonly grown in Anatolia were used in the study. Four of the eight durum wheat cultivars (Cesit-1252, Eminbey, Kiziltan 91, Mirzabey 2000) were grown in the Central Anatolia region, while the other four (Guney Yildizi, Maestrale, Svevo, and Zenit) were grown in South-eastern Anatolia in 2014–2015 growing season. Annual and long-term precipitations were 301.2 mm and 336.3 mm in the Central Anatolia region and 352 mm and 448 mm in the South-eastern Anatolia region, respectively. In South-eastern Anatolia, the monthly temperature was 5°C higher in November but 8°C lower in January compared to the long-term average temperature. In Central Anatolia, the monthly temperature was 3.5 °C lower in December and 8.4°C lower in April but 3.5 °C higher than the long-term average temperature in January (Table 1).

The wheat samples were cleaned by removing foreign materials using laboratory grain cleaning equipment (Quator, Tripette & Renaud, France). The grain samples were tempered overnight to 16.5% moisture content and milled into semolina using a Buhler pneumatic laboratory mill (Model MLU 202D, Uzwil, Switzerland) designed explicitly for semolina milling. The semolina was purified using a laboratory purifier (Chopin, Type: Sasseur, Villeneuve, France).

Analyses

Physical analyses

The degree of vitreousness was determined according to ICC Standard No: 129 (ICC., 2008). Hectoliter weight was determined using the one-liter hectoliter instrument (Ohaus, Chicago, USA) according to the procedure by Vasilijevic and Banasik (1980), and results were reported in kilograms/hectoliter. Thousand kernel weight was determined using an electronic seed counter (Numigral II, France), where the number of kernels in a 20 g clean sample was determined. Kernel size distribution was determined using a sieving system (Sortimat Pfueffer-Mess and Prüfgerate, Germany) equipped with three sieves (2.2, 2.5, and 2.8 mm) as described by Williams *et al.* (1988). The

Table 1. Annual precipitation and temperature during the study.

	Central Anatolia		South- Eastern Anatolia		Central Anatolia		South- Eastern Anatolia	
	Precipitation (mm)				Temperature (C)			
	Monthly	Long-term	Monthly	Long-term	Monthly	Long-term	Monthly	Long-term
September	18.0	18.0	0	5	17.9	17.0	24	25
October	16.0	22.7	0	32	9.8	11.5	20	21
November	18.0	29.1	29	49	7.5	5.7	18	13
December	4.2	37.7	51	72	–2.6	0.9	5	7
January	29.0	36.3	48	68	2.3	–0.9	–4	4
February	7.6	34.0	41	67	5.0	1.0	4	3
March	38.2	35.7	47	71	6.3	5.1	8	6
April	28.6	40.2	50	69	1.3	9.7	12	11
May	66.8	46.9	42	42	14.7	14.4	13	16
June	74.8	35.7	44	9	17.9	18.1	22	23
Total	301.2	336.3	352	484	80.1	82.5	122	129

hardness index was determined using SKCS 4100 (Perten Instruments, Huddinge, Sweden), according to AACCI Method No. 55-31 (AACCI., 2000). Physical analyses were carried out in two replicates.

Chemical analyses
Protein analysis was conducted by the Dumas method (Velp Scientifica NDA–701, Italy) according to AACCI Method No. 46-08 (2000) and expressed using the conversion factor (Nx5.7). The moisture content of the samples was determined according to AACCI Method No. 44-01 (AACCI., 2000). The ash content of the samples was determined according to AACCI Method No. 08-01 (AACCI., 2000). The beta-carotene content of durum wheat was determined according to AACCI Method No.14-50 (AACCI., 2000). The total dietary fiber (TDF) was determined according to AACCI Method No. 32-07.01 (AACCI., 2000). The phytic acid content of the samples was determined according to Vaintraub and Lapteva (1988) by using a GENESYS10S UV-VIS spectrophotometer (Thermo Scientific, Waltham, MA, USA) at 500 nm against distilled water.

The mineral element concentration of durum wheat was determined according to Ryan (2005). For the mineral content of the samples, approximately 0.4 g from each ground sample was acid-digested in a closed-vessel microwave system (CEM Corporation, Matthews, North Carolina). After the digestion, the total volume was brought to 20 ml with double deionized water (ddH_2O), and the digests were filtered through ash-less quantitative filter papers. The concentrations of trace minerals in these digests were determined using an inductively coupled plasma optical emission spectrometer (ICP-OES; Agilent 5100 Mulgrave, Australia). Mineral content analyses were done in two replicates.

Physicochemical analyses
SDS sedimentation and modified SDS sedimentation values were determined according to Williams *et al.* (1988) in two replicates.

Statistical analyses
Data from this study were reported as mean and standard deviation. All data were analyzed using one-way analysis of variance (ANOVA), and statistical analysis was performed with the software JMP (Version 10.0.0, SAS Institute Inc. USA). Means were identified as significantly different based on Fischer's protected least significant differences (LSD) at a probability level of 5%. Principal component analysis (PCA) was performed using JMP 10 statistical software (SAS Institute Inc., USA).

Results and discussion

Durum wheat and semolina samples

Physical and chemical properties of durum wheat samples
The physical properties of the durum wheat cultivars are presented in Table 2. Significant differences existed among the samples' hectoliter weights and thousand kernel weights ($p<0.05$). The highest and lowest hectoliter weight values were determined as 79.90 kg/hl and 75.05 kg/hl for Svevo and Kiziltan, respectively. The thousand kernel weight of cv. Cesit-1252 (51.92 g) was the highest, while that of cv. Zenit (37.08 g) was the lowest. Thousand kernel weight indicates kernel size, density, and homogeneity. Larger kernels have a higher endosperm to bran ratio than smaller kernels, and semolina yield is usually lower in smaller grains. Therefore, thousand kernel weight is considered an important factor in evaluating the milling performance of durum wheat (Wang and Fu, 2020).

Table 2. Physical properties of durum wheat samples.

Cultivar	HW (kg/hl)	TKW* (g)	Hardness (%)	Vitreousness (%)	KS1 (%)	KS2 (%)
Cesit-1252	78.41 ± 0.11[b]	51.92 ± 0.14[a]	79.40 ± 0.59[d]	97 ± 1[ab]	75.54 ± 0.47[b]	21.50 ± 0.15[d]
Eminbey	76.46 ± 0.24[c]	44.60 ± 0.05[c]	74.34 ± 1.41[e]	97 ± 1[ab]	54.32 ± 2.21[e]	30.99 ± 1.12[b]
Kiziltan	75.05 ± 0.05[d]	44.99 ± 0.24[c]	69.25 ± 0.64[f]	98 ± 0[ab]	74.08 ± 0.69[b]	21.57 ± 0.36[d]
Mirzabey	76.50 ± 0.10[c]	47.47 ± 0.04[b]	72.01 ± 0.09[e]	91 ± 1[c]	82.74 ± 0.91[a]	15.14 ± 1.10[e]
GuneyYildizi	78.25 ± 0.25[b]	39.51 ± 0.01[e]	80.99 ± 0.54[cd]	97 ± 1[ab]	61.39 ± 0.70[c]	25.07 ± 0.34[c]
Maestrale	78.60 ± 0.10[b]	40.31 ± 0.08[d]	83.32 ± 1.23[c]	95 ± 1[b]	58.57 ± 0.91[cd]	31.48 ± 0.78[b]
Svevo	79.90 ± 0.06[a]	38.12 ± 0.18[f]	86.16 ± 0.86[b]	99 ± 1[a]	56.67 ± 0.32[de]	29.78 ± 0.34[b]
Zenit	78.70 ± 0.04[b]	37.08 ± 0.22[g]	94.48 ± 0.09[a]	97 ± 1[ab]	33.47 ± 0.21[f]	41.50 ± 1.26[a]
LSD	**0.462**	**0.474**	**2.660**	**3.051**	**3.232**	**2.584**

Values followed by different letters in the same column are significantly different ($p< 0.05$) by the least significant difference (LSD) test.
HW: Hectoliter Weight, TKW: Thousand Kernel Weight, KS: The kernel size; K S1>2.8 mm, 2.8 mm>KS2>2.5 mm.
*: Expressed on dry matter basis (dmb).

Significant differences (p<0.05) were also observed in the Hardness index values (Table 2), ranging from 69.25% (Kiziltan) to 94.48% (Zenit). Vitreousness ratio is an important quality criterion in durum wheat, affecting the semolina yield. The samples in this study had relatively higher vitreousness ratios (>90%). The samples can be classified into three groups based on the kernel size (KS); (KS1>2.8 mm, 2.8 mm>KS2>2.5 mm, and 2.5 mm>KS3>2.2 mm). The kernels bigger than 2.8 mm (KS1) were in the range of 33.47-82.74%, and the amount of KS2 was in the range of 15.14-41.50% (Table 1).

The chemical and physicochemical properties of the durum wheat samples are presented in Table 3. There were statistically significant (p<0.05) differences between the samples in ash, protein, and beta-carotene contents, SDS sedimentation, and modified SDS sedimentation values. A significant correlation was found (p< 0.001) between ash content and phytic acid values (r=0.953). The ash content of the genotypes ranged from 1.37% (Mirzabey) to 1.87% (Zenit). For the production of high-quality pasta, durum wheat semolina with a minimum protein content of 12% (14% moisture basis) is preferred (Manthey and Twombly, 2006). As the protein content increases, the cooked pasta becomes firmer, less sticky, and does not disintegrate when overcooked (Dexter and D'Egidio, 2012). In the present study, protein contents were relatively high and exhibited significant variations among the cultivars.

SDS sedimentation values of the cultivars ranged from 9 (Mirzabey) to 25 ml (Eminbey), and significant differences were observed among the cultivars. In the present study, the beta-carotene contents of the samples ranged from 4.38 to 8.68 ppm. Pasta manufacturers prefer durum wheat with higher yellow pigment contents (> 6 ppm). Beta-carotene content was below this limit only for cv. Cesit-1252.

Total dietary fiber and phytic acid contents of durum wheat and semolina samples

Total dietary fiber (TDF) and phytic acid contents of the durum wheat and semolina samples are presented in Table 4. The TDF contents of the durum wheat samples ranged between 13.05 and 15.28 g/100 g, and those of semolina samples ranged between 4.35 and 5.57 g/100 g. Zenit had the highest TDF content in both durum wheat and semolina. The lowest TDF content in durum wheat samples was in cv. Kiziltan and the lowest TDF content in semolina samples were in cv. Cesit-1252. The wheat and semolina samples' phytic acid and dietary fiber contents were generally higher in South-eastern Anatolia than in the Central Anatolia region. The TDF contents of the durum wheat reported in the literature range of 9.6-14.4 g /100 g (Gebruers *et al.*, 2010). The amount of phytic acid in the durum wheat samples varied between 0.78% and 1.49%, and semolina samples varied between 0.30-0.47%. An average 63.6% reduction was observed in the wheat samples' phytic acid content during semolina production. The amount of phytic acid in wheat was reported to be between 0.39% and 1.35% (Frossard *et al.*, 2000), and in semolina samples between 0.16-0.34% (Tabekhia and Donelly, 1982). The highest amount of phytic acid was observed in both durum wheat and semolina samples of cv. The lowest amount of phytic acid in durum wheat and semolina samples was Zenit in CVS. Mirzabey and Kiziltan, respectively. There were significant correlations (p<0.001) between TDF and phytic acid contents in both the durum wheat (r = 0.782) and semolina samples (r = 0.763).

Table 3. Chemical properties of durum wheat cultivars.

Cultivar	Ash* (%)	Protein* (Nx5.7, %)	Sedimentation**		Beta Carotene (ppm)
			SDS (ml)	Modified (ml)	
Cesit-1252	1.52 ± 0.04[e]	18.47 ± 0.15[b]	20 ± 0.00[c]	22 ± 0.00[b]	4.38 ± 0.06[f]
Eminbey	1.63 ± 0.01[c]	16.27 ± 0.01[d]	25 ± 0.00[a]	28 ± 0.00[a]	6.06 ± 0.01[e]
Kiziltan	1.54 ± 0.00[de]	18.77 ± 0.01[a]	16 ± 0.00[e]	16 ± 0.00[e]	6.79 ± 0.03[d]
Mirzabey	1.37 ± 0.00[f]	14.31 ± 0.07[f]	9 ± 0.00[f]	9 ± 0.50[f]	6.13 ± 0.04[e]
GuneyYildizi	1.51 ± 0.03[e]	16.37 ± 0.14[d]	18 ± 0.00[d]	19 ± 0.00[d]	7.13 ± 0.07[c]
Maestrale	1.77 ±0.01[b]	17.36 ± 0.00[c]	20 ± 0.00[c]	19 ± 0.00[d]	6.82 ± 0.10[d]
Svevo	1.59 ± 0.01[cd]	14.85 ± 0.07[e]	16 ± 0.00[e]	16 ± 0.00[e]	7.64 ± 0.06[b]
Zenit	1.87 ± 0.03[a]	16.31 ± 0.04[d]	21 ± 0.00[b]	21 ± 0.00[c]	8.68 ± 0.07[a]
LSD	**0.070**	**0.267**	**1.2**	**1.5**	**0.182**

Values followed by different letters in the same column are significantly different (p< 0.05) by the least significant difference (LSD) test.
*: Expressed on dry matter basis (dmb).
**: Expressed on a 14% moisture basis (dmb).

Table 4. Total dietary fiber and phytic acid contents of wheat and semolina samples.

Cultivar	Wheat		Semolina	
	TDF* (g/100g)	PA* (%)	TDF* (g/100g)	PA* (%)
Cesit-1252	13.08 ± 0.01[d]	1.10 ± 0.02[c]	4.35 ± 0.06[e]	0.37 ± 0.006[c]
Eminbey	13.88 ± 0.16[b]	1.05 ± 0.02[cd]	4.97 ± 0.02[c]	0.45 ± 0.005[a]
Kiziltan	13.05 ± 0.28[d]	0.95 ± 0.02[e]	4.59 ± 0.00[d]	0.30 ± 0.014[d]
Mirzabey	13.64 ± 0.14[bc]	0.78 ± 0.03[f]	4.49 ± 0.02[de]	0.32 ± 0.005[d]
GuneyYildizi	13.15 ± 0.02[d]	0.97 ± 0.01[de]	5.12 ± 0.08[b]	0.39 ± 0.000[b]
Maestrale	13.94 ± 0.12[b]	1.31 ± 0.01[b]	4.90 ± 0.08[c]	0.45 ± 0.005[a]
Svevo	13.23 ± 0.06[cd]	1.06 ± 0.04[c]	5.15 ± 0.01[b]	0.38 ± 0.004[bc]
Zenit	15.28 ± 0.06[a]	1.49 ± 0.04[a]	5.57 ± 0.04[a]	0.47 ± 0.005[a]
LSD	**0.446**	**0.084**	**0.153**	**0.022**

Values followed by different letters in the same column are significantly different (p< 0.05) by the least significant difference (LSD) test.
TDF: Total dietary fiber, PA: Phytic acid.
*: Expressed on dry matter basis (dmb).

Mineral element concentration of durum wheat samples

Durum wheat is a good source of minerals, but milling reduces their concentrations due to their lower concentration in the endosperm. The mineral element composition of durum wheat can vary significantly depending on genotype and the growing location.

Mineral element (Cu, Mg, Zn, P, Fe, K, Ca, Na, B, Mn, and Ni) contents of the durum wheat cultivars are given in Tables 5 and 6. Svevo had the highest P (4147.9 $mg.kg^{-1}$), K (4849.6 $mg.kg^{-1}$), Mg (1679 $mg.kg^{-1}$), Na (32.44 $mg.kg^{-1}$), B (0.73 $mg.kg^{-1}$) and Ni (1.76 $mg.kg^{-1}$) concentrations whereas Mirzabey had the highest Ca (749.4 $mg.kg^{-1}$) and Mn concentrations (39.94 $mg.kg^{-1}$). Guney Yildizi had the highest Cu concentration (6.17 $mg.kg^{-1}$) while Eminbey had the highest Fe (41.17 $mg.kg^{-1}$) and Zn concentrations (31.65 $mg.kg^{-1}$). In terms of mineral element concentration, the differences between the varieties were statistically significant ($p<0.05$). There were significant correlations between phytic acid and Ca ($r = -0.772$) content ($p < 0.001$) and also between phytic acid and Zn ($r = -0.634$) content ($p<0.01$).

In a study on the durum wheat varieties in Italy, the mineral element composition has been evaluated. The Fe, Zn, Cu, Mn, Na, Mg, K and Ca contents were found as 33.6–65.6 mg/kg, 28.5–46.3 mg/kg, 5.8–14.0 mg/kg, 41.3–59.8 mg/kg, 19.2–37.7 mg/kg, 1056–1535 mg/kg, 4061–5274 mg/kg and 388–640 mg/kg, respectively (Ficco *et al.*, 2009).In the present study, the concentrations of Cu, Fe, Mn, and Zn minerals were lower than those cited above (Ficco *et al.*, 2009). The difference can be explained by the fact that the concentrations of mineral elements in grain are affected by various factors such as variety, climate, growing location, and year.

Mineral element concentration of semolina samples

Mineral element (Cu, Mg, Zn, P, Fe, K, Ca, Na, B, Mn, and Ni) contents of the semolina samples are given in Tables 7 and 8. Cesit-1252 had the highest K (2159.8 $mg.kg^{-1}$), Mg (548.6 $mg.kg^{-1}$), Na (35.55 $mg.kg^{-1}$), and Mn (8.99 $mg.kg^{-1}$) concentrations while Maestrale had the highest Fe (23.69 $mg.kg^{-1}$) and Ni (1.29 $mg.kg^{-1}$) concentrations. The concentration of P in Zenit, Ca in Svevo, B in Eminbey, Cu in Kızıltan-91, Zn in Guney Yildizi, were the highest. There were significant differences among the semolina samples of the cultivars in terms of mineral element concentration ($p<0.05$). The K, Mg, Ca, and P results of the present study were generally lower than the ones reported by Matsuo *et al.*, 1994. at the same time, Fe and Zn concentrations were higher than those reported by Szira *et al.* (2014) for semolina samples.

The Zn, Fe, P, Ca, and B concentrations of the wheat samples grown in Central Anatolia were higher than those in South-eastern Anatolia. However, the contents of the same minerals (Zn, Fe, P, Ca, B) in the semolina samples produced from the wheat grown in Central Anatolia were lower than those grown in South-eastern Anatolia. Based on these results, it can be concluded that durum wheat grown in Central Anatolia seems to be more suitable for the production of whole wheat pasta, while durum wheat grown in Southeast Anatolia might be better for regular pasta products without bran to get pasta with higher levels of these essential minerals. However, further investigations are needed to confirm these preliminary findings.

Biplot analysis of physical/chemical properties and mineral element concentrations

The biplot analysis explained 78.1 % of total variation (PC1: 44.0% and PC2: 34.1%) in yield and physical and

Table 5. Mineral element concentration of durum wheat cultivars.

Cultivar	P mg.kg^{-1}	K mg.kg^{-1}	Ca mg.kg^{-1}	Mg mg.kg^{-1}	Na mg.kg^{-1}	B mg.kg^{-1}
Cesit-1252	3546.9 ± 0.04^{c}	4491.7 ± 0.53^{b}	419.2 ± 0.30^{g}	1557.7 ± 0.59^{b}	30.78 ± 0.20^{b}	0.59 ± 0.02^{b}
Eminbey	3318.0 ± 0.23^{f}	3592.7 ± 0.42^{h}	550.7 ± 0.46^{b}	1418.6 ± 0.28^{f}	28.22 ± 0.14^{de}	0.42 ± 0.01^{cd}
Kiziltan	3945.7 ± 0.42^{b}	4034.5 ± 0.47^{d}	513.7 ± 0.17^{c}	1498.1 ± 0.22^{d}	28.33 ± 0.11^{d}	0.58 ± 0.03^{b}
Mirzabey	3487.7 ± 0.09^{d}	3635.5 ± 0.24^{g}	749.4 ± 0.40^{a}	1399.6 ± 0.13^{g}	27.88 ± 0.06^{e}	0.45 ± 0.01^{c}
GuneyYildizi	3230.0 ± 0.16^{g}	4107.9 ± 0.17^{c}	486.7 ± 0.54 **d**	1492.1 ± 0.45^{e}	28.72 ± 0.09^{c}	0.37 ± 0.02^{d}
Maestrale	2868.0 ± 0.28^{h}	3931.1 ± 0.22^{e}	469.7 ± 0.38 **e**	1290.6 ± 0.27^{h}	28.52 ± 0.02^{cd}	0.70 ± 0.02^{a}
Svevo	4147.9 ± 0.29^{a}	4849.6 ± 0.37^{a}	460.5 ± 0.11 **f**	1679.0 ± 0.24^{a}	32.44 ± 0.04^{a}	0.73 ± 0.02^{a}
Zenit	3329.4 ± 0.75^{e}	3639.1 ± 0.22^{f}	372.4 ± 0.23 **h**	1511.5 ± 0.23^{c}	28.23 ± 0.13^{de}	0.55 ± 0.01^{b}
LSD	**1.15**	**1.15**	**1.15**	**1.08**	**0.369**	**0.061**

Values followed by different letters in the same column are significantly different (p< 0.05) by the least significant difference (LSD) test.

Table 6. Mineral element concentration of durum wheat cultivars.

Cultivar	Cu mg.kg^{-1}	Fe mg.kg^{-1}	Mn mg.kg^{-1}	Ni mg.kg^{-1}	Zn mg.kg^{-1}
Cesit-1252	5.60 ± 0.20^{b}	30.26 ± 0.06^{e}	32.92 ± 0.04^{e}	0.86 ± 0.01^{d}	19.52 ± 0.07^{d}
Eminbey	5.25 ± 0.05^{c}	41.17 ± 0.07^{a}	37.82 ± 0.08^{b}	0.89 ± 0.01^{d}	31.65 ± 0.07^{a}
Kiziltan	4.28 ± 0.02^{d}	40.85 ± 0.10^{b}	31.05 ± 0.20^{f}	0.64 ± 0.02^{e}	27.54 ± 0.11^{c}
Mirzabey	4.37 ± 0.02^{d}	36.40 ± 0.10^{d}	39.94 ± 0.21^{a}	0.48 ± 0.02^{f}	27.44 ± 0.29^{c}
GuneyYildizi	6.17 ± 0.01^{a}	27.42 ± 0.08^{f}	34.70 ± 0.06^{d}	1.23 ± 0.09^{b}	18.81 ± 0.02^{e}
Maestrale	5.67 ± 0.05^{b}	25.06 ± 0.04^{g}	32.90 ± 0.22^{e}	1.06 ± 0.04^{c}	17.97 ± 0.15^{f}
Svevo	4.50 ± 0.02^{d}	36.99 ± 0.13^{c}	30.04 ± 0.10^{g}	1.76 ± 0.04^{a}	28.97 ± 0.08^{b}
Zenit	5.44 ± 0.04^{bc}	36.74 ± 0.08^{c}	35.40 ± 0.12^{c}	1.20 ± 0.05^{bc}	15.97 ± 0.12^{g}
LSD	**0.122**	**0.282**	**0.473**	**0.140**	**0.446**

Values followed by different letters in the same column are significantly different (p< 0.05) by the least significant difference (LSD) test.

Table 7. Mineral element concentration of semolina samples.

Cultivar	P mg.kg^{-1}	K mg.kg^{-1}	Ca mg.kg^{-1}	Mg mg.kg^{-1}	Na mg.kg^{-1}	B mg.kg^{-1}
Cesit-1252	1714.9 ± 0.64^{c}	2159.8± 0.57^{a}	336.2 ± 0.23^{b}	548.6± 0.10^{a}	35.55± 0.10^{a}	2.77± 0.07^{a}
Eminbey	1489.9 ± 0.37^{g}	2087.8 ± 0.13^{b}	265.1 ± 0.25^{g}	397.0 ± 0.06^{g}	32.36 ± 0.28^{b}	2.88± 0.11^{a}
Kiziltan	1377.3 ± 0.24^{g}	2034.1 ± 0.30^{c}	291.5 ± 0.25^{f}	408.0 ± 0.17^{e}	28.43 ± 0.20^{d}	2.26 ± 0.06^{c}
Mirzabey	1753.9 ± 0.28^{b}	1688.3± 0.16^{f}	307.4 ± 0.08^{d}	441.5 ± 0.11^{d}	32.17± 0.38^{b}	2.37 ± 0.08^{bc}
GuneyYildizi	1589.7± 0.34^{d}	1996.0± 0.96^{d}	298.1 ± 0.58^{e}	481.1 ± 0.07^{c}	35.06± 0.24^{a}	2.36± 0.04^{bc}
Maestrale	1574.0 ± 0.27^{e}	1509.6± 0.17^{g}	331.0 ± 0.31^{c}	396.7 ± 0.37^{g}	30.99± 0.44^{c}	2.51 ± 0.14^{b}
Svevo	1565.6 ± 0.20^{f}	1474.8 ± 0.24^{h}	438.6 ± 0.42^{a}	403.3 ± 0.13^{f}	32.01 ± 0.10^{b}	2.28± 0.03^{c}
Zenit	1881.9 ± 0.10^{a}	1981.0 ± 0.07^{e}	264.7 ± 0.14^{g}	495.3 ± 0.21^{b}	34.93 ± 0.33^{a}	2.28 ± 0.03^{c}
LSD	**0.780**	**0.987**	**0.739**	**0.413**	**0.652**	**0.185**

Values followed by different letters in the same column are significantly different (p< 0.05) by the least significant difference (LSD) test.

Table 8. Mineral element concentration of semolina samples.

Cultivar	Cu mg.kg^{-1}	Fe mg.kg^{-1}	Mn mg.kg^{-1}	Ni mg.kg^{-1}	Zn mg.kg^{-1}
Cesit-1252	3.06 ± 0.08^{a}	19.72 ± 0.06^{c}	8.99± 0.18^{a}	0.74± 0.03^{c}	12.49± 0.03^{c}
Eminbey	2.39 ± 0.03^{c}	20.40± 0.06^{b}	6.16 ± 0.11^{d}	0.57 ± 0.07^{d}	12.54 ± 0.08^{c}
Kiziltan	2.74 ± 0.08^{b}	14.26 ± 0.11^{e}	6.60 ± 0.11^{c}	0.53 ± 0.06^{d}	10.87 ± 0.28^{d}
Mirzabey	2.48 ± 0.08^{c}	23.69± 0.14^{a}	5.89 ± 0.17^{d}	1.29 ± 0.07^{a}	15.13 ± 0.07^{b}
GuneyYildizi	3.24 ± 0.03^{a}	13.32± 0.31^{f}	7.72 ± 0.11^{b}	0.50 ± 0.06^{d}	12.28 ± 0.14^{c}
Maestrale	2.73 ± 0.11^{b}	17.10 ± 0.07^{d}	7.96 ± 0.10^{b}	0.20 ± 0.04^{e}	17.08± 0.27^{a}
Svevo	2.38 ± 0.08^{c}	14.27 ± 0.07^{e}	7.75± 0.10^{b}	0.47± 0.04^{d}	15.12 ± 0.17^{b}
Zenit	2.50 ± 0.17^{c}	20.57 ± 0.20^{b}	5.89 ± 0.10^{d}	0.97 ± 0.06^{b}	15.32± 0.06^{b}
LSD	**0.219**	**0.351**	**0.294**	**0.126**	**0.380**

Values followed by different letters in the same column are significantly different ($p < 0.05$) by the least significant difference (LSD) test.

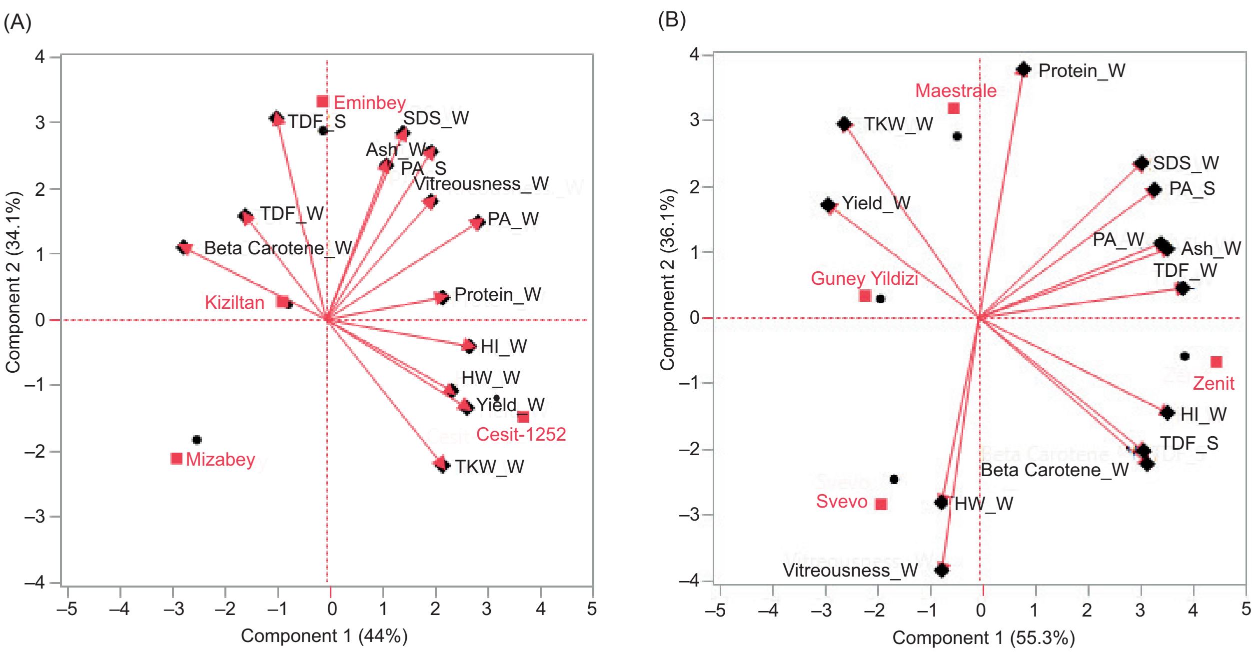

Figure 1. (A) Principal component analysis (PCA) of physical and chemical properties of durum wheat and semolina cultivars in the Central Anatolia Region. (B) Principal component analysis (PCA) of physical and chemical properties of durum wheat and semolina cultivars in the South-eastern Anatolia Region.

TKW: Thousand kernel weight; HW: Hectoliter weight; HI: Hardness index; PA: Phytic acid; SDS: SDS Sedimentation value; TDF: Total Dietary Fiber; S=Semolina; W=Wheat

chemical properties for the samples grown in the Central Anatolia region (Figure 1A). PA content of cv. Mirzabey was lower than the other cultivars. Eminbey cv. had a higher TDF and SDS sedimentation value than the other cultivars in grain. Kiziltan cv. had higher protein content and beta-carotene levels in the grain. In terms of yield values, Cesit-1252 had higher, and Eminbey had lower values than the other cultivars.

The biplot analysis explained 91.4% of total variation (PC1: 55.3% and PC2: 36.1%) in yield and physical and chemical properties of the samples grown in the Southeast Anatolia region (Figure 1B). Meastrale cv. had higher values in yield, TKW, and protein content. Svevo had a higher hectoliter weight value. Güney Yildizi had lower PA content in grain. Zenit had higher SDS sedimentation and beta carotene content in grain

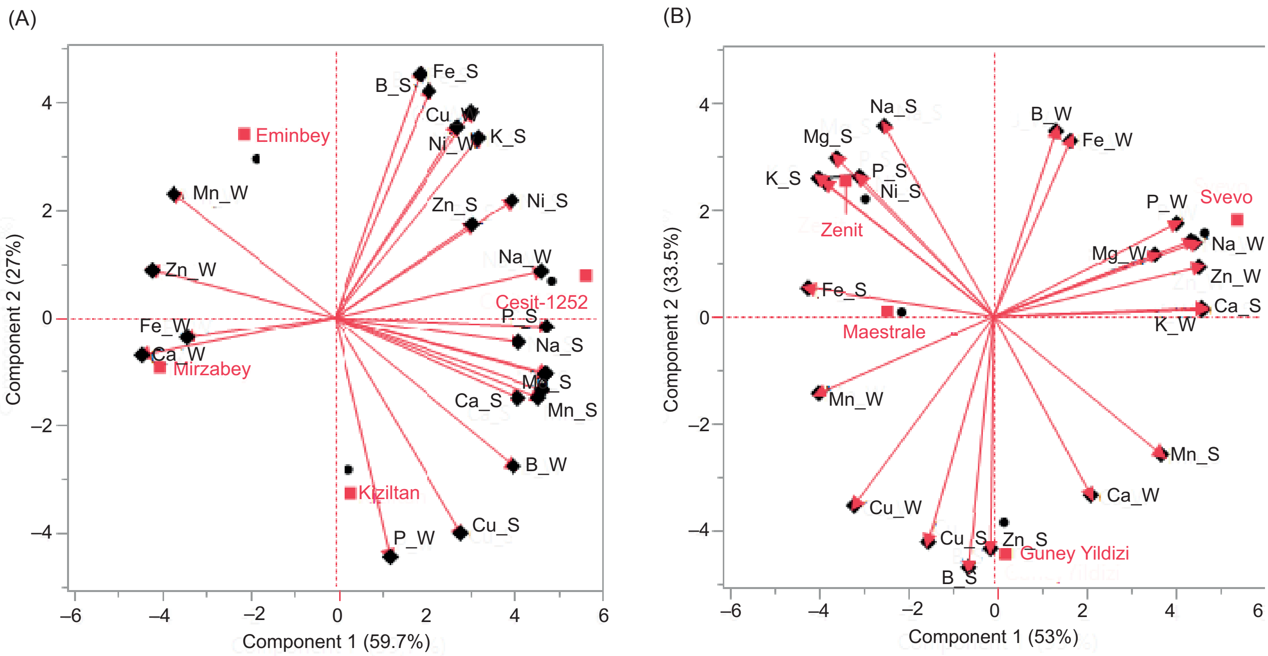

Figure 2. (A) Principal component analysis (PCA) of mineral element concentration in durum wheat and semolina cultivars in the Central Anatolia Region. (B) Principal component analysis (PCA) of mineral element concentration in durum wheat and semolina cultivars in South-eastern Anatolia Region.
S: Semolina; W: Wheat.

and higher TDF in semolina than other cultivars (Figure 1B).

The biplot graph indicated that the first two components explained 86.7% (PC1: 59.7% and PC2: 27.0%) of the total variation in grain and semolina mineral contents in the Central Anatolia Region (Figure 2A). Among the wheat samples, Kiziltan had higher P, Cesit-1252 had higher K, Mg, Na, Mirzabey had higher Ca, Mn and Eminbey had higher Fe, Ni, and Ni Zn contents. In the semolina samples, Cesit-1252 had higher P, K, Ca, Mg, Na, B, Mn, and Ni, Eminbey cv. had higher values in terms of Fe and Zn contents (Figure 2a).

The biplot explained 86.5% of total variation (PC1: 53% and PC2: 33.5%) in the Southeast Anatolia region's grain and semolina mineral contents (Figure 2B). Among the wheat samples, Svevo had higher P, K, Mg, Na, B, Fe, Ni, and Zn contents. In the semolina samples, Zenit had higher P, K, Mg, and Na contents (Figure 2B).

Conclusion

The physical, chemical and physicochemical properties of durum wheat are associated with the cooking quality and nutritional properties of end products. To ensure durum wheat with these properties, the strategies of breeding programs should be based on the demands of a farmer, miller, pasta manufacturer, consumer, and international export market. Therefore, breeders need to determine/analyze these characteristics and use this information to select breeding material.

The durum wheat genotypes used in the present study varied widely regarding all parameters. The differences between the quality and nutritional characteristics of the cultivars were found to be statistically significant ($p<0.05$). The biplot analysis explained 77.0% and 91.4% of the total variation in yield and physical and chemical properties for the samples grown in the Central Anatolia and Southeast Anatolia regions, respectively. The biplot analysis explained >86% of the total variation in grain and semolina mineral contents in both regions. Improving mineral content in cereal products is a possible strategy to increase human mineral intake. The results reported in this study open the possibility of designing a specific breeding program to improve the nutritional value of durum wheat by identifying cultivars and regions with high mineral concentrations and low phytic acid content.

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