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Original article

Phytochemical content and antioxidant activity of einkorn (*Triticum monococcum* ssp. *monococcum*), bread (*Triticum aestivum* L.), and *durum* (*Triticum durum* Desf.) wheat

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Summary. *Introduction.* Wheat (*Triticum* ssp.), a major cereal, and its marginally grown hulled ancestor einkorn (*Triticum monococcum* ssp. *monococcum*), have bioactive compounds reducing and preventing chronic diseases such as diabetes, cancer, and cardio vascular diseases, besides highly desired nutritional properties. *Methods.* We evaluated the total phenolics and flavonoids and quantified their phenolic acids, α-tocopherol by high performance liquid chromatography, and their 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging activity. *Results.* Ferulic acid (148.67-764.04 μg/g), p-coumaric acid (5.06-54.09 μg/g), and total phelonic content (2.06-8.11 μmol GAE/g) of einkorn were significantly higher than bread and durum wheat ($p<0.05$). *Conclusion.* Results suggested that einkorn is a rich gene resource for the improvement of modern healthier wheat cultivars.

Key words: bioactive compounds, bread wheat, durum wheat, einkorn, phenolic acids, *Triticum monococcum* ssp. *monococcum*

Introduction

Wheat (*Triticum* ssp.), cultivated for centuries in the Middle-East, Central Asia, Europe, and North-Africa, is one leading staple crop. With the evolution from wild ancestors, cultivated einkorn (*Triticum monococcum* spp. *monococcum*), emmer (*Triticum dicoccum* Schrank.), durum (*Triticum durum* Desf.), and bread (*Triticum aestivum* L.) wheat contributed highly to the diet –and, of course, to the health– of human (1). Einkorn (*Triticum monococcum* spp. *monococcum*), the first cultivated wheat resulted in the modern durum and bread wheats (2). Einkorn was first domesticated around the Karacadag Mountains, Diyarbakir, Turkey (3). It, with its capability of adapting to adverse environmental conditions and possessing rich gene resources for wheat improvement (4), for instance, chromosome 7A, having a stem rust resistance, has been introduced into modern wheat cultivars (5). Unfortunately, its cultivation is marginalized into Kastamonu, Bolu, Bilecik, and Sinop provinces of Turkey, today (6). There are, too, some limited einkorn (*Triticum monococcum* spp. *monococcum*) production regions in the Caucasus, Balkans, Spain, and Italy (7-9).

Wheat has healthy compounds in human diet, such as fiber, phytochemicals, antioxidants etc. (10). Fiber eases digestion and, therefore, decreases the intestinal cancer risks (11). Phytochemicals inhibits radical oxidation with DNA or other cell components and protects the plant cells from the deleterious compounds. Bioactive phenolic acids, tocols (vitamin E), and carotenoid compounds in wheat showing antioxi-

dant activity (12, 13), prevent or reduce the risk for chronic diseases: type 2 diabetes, ischemic heart disease, colon and breast cancers (14-17). Furthermore, some bioactive compounds, phenolic acids, antioxidants, and vitamin E exist in all wheat, though more in wild wheat speciess (18,19).

Wheat has been traditionally preferred by consumers for grain products so far. As more attention has been given to wheat cultivars with strong gluten, protein content, starch composition, and resistance to biotic and abiotic stresses in bread wheat (20, 21), and yellow-colored pasta product in durum wheat (22), health compounds such as fibers, phytochemicals, and bioactive compounds have been underestimated. Here, therefore, the aim of this study was to investigate 1) differences among total phenols, flavonoids, antioxidant activities of 12 different einkorn, durum, and bread wheat populations/cultivars, and 2) quantify their ferulic, p-coumaric, and α-tocopherol compositions by reverse-phase high performance liquid chromatography (HPLC).

Materials and methods

Grain sample collection

Five bread (*Triticum aestivum* L. Cvs.: Akbaşak, Bayraktar, Gerek 79, Seval, Demir-2000), five durum (*Triticum durum* Desf, Cvs.: C-1252, Altin 40-98, ANK-98, Kiziltan-91, Altıntaş) cultivars, and two einkorn (*Triticum monococcum* spp. *monococcum*) populations from Seben-Bolu and ihsangazi-Kastamonu (Table 1) were studied. Bread and durum wheat cultivars were provided by Central Research Institute for Agricultural Research (CRIFC), Ankara and by Anatolian Research Institute (ARI), Eskişehir. Two different einkorn populations originating from Seben-Bolu and ihsangazi-Kastamonu were provided by Bolu Quality and Feed Industry Corporation, Turkey.

Materials and reagents

Folin-Ciocalteu, Merck (Darmstad, Germany), was used to evaluate total phenolic content of each extract and gallic acid, Merck (Darmstad, Germany), for construction of the calibration curve in total phe-

Table 1. Types, species, genomes, names, and locations of wheat entries.

Common Name	Species and Subspecies	Genome	Population or Cultivar	Location
Einkorn	*T. monococcum* ssp. *monococcum*	AA	ID - 1	İhsangazi / Kastamonu
Einkorn	*T. monococcum* ssp. *monococcum*	AA	ID - 2	Seben / Bolu
Bread wheat	*T. aestivum* L.	AABBDD	Akbasak 073 - 44	CRIFC[1], Ankara
Bread wheat	*T. aestivum* L.	AABBDD	Bayraktar	CRIFC[1], Ankara
Bread wheat	*T. aestivum* L.	AABBDD	Gerek - 79	ARI[2], Eskişehir
Bread wheat	*T. aestivum* L.	AABBDD	Seval	CRIFC[1], Ankara
Bread wheat	*T. aestivum* L.	AABBDD	Demir - 2000	CRIFC[1], Ankara
Durum wheat	*T. durum* Desf.	AABB	C - 1252	CRIFC, Ankara
Durum wheat	*T. durum* Desf.	AABB	Altintas	ARI, Eskişehir
Durum wheat	*T. durum* Desf.	AABB	Altin 40 - 98	CRIFC[1], Ankara
Durum wheat	*T. durum* Desf.	AABB	ANK - 98	CRIFC[1], Ankara
Durum wheat	*T. durum* Desf.	AABB	Kiziltan - 91	CRIFC[1], Ankara

[1]CRIFC: Central Research Institute for Agricultural Research; [2]ARI: Anatolian Research Institute

nol evaluation. 2-Dipheny-1-picryhydrazyl radical (DPPH) from Sigma-Aldrich (Steinheim, Germany) was used to perform antioxidant activity. Catechol, used for constructing calibration curve in total flavonoid evaluation and ferulic acid, p-coumaric acid, and α-tocopherol were purchased from Sigma-Aldrich (Steinheim, Germany).

Extractions and sample preparation for testing

All wheat grains were extracted for free phenolic content (FPC), bound phenolic content (BPC), total flavonoid content (TFC), phenolic acids (ferulic acid and p-coumaric), and α-tocopherol quantification by HPLC. Phenolic acids generally exist in a free, esterified or glycosylated form in plants. The bound phenolic acids of wheat were extracted with alkaline hydrolysis after liberated free phenolic acids with methanol.

a. Extraction of wheat grains for FPC, TFC, and DPPH assay:
   All wheat grains were de-hulled and grounded into a fine powder. 30 g of each grounded sample were extracted by soxhlet for 24 hours at ambient temperature with 300 mL of 100% methanol. Methanolic extracts were evaporated and stored at -20°C.
b. Extraction for BPC:
   The residues from the soxhlet extraction were used for the bound phenolic extraction. Bound phenolics were then released by alkaline hydrolysis using 4 M NaOH before extraction. After adjusting the pH of alkaline solutions to 2.0 by 6 N HCl, the mixtures were extracted with ethyl acetate and diethyl ether (1:1, v/v) until a white color was observed. Subsequently, solvent was evaporated at 30°C to dryness under nitrogen gas and stored at -20°C (23).
c. Extraction for α-tocopherol:
   Approximately 0.4 g of each sample was weighed for α-tocopherol extraction, 200 µL of catechol (0.2 g/mL) and 5 mL of 0.5 mol/L methanolic KOH was added to solutions and stirred. The solutions were subsequently placed into a water bath at 80°Cfor 15 minutes and shaken on the vortex every 5 minutes thrice with 1 min resting interval. Then, 1 mL distilled water and 5 mL hexane were added into the solutions before they were prepared. The mixtures were stirred for 1 minute, then the 3 mL of hexane aliquot of each samples was transferred into the flasks and hexane was evaporated. Dry residues were dissolved in 0.5 mL of methanol and transferred into the glass vials (1.50 mL) through nylon filter (0.22 µm) for HPLC analysis (24).

Determination of total phenolic content

TPC of extracts was determined using Folin-Ciocalteau procedure (25). Briefly, 20 µL of extracts (1 mg/mL) was mixed with 1.58 mL distilled water. Then, mixture was oxidized with the addition of 100 µL of Folin-Ciocalteau reagent. The mixture was neutralized with the addition of 300 µL of saturated Na_2CO_3 (w/v) solution after 2 minutes of reaction. The mixtures were allowed to stand at ambient temperature for 120 minutes until the characteristic blue color developed. The absorbance of resulting blue-colored mixtures was measured at 765 nm. Gallic acid was used as a calibration standard and results were represented as micromoles (µmol) gallic acid equivalent (GAE) per gram of whole grain. Data were summarized as mean ± SD of three replications.

Determination of total flavonoid content

TFC of extracts was determined according to Chang et al. (26). Briefly, 500 µL of extracts (1 mg/mL) was reacted with 5% $NaNO_2$ (w/v), after 5 minutes, 10% $AlCl_3$ (w/v) was added for 1 minute, followed by 4% NaOH (w/v). The mixtures were allowed to stand at ambient temperature for 30 minutes until their characteristic pink color was developed. The absorbance of solutions was measured at 510 nm. Catechol was used as a calibration standard and results were represented as micromoles (µmol) catechol equivalent (CTE) per gram of whole wheat. Data were reported as mean ± SD of three replications.

Briefly, 10 mg of extracts was dissolved in 10 ml of 100% methanol and solutions were diluted to 200, 100, 50, 25, or 12.5 µg/mL. Subsequently, 500 µL of each diluted solutions were reacted with 1.50 mL of 1 M DPPH solution in 100% methanol (w/v) for 30 minutes. The absorbance of solutions was measured at 517 nm (27). The control was the ascorbic acid. Data were reported as percentage of DPPH inhibition as in the following, where

DPPH %inhibition=$[(Absorbance_{control}-Absorbance_{sample}/Absorbance_{control})]\times100$

Phenolic acids (Ferulic acid, p-coumaric), and α-tocopherol analyses by HPLC Ferulic and p-coumaric acid analyses were performed based on a pre-described method (23) with some modifications. The samples and standards at 10 µL were injected using ACC-3000 Autosampler attached to Ultimate 3000 HPLC system equipped with 3000 pump and diode array detector, Dionex (Olten, Switzerland). The phenolic acids were separated on a reverse phase Ace 5 C18 Column (150 mm × 4.6 mm). Eluent A was ultra-distillated water while eluent B was acetonitrile, both containing 0.1% formic acid (v/v). The solvent gradient was at a flow rate of 800 µL/min, with 0 min 100% A; 10 min 85% A; 15 min 50% A; 20 min 100% A. α-tocopherol analysis was performed according to a previously described method (23). It was separated on reverse phase Ace 5 C18 Column (150 mm × 4.6 mm). Eluent A was 96% methanol and 4%ultradistillated water. Column temperature was set at 36°C and the solvent gradient, at a flow rate of 800 µl/min, was as the following: 0-20 min 100% A.

Statistical analysis

A completely randomized block design with three replications was run for each character of all wheat samples studied. Mean differences were separated by Duncan's Multiple Range test using SPSS version 18.0 (SPSS Inc. Chicago, IL). All data, then, were reported as mean ± standard deviations, based on three replications.

Results and discussion

Total phenolic contents

Phenol compounds are mainly concentrated in the cell wall of cereal grain as bound form and cannot be easily extracted with ethanol, methanol, or acetone but be released by alkali hydrolysis (23).

Phenolic contents of wheat cultivars and populations were determined as free and bound (Figure 1). BPC was significantly higher than FPC ($p<0.05$). FPC in wheat cultivars and populations ranged between 0.29 ± 0.02 and 0.75 ± 0.03 µmol GAE/g. The average was 0.52 ± 0.03 µmol GAE/g. Kızıltan-91 had the highest FPC (0.75 ± 0.03 µmol GAE/g), and was followed by Altin 40-98 (0.63 ± 0.05 µmol GAE/g), ID-1 (0.63 ± 0.03 µmol GAE/g), ID-2 (0.62 ± 0.02 µmol GAE/g), Akbasak (0.55 ± 0.02 µmol GAE/g), C-1252 (0.51 ± 0.01 µmol GAE/g), Ank-98 (0.47 ± 0.04 µmol GAE/g), Bayraktar (0.46 ± 0.03 µmol GAE/g), Demir-2000 (0.44 ± 0.03 µmol GAE/g), Seval (0.42 ± 0.06 µmol GAE/g), Altintas (0.42 ± 0.03 µmol GAE/g), and Gerek-79 (0.29 ± 0.02 µmol GAE/g), respectively. Overall, no significant differences existed among einkorn, bread, and durum wheats, though within each species for cultivars and/or populations ($p<0.05$).

BPC of wheat populations and cultivars varied from 1.60 ± 0.30 µmol GAE/g to 7.49 ± 0.08 µmol GAE/g with an average of 3.56 ± 0.09 µmol GAE/g. The highest amount of BPC was in ID-1 (7.49 ± 0.08 µmol GAE/g), and followed by ID-2 (6.37 ± 0.06 µmol GAE/g), ANK-98 (3.34 ± 0.13 µmol GAE/g), Akbasak (3.33 ± 0.01 µmol GAE/g), Gerek-79 (3.16 ± 0.05 µmol GAE/g), Demir-2000 (3.14 ± 0.07 µmol GAE/g), Seval (2.93 ± 0.05 µmol GAE/g), Altintas (2.91 ± 0.05 µmol GAE/g), C-1252 (2.85 ± 0.01 µmol GAE/g),and Kiziltan-91 (2.83 ± 0.05µmol GAE/g), Altin 40-98 (2.73 ± 0.13 µmol GAE/g), Bayraktar (1.60 ± 0.30 µmol GAE/g), respectively. Bound phenolic, on the average, was almost 7-fold higher than free phenolic of wheat populations and cultivars and, ranged between 2.06 ± 0.27 µmol GAE/g and 8.11 ± 0.06 µmol GAE/g, while TPC (ranged 2.06-8.11 µmol GAE/g) was 4.07 ± 0.08 µmol GAE/g. While einkorn populations were significantly higher than bread and durum wheat cultivars ($p<0.05$), there was no significant differences among bread and durum

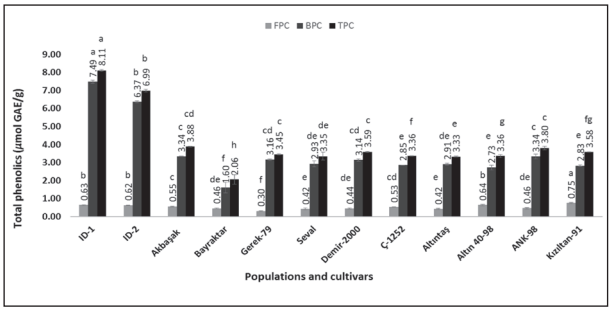

Figure 1. Free, bound, and total phenolic content of wheat cultivars and populations (mean ± SD). The vertical bars represent the standard deviation of each data point. Bars with no common letters are significantly different ($p < 0.05$).

wheat cultivars ($p<0.05$). However, differences within bread and durum wheat cultivars were evident.

Einkorn, durum, and bread wheat investigated in this study showed similarities with TPC values of ten diploid einkorns, another diploid *T. urartu* Tum., two tetraploids, and two hexaploid wheat species and accessions (extracted with ethanol and ranged 570-1012 mg GAE/kg dry matter) reported by Yilmaz et al. (28) and there was significant differences between wild wheat and modern wheat species and accessions ($p<0.05$). Also, there was significant differences between wild and modern wheat cultivars and lines reported by Ciccoritti et al. (29) showed similarity ($p<0.001$). Ranged from 2.55 to 8.58 µmol GAE/g of emmer, einkorn (collected from the same region -western Blacksea), and bread wheat landraces reported by Serpen et al. (30), however, TPC values of our einkorns were about 2.2-fold higher than those values of einkorn populations. In a study by Adom et al. (31), TPC values of some durum and bread wheat varieties ranged from 7.09-8.59 µmol GAE/g were similar to our results as well. On the other hand, there was another study indicating that our einkorn TPC was higher than those of eight soft red winter wheat cultivars (32). The differences for the TPC of cultivars and populations may be due to environment X genotype interaction.

Total flavonoid content

Flavonoids act on several cellular activities such as cell signal transduction, apoptosis, and reactive oxygen. Consumption of high flavonoid food reduces chronic diseases including cancer and alzhemier (33, 34).

TFC of wheat cultivars and populations were expressed as micromoles CTE per gram of whole wheat (Figure 2). TFC of wheat populations and cultivars were between 0.04 ± 0.02 µmol CTE/g -0.39 ± 0.01µmol CTE/g. The average TFC was 0.23± 0.02 µmol CTE/g of whole wheat. The highest amount of TFC was in Altintas (0.39 ± 0.01µmol CTE/g), followed by C-1252 (0.35 ± 0.03 µmol CTE/g), ID-2 (0.33 ± 0.04 µmol CTE/g), ID-1 (0.28 ± 0.02 µmol CTE/g), Bayraktar (0.28 ± 0.01 µmol CTE/g), ANK-98 (0.28 ± 0.02 µmol CTE/g), Akbasak (0.26 ± 0.02 µmol CTE/g), Altin (0.18 ± 0.02 µmol CTE/g), Seval (0.15 ± 0.01 µmol CTE/g), Demir-2000 (0.12 ± 0.03 µmol CTE/g), Kiziltan-91 (0.09 ± 0.01 µmol CTE/g), and the lowest one was Gerek-79 (0.04 ± 0.02 µmol CTE/g). While there were no significant differences among einkorn, bread wheat and durum wheat; cultivars and/or populations within each species were different from each other ($P<0.05$).

That the studies up to date used different standards in total phenolics and flavonoids made comparisons among studies difficult. Dinelli et al. (13) reported TFC (bound+free) of 22 different old and modern common wheat cultivars ranged between 872-1715 µmol cathecin equivalent/100g in grains were significantly different ($p<0.05$). That result showed similarity in our results for the variation within species and cultivars. The range of TFC of 12 different emmers were 1.06-2.29 µmol cathecin equivalent/g, of 6 different einkorn landraces were 0.80-1.59 µmol cathecin equivalent/g and of 2 bread wheat cultivars were 1.32-1.35 µmol cathecin equivalent/g (30). These results were higher than the cultivars and populations investigated in our study and there was significant difference between emmer and einkorn landraces ($p<0.05$). Differences in these two studies might be attributed to the differences in the standards, populations, and cultivars.

DPPH radical scavenging activity

DPPH assay are widely evaluated the free radical scavenging effectiveness of various antioxidant substances. The reduction capability on the DPPH radical is determined by the decrease in its absorbance at 517 nm induced by antioxidants. The decrease in absorbance of DPPH radical caused by antioxidants is due to the reaction between antioxidant molecules and radicals.

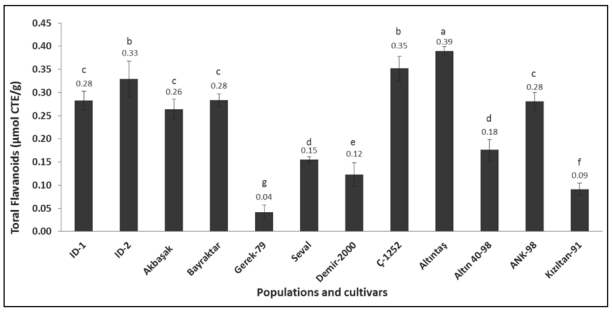

Figure 2. Total flavonoid content of wheat cultivars and populations (mean ± SD). The vertical bars represent the standard deviation of each data point. Bars with no common letters are significantly different ($p < 0.05$).

The percentage of DPPH radical inhibition of wheat populations and cultivars (Table 2) indicated that, at minimum concentration (12.5 μg/ml), wheat populations and cultivars significantly tended to scavenge of DPPH radicals ($p<0.05$). Until 200 μg/ml concentration, there was a significant increase in scavenging activity of DPPH radicals ($p<0.05$). At minimum concentration (12.5 µg/ml), ID-2 (2.79%), Gerek-79 (2.41%), and Kiziltan-91 (2.39%) showed highest scavenge activity of DPPH radicals than those of others, respectively. On the other hand, Altintas (0.06%) and Seval (0.15%) showed the lowest scavenging activity. At 25 µg/ml, Demir-2000 (5.53%) and Seval (5.37%) had the highest scavenge activity, respectively, however, Altintas (0.28%) had the lowest scavenging activity in the wheat cultivars and populations. At concentration of 50 µg/ml, Kiziltan-91 (6.62%), Demir-2000 (5.72%) and ID-2 (5.54%) showed highiest scavenge activity, respectively, but Altintas (0.42%) had the lowest one. At concentration of 100 µg/ml, Altin 40-98 (21.10%) had highest one, but Altintas (2.22%) lowest one. At 200 µg/ml concentration, Altin 40-98 (22.34%) and Kiziltan-91 (21.43%) showed the highest scavenging activity. However, Bayraktar (9.68%) and Altintas (10.69) had the lowest one among wheat species and cultivars. There was no significant difference between einkorn, bread, and durum wheat cultivars and populations ($p<0.05$).

The data obtained in DPPH test, by various procedures and solvents in different studies make comparisons difficult. In this study, data were expressed as the percentage inhibition of DPPH radicals, because scavenge 50% of radical (IC_{50}) values of wheat cultivars and populations were higher than the literature (data not shown). However, in comparison of DPPH radical scavenging activity of *T. aestivum*, *T. turgidum* ssp. *durum*, *T. turgidum* ssp. *dicoccum*, and *T. monococcum* reported by Ciccoritti et al. (29) ranged between 87±3 and 93±8, data represented as ED_{50} (mg of wheat milled grain required to obtain 50% DPPH scaveng-

Table 2. The percentage inhibition of radical scavenging activity of cultivars and populations at different concentration.

Entries	**% of DPPH inhibition**[1]				
	12.5 µg/mL	25 µg/mL	50 µg/mL	100 µg/mL	200 µg/mL
Ascorbic acid	96.29	96.86	96.57	96.57	96.57
ID - 1	0.35^{cd}	2.51^{c}	4.35^{ab}	9.44^{cde}	13.89^{bc}
ID - 2	2.79^{a}	3.87^{b}	5.54^{a}	9.47^{cde}	16.43^{b}
Akbasak 073 - 44	0.61^{bc}	0.76^{f}	1.60^{bc}	4.30^{fg}	11.62^{cde}
Bayraktar	0.66^{bc}	1.54^{e}	1.51^{bc}	4.97^{efg}	9.68^{e}
Gerek - 79	2.41^{a}	2.35^{c}	4.28^{ab}	7.94^{def}	15.52^{b}
Seval	0.15^{d}	5.37^{a}	4.04^{ab}	9.56^{cde}	12.47^{cd}
Demir - 2000	0.91^{b}	5.53^{a}	5.72^{a}	11.85^{bcd}	16.11^{b}
C - 1252	0.75^{bc}	2.55^{c}	2.55^{bc}	8.41^{def}	16.62^{b}
Altintas	0.06^{d}	0.28^{g}	0.42^{c}	2.22^{g}	10.69^{de}
Altin 40 - 98	0.38^{cd}	1.97^{d}	2.26^{bc}	21.10^{a}	22.34^{a}
ANK - 98	0.43^{cd}	0.87^{f}	3.98^{ab}	13.64^{bc}	16.52^{b}
Kızıltan - 91	2.39^{a}	3.73^{b}	6.62^{a}	16.31^{b}	21.43^{a}

[1]*Mean values with the same letter within the column are not significantly different from each other at P < 0.05.*

ing on dry basis), showed that there was no significant difference between wheat species ($p<0.05$). In another study reported by Yilmaz et al. (28) of *T. monococcum, T. aestivum* L., and *T. durum* Desf. extracted with 3 different solvents revealed the same result as our study. On the other hand, there was significantly difference between cultivars and landraces of emmer, einkorn, and bread wheat in the assessment of antioxidant acitivities by 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid)($ABTS^{\cdot+}$) assay reported by Serpen et al. (30) ($p<0.05$).

Ferulic acid and p-coumaric content

Wheat phytochemicals are mainly composed of phenolic acids. They highly contribute to the antioxidant properties. Ferulic and p-coumaric acid are the most abundant chemicals in the wheat kernels, respectively. In this study, phenolic acids, ferulic acid, and p-coumaric acid were determined within wheat.

Ferulic acid contents of wheat cultivars and populations (Table 3) were expressed as total (free+ bound) ferulic acid content. The average ferulic acid content was 485.63± 9.76μg/g of whole wheat. ID-1 (764.04± 2.40 μg/g) had the highest ferulic acid content, followed by ID-2 (762.89 ± 14.17 μg/g), which were significantly higher than those of other wheat cultivars ($p<0.05$). Moreover, Demir-2000 (554.82 ± 8.55 μg/g) had the highest amount of ferulic acid among bread wheat cultivars and ANK-98 (480.11 ± 31.30 μg/g) possessed the highest amount of ferulic acid among durum wheat cultivars. There were significant differences among einkorn and other bread and durum wheat species and their cultivars ($p<0.05$). However, there were no differences between bread and durum wheat species and cultivars ($p<0.05$). Einkorn had 1.8-fold more ferulic acid than bread and durum wheat.

Highest p-coumaric content among wheat cultivars and species was in ID-1 (54.09 ± 1.76 μg/g) and ID-2 (47.64 ± 2.31 μg/g), which were significantly higher than those of other wheat species and cultivars ($p<0.05$). Furthermore, Demir-2000 (33.45 ± 1.23 μg/g) had the highest amount of p-coumaric acid among bread wheat cultivars and Altin 40-98 (23.83 ± 0.73 μg/g) had the highest ferulic acid among durum wheat cultivars. On the average, concentration of p-coumaric was 25.18 ±1.06 μg/g. Furthermore, einkorn

Table 3. Average concentration (μg/g) of bioactive compounds in einkorn, bread, and durum wheat cultivars and populations.

Entries	ferulic acid[1]	p-coumaric[1]	α-tocopherol[1]
ID-1	764.04 ± 2.40^{a}	54.09 ± 1.76^{a}	1.41 ± 0.07^{c}
ID-2	762.89 ± 14.17^{a}	47.64 ± 2.31^{b}	3.16 ± 0.70^{bc}
Akbasak 073 - 44	478.76 ± 23.90^{d}	15.28 ± 0.35^{g}	1.59 ± 0.70^{c}
Bayraktar	148.67 ± 13.99^{g}	5.06 ± 0.01^{i}	3.81 ± 1.40^{b}
Gerek - 79	476.50 ± 6.52^{c}	29.38 ± 0.06^{d}	4.01 ± 1.19^{b}
Seval	460.08 ± 1.11^{de}	26.45 ± 1.82^{de}	3.27 ± 0.12^{bc}
Demir - 2000	554.82 ± 8.55^{b}	33.45 ± 1.23^{c}	9.51 ± 0.49^{a}
C - 1252	439.73 ± 17.09^{e}	22.32 ± 1.22^{f}	7.68 ± 0.70^{a}
Altintas	467.20 ± 16.26^{de}	15.30 ± 0.11^{g}	3.09 ± 0.70^{bc}
Altin 40 - 98	397.80 ± 12.18^{f}	23.83 ± 0.73^{ef}	3.51 ± 0.70^{bc}
ANK - 98	480.11 ± 31.30^{d}	11.32 ± 1.59^{h}	4.38 ± 1.40^{b}
Kiziltan - 91	396.96 ± 29.95^{f}	18.08 ± 1.55^{g}	1.66 ± 0.70^{c}

[1]Data represented as mean ± SD, mean values with the same letter within the column are not significantly different from each other at P < 0.05.

had 2.5-fold higher p-coumaric than bread and durum wheat species and cultivars. While significant differences were observed between einkorn populations and cultivars of bread / durum wheat ($p < 0.05$), there was no significant difference between durum and bread wheat cultivars ($p < 0.05$).

Similar results were observed in ten diploid einkorns, another diploid *T. urartu* Tum., two tetraploids, and two hexaploid wheat species and accessions, which ranged between 471.1-724.9 mg/kg dry matter in ferulic acid and 102.1-10.8 mg/kg dry matter in p-coumaric (28). Similar results occurred for ferulic acid and p-coumaric (35) and for Maryland soft red winter wheats. They ranged between 455.92-621.47 μg/g for ferulic (32) and 25.05-54.21 μg/g for p-coumaric, lower than those of our einkorn populations. Furthermore, ferulic acid values in this study were similar to those of emmer and einkorn species reported by Serpen et al. (30). While they ranged, there, between 232.66- 775.30 μg/g. p-coumaric they were higher than those of 25.05-54.21 μg/g our study. However, concentrations of ferulic acid of einkorn populations reported in this study were about 2.5-fold higher than those einkorn landraces.

α - tocopherol content

Vitamin E (tocopherols and tocotrienols) compounds play an important role in the antioxidation of cell membrane and lipoproteins. They also have many beneficial functions to human health, such as preventing cancer, cardiovascular diseases, a protective effect lowering LDL cholesterol by inhibiting cholesterol biosynthesis, and expressing an antioxidant activity (36).

The highest α-tocopherol in this study was within Demir-2000 (9.51±-0.49 μg/g of whole wheat), whereas the lowest was within ID-1 (5.06 ± 0.01 μg/g of whole wheat). The average of all was 3.92±0.41 μg/g. No difference existed among einkorn, durum, and bread wheat species, but among cultivars and populations ($p<0.05$).

In a study, Hejtmankova et al. (24), with two einkorn, two emmer, and three spring wheat cultivars (ranged between 5.69-8.57 mg/kg dry matter) reported significant differences between species and cultivars, which was similar to ours ($p<0.05$). Demir-2000 and C-1252 showed similar results to hard wheat cultivars, Einkorn, emmer, and soft wheat cultivars (19), ranged for α-tocopherol between 5.50-11.90 μg/g of α-tocopherol. But, other cultivars and populations had lower values than those. These differences may be explained by genotype and environmental differences.

Conclusion

Preference of consumers in preventing and controlling chronic diseases by cereal based diets may successfully be carried out by cultivating new wheat cultivars rich in bioactive compounds. In this study, einkorn populations had significantly higher ferulic, p-coumaric and TPCs than modern bread and durum wheat cultivars ($p<0.05$). Results here suggested the possibility of production of einkorn wheat populations, and hopefully possibility of cultivars rich in particular health beneficial component(s) may provide benefit to the consumers. In addition, higher TPC of einkorn may offer novel wheat genetic resources for the improvement of new wheat cultivars and the development of wheat-based functional foods.

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