

Bioactive Compounds and Fatty Acid Composition of New Turkish Hazelnut Cultivars

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ABSTRACT

This study was carried out to determine oil content, total phenolics, total flavonoids, and total antioxidant activity (according to DPPH and FRAP assay) of *Corylus colurna* (Turkish hazel), 18 Turkish standard hazelnut cultivars (*Corylus avellana* cvs. Tombul, Palaz, Çakıldak, Foşa, Mincane, Sivri, Kara, İncekara, Kalınkara, Cavcava, Yuvarlak Badem, Yassı Badem, Kargalak, Uzunmusa, Kan, Allahverdi, Okay 28, and Giresun Melezi) and 2 hazelnut clones (*Corylus avellana* cl. Kuş and Acı). Total phenolics of the hazelnut cultivars varied between 28.04 g GAE 100 g⁻¹ dw *C. colurna* and 113.01 g GAE 100 g⁻¹ dw (Allahverdi). The highest FRAP antioxidant activity was obtained from the 'Yuvarlak Badem' cultivar (269 mmol TE 100 g⁻¹ dw) and the highest DPPH antioxidant activity was obtained from the 'Çakıldak' cultivar (25.37 mmol TE 100 g⁻¹ dw). 'Kan' hazelnut cultivar had significantly higher total flavonoids (6.50 g QE 100 g⁻¹ dw) than the other cultivars and genotypes. The highest oil ratio was observed in 'Sivri' (72.6%) and the lowest in 'Giresun Melezi' (57.2%). Present findings revealed that among the newly registered hazelnut cultivars of Turkey, 'Allahverdi' cultivar was prominent for total phenolics and antioxidant activity; 'Okay 28' cultivar was prominent for oil content and 'Giresun Melezi' cultivar was prominent for protein and fatty acids.

KEYWORDS

Antioxidant activity; DPPH assay; flavonoids; phenolics; oil content

Introduction

Hazelnut belongs to the *Corylus* genus of the *Coryloidea* sub-family of the *Betulaceae* family of *Fagales* order (Erdoğan and Mehlenbacher, 2000). Hazelnut has a production area of about 1 million hectares worldwide and it is among the mostly widely produced nuts. Turkey is the leading hazelnut producer in the world. With about 712.000 ha production area, Turkey alone constitutes 76% of the world hazelnut production areas (Balık, 2018; Balık and Beyhan, 2019). Hazelnut has great contributions to Turkey's economy. With a rich protein and oil content and nutritional composition, hazelnut is a prominent nut.

Nuts have edible seeds and have quite intense and different contents as compared to other fruit species. Hazelnut is among the important members of this group. Hazelnut has a significant place in human nutrition. The 100 g hazelnut supplies about 634 cal energy (Baysal, 1993). The carbohydrate content of hazelnut varies between 10% and 12%. About 2.8–7.9% of the dry matter is composed of sugar (Botta et al., 1994) and 90% of the total sugar is composed of sucrose. Glucose and fructose have about a 1% share in total sugar. About 1–3.6% of the dry matter is composed of starch. The protein ratio of hazelnut varied between 10–24% and 100 g of hazelnut meets about 22% of the daily protein need of an individual (Pala et al., 1996). Hazelnut is quite rich in unsaturated fatty acids and thus reduces blood cholesterol levels. Hazelnut has an oil content of between 50% and 70%. Oleic acid is the major fatty acid and it is respectively followed by linoleic, palmitic, stearic, and linolenic acid (Balık,

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2018; Garcia et al., 1994). Oleic acid reduces blood cholesterol level and linoleic acid reduces arteriosclerosis. Linoleic and linolenic acids reduce blood lipid and glycerol levels and prevents high blood pressure (Kayahan, 1981). Hazelnut oil does not contain cholesterol, the primary causative of cardiovascular diseases. On the other hand, hazelnut contains about 1–3.4% ash and it is an important source of minerals. The 100 g hazelnut can meet daily Fe, Mg, Cu, Mn, K, P, Zn, and Ca needs of an individual (Köksal, 2002). The high oil content of hazelnut has been reported by several researchers. While the oil content of Turkish hazelnut cultivars varies between 55% and 63.3%, the protein content varies between 14.21% and 20.5% (Balık, 2016).

Wollgast and Anklam (2000) declared that plant phenolics were not nutrients for humans. Nevertheless, their inclusion into the diet is beneficial, because many could potentially play a major role in human health promotion and disease risk prevention. Many phenolic compounds exhibiting antioxidant properties have been studied and proposed for protection against numerous pathologies associated with oxidative damage. Plant phenols have been reported to show anticarcinogenic, antiatherogenic, antiulcer, antithrombotic, anti-inflammatory, antiallergic, immune modulating, antimicrobial, vasodilatory, and analgesic effects (Contini et al., 2009).

Hazelnuts contain a series of antioxidants that may cooperate in concert, providing the body with potential help in hindering the free radical threat, thus improving human well-being by countering the initiation and progression of oxidative stress-mediated disorders and diseases (Güzel et al., 2009; Tüfekçi and Karataş, 2018).

There are several studies conducted about the nutritional composition of hazelnuts (Balık, 2018; Balık et al., 2017; Köksal et al., 2006; Yılmaz et al., 2019). However, there are not any comparative studies about the nutritional composition of new registered ‘Okay 28,’ ‘Giresun Melezi,’ and ‘Allahverdi’ hazelnut cultivars of Turkey.

In this study, protein, oil, fatty acids, total phenolics, total flavonoids, and antioxidant activity of three new Turkish hazelnut cultivars (Allahverdi, Giresun Melezi, Okay 28) were compared with the values of 15 commercial hazelnut cultivars and 3 genotypes.

Materials and Methods

Plant Materials

Nuts of ‘Tombul,’ ‘Palaz,’ ‘Çakıldak,’ ‘Foşa,’ ‘Mincane,’ ‘Uzunmusa,’ ‘Kargalak,’ ‘Sivri,’ ‘Kan,’ ‘Kalınkara,’ ‘İncekara,’ ‘Kara,’ ‘Yassı Badem,’ ‘Yuvarlak Badem,’ ‘Cavcava,’ ‘Allahverdi,’ ‘Okay 28,’ ‘Giresun Melezi,’ ‘Acı,’ and ‘Kuş’ standard and local cultivars of *Corylus avellana* L. genus and nuts of *Corylus colurna* L. genus (Turkish hazel) harvested from the collection orchard of Giresun Hazelnut Research Institute were used as the plant material of the study. Experimental orchard is located in Giresun province (40°54’36.3”N 38°20’42.5”E) with an altitude of 10 m.

Chemical Reagents

Gallic acid, Folin-Ciocalteu reactive, o-dianisidine, ABTS radical, Trolox, and TPTZ were purchased from Sigma (St. Louis, MO) and Na₂CO₃, methanol, KCl, H₂O₂, sodium acetate, acetic acid were purchased from Merc Co. with maximum purity.

Methods

Nuts of three plants of each variety were individually collected. Harvested nuts were de-husked manually and sun-dried naturally as to reduce kernel moisture to a 6% level. Nuts were deshelled manually and kernels were ground in a blender (Waring, Germany). Analyses were conducted at Postharvest Physiology Laboratory of Horticulture Department of Agricultural Faculty of Ordu University.

Crude Oil and Protein (%)

Hazelnut kernel total oil content was determined with the Weende analysis method and expressed as the percentage of dry matter (Ayfer et al., 1986). The nitrogen content of ground kernels was determined with the aid of the Kjeldhal method and the resultant value was multiplied by 6.25 to get the protein ratio ($N \times 6.25$) (Özenç et al., 2015).

Total Phenolics and Total Flavonoids

Total phenolics were determined with Folin-Ciocalteu's method. Initially, 500 μL fresh fruit extract was supplemented with 4.2 mL distilled water, then with 100 μL Folin-Ciocalteu's and 2% sodium carbonate (Na_2CO_3). The resultant solution was incubated for 2 h and absorbance readings were performed in a spectrophotometer at 760 nm. Gallic acid equivalent (GAE) of resultant absorbance values were calculated and results were expressed in mg GAE kg^{-1} (Beyhan et al., 2010). Total flavonoids were determined with the use of Chang et al. (2002) method. Initially, 500 μL fruit extract was supplemented with 3.8 mL methanol, then with 0.1 mL 10% $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ and CH_3COOK . Absorbance readings were performed in a spectrophotometer at 415 nm. Quercetin equivalent (QE) of resultant readings were calculated and results were expressed in mg QE kg^{-1} .

Antioxidant Activity

DPPH Assay

Modified Brand-Williams et al. (1995) method was used in DPPH tests. For DPPH analysis, 0.26 mM DPPH (1,1-diphenyl-2-picryl-hydrazil) solution was prepared. About 300 μL fruit extract was supplemented with 2700 μL ethyl alcohol and 1 mL DPPH solution. The resultant mixture was vortexed and kept in the dark for 30 min. Following the incubation of the samples, absorbance readings were performed in a spectrophotometer at 517 nm. Trolox (10–100 $\mu\text{mol L}^{-1}$) equivalent (TE) of resultant absorbance readings were calculated and results were expressed in $\mu\text{mol TE kg}^{-1}$.

FRAP Test

Modified Benzie and Strain (1996) method was used in FRAP tests. About 150 μL fresh fruit extract was supplemented with 1.1 mL phosphate buffer and 1.25 mL potassium ferric cyanide, then with 1.25 mL TCA and 0.25 mL $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$. The resultant solution was vortexed and absorbance readings were performed in a spectrophotometer at 700 nm. Results were expressed in $\mu\text{mol TE kg}^{-1}$.

Fatty Acid Composition

For fatty acid analyses in gas chromatography (GC), initially, fatty acid methyl esters (FAMES) were prepared from the total oil content of hazelnut through the modified version of the following procedure. At first, 1 mL total oil was placed into a tube and supplemented with 2 mL H_2SO_4 (dissolved in 10% methanol). The mixture was incubated at 57°C and 140 rpm for 40 minutes and cooled off at room temperature. Incubated samples were supplemented with 1 mL NaHCO_3 (2%) and vortexed. Following vortexing, samples were supplemented with 1 mL hexane and shaken for a minute. The upper hexane layer including FAMES was transferred to a new tube and preserved at -20°C for further GC analyses. Samples were filtered through a 0.2 μm nylon membrane filter and analyzed in Shimadzu GC-20A (Kyoto, Japan) equipped with a flame-ionization detector. In GC analyses, Stabilwax DA column (0.25 mm \times 0.25 μm 60 m) was used, the flow rate was 3 mL/min and carrier gas was nitrogen. The initial column temperature was 100°C for 4 minutes and the column was gradually heated up to 245°C ($20^\circ\text{C}/\text{min}$) and kept at this temperature for 40 minutes. Then column temperature was raised to 250°C and hold at temperature for 5 minutes. Split injection (1:20) was performed at 250°C . Fatty acid peaks were defined by reference standards comparing retention times. Results were processed

with the aid of “GC Solution” software supplied by the manufacturer of GC and relative percentages of fatty acids were identified.

Statistical Analysis

Experimental data were subjected to statistical analyses with the aid of SAS Version 9.1 software. Significant means were compared with the aid of Tukey’s test at 5% level ($P < .05$).

Results and Discussion

Protein and oil ratios of hazelnut cultivars are provided in Table 1. Protein ratios varied between 12.91% and 21.61% with the greatest value in the ‘Yuvarlak Badem’ cultivar. The protein ratio of new hazelnut cultivars was identified as 16.08% for ‘Allahverdi,’ 14.39% for ‘Okay 28,’ and 18.87% for ‘Giresun Melezi.’ ‘Okay 28,’ and ‘Giresun Melezi’ cultivars were developed through hybrids breeding from the parents ‘Tombul’ and ‘Kargalak’ cultivars. However, while ‘Giresun Melezi’ had quite a high protein ratio, ‘Okay 28’ had a remarkably low protein ratio. Balık et al. (2016) reported protein ratios of Turkish hazelnut cultivars as between 14.21% (İncekara) and 20.5% (Kara) and Köksal et al. (2006) reported protein ratios of hazelnut cultivars as between 11.7% (Kalınkara) and 20.8% (Yuvarlak Badem). Pala et al. (1996) reported that 100 g hazelnut could meet 22% of the daily protein need of an individual. In this sense, ‘Giresun Melezi’ could be preferred to meet the protein needs of consumers. Present findings on protein ratios comply with the findings of previous studies.

Oil ratios varied between 57.2% (Giresun Melezi) and 72.6% (Sivri). Among the investigated hazelnut cultivars, ‘Giresun Melezi’ and ‘Allahverdi’ cultivars had relatively lower oil ratios as compared to the other cultivars. However, ‘Okay 28’ had a significantly high oil ratio (71.8%). Hazelnut oil is an important source of nutrient, thus ‘Okay 28’ cultivar could be considered as an important cultivar for oil production. Balık et al. (2016) reported oil ratios of Turkish hazelnut cultivars as between 55% (Yassı Badem) and 63.3% (Kuş) and Göncüoğlu Taş and Gökmen (2015) reported oil ratios of hazelnut cultivars as between 60.4% (Foşa) and 69.9% (Acı). Unsaturated fatty acids of hazelnuts constitute a valuable source of oil for human nutrition (Garcia et al., 1994). Such

Table 1. Protein and oil ratio of Turkish hazelnut cultivars.

Cultivars	Protein ratio (%)	Oil ratio (%)
Tombul	16.35 ± 0.08*-d	64.8 ± 0.20-f
Palaz	13.80 ± 0.11-l	64.6 ± 0.15-f
Çakıldak	16.02 ± 0.11-e	61.0 ± 0.12-ij
Foşa	14.94 ± 0.07-hı	64.2 ± 0.04-f
Mincane	13.99 ± 0.08-kl	61.8 ± 0.21-hı
Sivri	14.66 ± 0.05-ij	72.6 ± 0.34-a
İncekara	13.93 ± 0.09-l	66.4 ± 0.25-e
Kalınkara	14.05 ± 0.08-kl	60.6 ± 0.01-ij
Cavcava	16.75 ± 0.06-cd	63.2 ± 0.09-g
Yuvarlak Badem	21.61 ± 0.07-a	57.6 ± 0.10-k
Yassı Badem	15.22 ± 0.05-gh	70.2 ± 0.06-b
Kargalak	14.57 ± 0.10-ij	66.2 ± 0.01-e
Kara	nd.	68.8 ± 0.08-cd
Uzunmusa	14.48 ± 0.06-j	63.8 ± 0.15-g
Kuş	17.00 ± 0.10-c	62.0 ± 0.21-h
Acı	15.37 ± 0.10-fg	60.8 ± 0.27-j
Kan	16.54 ± 0.11-d	63.2 ± 0.09-g
Allahverdi	16.08 ± 0.45-ef	68.0 ± 0.13-d
Okay 28	14.39 ± 0.09-jk	71.8 ± 0.04-a
Giresun Melezi	18.87 ± 0.04-b	57.2 ± 0.09-k
Turkish hazel (<i>C. colurna</i>)	12.91 ± 0.09-m	69.4 ± 0.22-c

*: mean ± standard deviation. nd: not determined. Means indicated with the same letter in the same column are not significantly different according to Tukey’s test at $P < 0.05$.

differences in protein and oil ratios of hazelnut cultivars were mainly attributed to differences in genetics and ecological conditions (Balık and Beyhan, 2019b; Beyhan et al., 2007), cultural and technical practices (Yılmaz et al., 2019), and harvest times (Farinelli et al., 2001; Seyhan et al., 2007). Pollinator cultivars were also reported to have significant effects on protein ratios of walnuts (Golzari et al., 2016) and chestnuts (Xuhui et al., 2016). Saura Calixto et al. (1988) in Kodad and Company (2008) indicated that oil accumulation occurred when the cotyledons matured, thus both main and pollinator cultivar might have significant effects on oil ratio and composition. Similarly, it was reported that pollinator cultivars caused significant changes in oil ratios of chestnuts (Xuhui et al., 2016) and walnuts (Golzari et al., 2016).

Fatty acid compositions of Turkish hazelnut cultivars are provided in Table 2. Oleic acid was the major fatty acid and it was, respectively, followed by linoleic, palmitic, stearic, and palmitoleic acid. Oleic acid contents of hazelnut cultivars varied between 63.35% and 85.57% with the greatest value in 'Kargalak' cultivar. There were significant differences in oleic acid contents of hazelnut cultivars. Oleic acid content was identified as 78.19% in the 'Tombul' cultivar, which was mostly preferred by the consumers, as 82.39% in 'Palaz,' 80.03% in 'Çakıldak' and 80.70% in 'Foşa' cultivar with a rapid spread in recent years. The oleic acid content of 'Okay 28,' 'Giresun Melezi' and 'Allahverdi' was respectively identified as 82.19, 69.32%, and 74.71%. Balık et al. (2016) reported oleic acid contents of Turkish hazelnut cultivars as between 61.7% and 81.4% and Köksal et al. (2006) reported oleic acid contents of hazelnut cultivars as between 74.2% and 82.8%. It was reported that the nutritional and chemical composition of hazelnuts might vary with the cultivars, ecology, and cultural practices (Balık and Beyhan, 2019a; Köksal, 2002).

Linoleic acid contents of the hazelnut cultivars varied between 4.70% and 14.19% with the greatest value in the 'Yuvarlak Badem' cultivar. The differences in linoleic acid contents of the hazelnut cultivars were found to be significant. Linoleic acid content was 5.44% in 'Allahverdi,' 6.05% in 'Okay 28,' and 12.17% in 'Giresun Melezi.' Such differences were mainly attributed to the genetics of the cultivars and environmental conditions (Balık and Beyhan, 2019b). Balık et al. (2016) reported linoleic acid contents of Turkish hazelnut cultivars as between 6.3% and 21% and Köksal et al. (2006) reported linoleic acid contents of hazelnut cultivars as between 9.82% and 18.7%. Present linoleic acid

Table 2. Fatty acids of Turkish hazelnut cultivars.

Cultivars	Fatty acids (%)				
	Oleic acid	Linoleic acid	Palmitic acid	Stearic acid	Palmitoleic acid
Tombul	78.19 ± 0.03*-e	9.83 ± 0.01-f	7.71 ± 0.01-d	4.06 ± 0.03-hı	0.20 ± 0-gh
Palaz	82.39 ± 0.61-b	5.91 ± 0.07-mn	7.34 ± 0.16-fg	4.15 ± 0.52-h	0.20 ± 0-gh
Çakıldak	80.03 ± 0.01-cd	7.40 ± 0.01-ı	7.46 ± 0.04-ef	4.89 ± 0.03-d	0.23 ± 0-fg
Foşa	80.70 ± 0.02-c	7.98 ± 0.05-h	6.69 ± 0.03-kl	4.48 ± 0.06-ef	0.15 ± 0.01-ij
Mincane	76.90 ± 0.04-f	10.72 ± 0.01-e	7.67 ± 0.02-d	4.58 ± 0-e	0.13 ± 0.02-jk
Sivri	81.97 ± 0.02-b	6.83 ± 0.01-jk	7.20 ± 0.01-ghı	3.89 ± 0-ij	0.10 ± 0.01-k
İncekara	63.35 ± 1.00-k	5.47 ± 0.21-o	19.9 ± 0.51-a	11.22 ± 0.26-a	0.05 ± 0.01-l
Kalinkara	76.76 ± 0.02-fg	13.41 ± 0.02-b	6.58 ± 0.03-lm	3.07 ± 0.03-l	0.18 ± 0.01-hı
Cavcava	79.70 ± 2.39-cd	6.50 ± 0.26-l	7.03 ± 0.25-ij	6.60 ± 2.91-c	0.17 ± 0-hij
Yuvarlak Badem	74.07 ± 0.01-ı	14.19 ± 0.02-a	8.18 ± 0.01-c	3.25 ± 0.04-kl	0.31 ± 0-de
Yassı Badem	79.48 ± 0.01-d	8.92 ± 0-g	6.79 ± 0.01-k	4.23 ± 0.01-gh	0.58 ± 0.01-c
Kargalak	85.57 ± 0.74-a	4.70 ± 0.03-p	7.06 ± 0.21-hij	2.55 ± 0.99-n	0.13 ± 0.01-jk
Kara	73.78 ± 8.19-ı	5.73 ± 0.63-n	6.55 ± 0.73-lm	3.86 ± 0.44-j	10.08 ± 9.98-a
Uzunmusa	77.60 ± 0.05-ef	12.87 ± 0.02-c	7.26 ± 0-fgh	1.93 ± 0.02-o	0.34 ± 0.01-d
Kuş	75.70 ± 1.61-gh	12.98 ± 1.17-c	7.77 ± 0.42-d	3.28 ± 0.01-k	0.27 ± 0.04-ef
Acı	79.70 ± 2.36-cd	6.70 ± 0.19-k	6.87 ± 0.19-jk	6.62 ± 2.76-c	0.11 ± 0.01-jk
Kan	82.19 ± 0.09-b	6.32 ± 0.03-l	7.07 ± 0.09-hij	4.23 ± 0.03-gh	0.19 ± 0-ghı
Allahverdi	74.71 ± 8.07-hı	5.44 ± 0.64-o	6.46 ± 0.69-m	3.36 ± 0.44-k	10.02 ± 9.84-b
Okay 28	82.19 ± 0.01-b	6.05 ± 0-m	7.23 ± 0-ghı	4.36 ± 0.01-fg	0.18 ± 0.01-hı
Giresun Melezi	69.32 ± 0.01-j	12.17 ± 0.01-d	10.34 ± 0.02-b	7.62 ± 0.01-b	0.54 ± 0.01-c
Turkish hazel (<i>C. colurna</i>)	82.16 ± 0-b	6.90 ± 0.02-j	7.57 ± 0-de	2.81 ± 0.02-m	0.57 ± 0-c

*: mean ± standard deviation. Means indicated with the same letter in the same column are not significantly different according to Tukey's test at

contents were lower than the literature findings. Bonvehi and Cool (1993) conducted a study about oil ratios, stability, and fatty acids of Catalonia hazelnut cultivars and reported that linoleic acid was the major fatty acid in the fruit set period, but oleic acid contents increased in the ripening period and became the major fatty acid. High oleic/linoleic acid ratio of fatty acids indicates oil stability and resistance against deterioration (Kester et al., 1993) and nutritional value (Vezvaei and Jackson, 1996).

Palmitic acid contents of the hazelnut cultivars varied between 6.46% and 19.9% with the greatest value in the 'İncekara' cultivar. Although 'İncekara' does not have a high commercial value, it is used as an ideal pollination since it generates plenty of catkins and round nuts. İncekara has the longest pollination duration and the best pollen quality, thus it is commonly used for pollination of 'Tombul' cultivar with the best quality. 'Allahverdi' cultivar, the newest registered hazelnut cultivar developed through selection breeding, had the lowest palmitic acid content. Balık et al. (2016) reported palmitic acid contents of Turkish hazelnut cultivars as between 4.07% and 12.9%; Köksal et al. (2006) as between 4.72% and 5.87%, and Göncüoğlu Taş and Gökmen (2015) as between 4.59% and 7.08%.

Stearic acid contents of the hazelnut cultivars varied between 1.93% and 11.2% with the greatest value again in 'İncekara' as it was in palmitic acid. Balık et al. (2016) reported stearic acid contents of Turkish hazelnut cultivars as between 2.1% and 5.9%, Köksal et al. (2006) as between 0.86% and 2.49%, and Göncüoğlu Taş and Gökmen (2015) as between 2.16% and 4.61%. Except for the 'İncekara' cultivar, the stearic contents of the other cultivars were similar to the literature findings.

Palmitoleic acid contents of the hazelnut cultivars varied between 0.05% and 10.08%. The palmitic acid content of hazelnut is generally reported as <1%. However, quite high values were seen in 'Kara' (10.08%) and 'Allahverdi' (10.02%) cultivars of the present study. Except for the 'Kara' and 'Allahverdi' cultivars, palmitoleic acid contents of the other cultivars were similar to the literature findings. Balık et al. (2016) reported palmitoleic acid contents of Turkish hazelnut cultivars as between 0.01% and 0.16% and Köksal et al. (2006) reported palmitoleic acid contents of hazelnut cultivars as between 0.22% and 0.48%.

Total phenolic contents of hazelnut cultivars are provided in Table 3. Among hazelnut cultivars, *C. colurna* L. had the lowest total phenolic compounds with 2803.5 mg GAE kg⁻¹, while 'Allahverdi' had the highest with 11300.6 mg GAE kg⁻¹. Among the hybrid cultivars, 'Okay 28' had total phenolics of 5121.8 mg GAE kg⁻¹ and 'Giresun Melezi' had total phenolics of 4778.0 mg

Table 3. Total phenolics, total flavonoids, and antioxidant activity of Turkish hazelnut cultivars.

Cultivars	Total phenolics (mg GAE kg ⁻¹)	Total flavonoids (mg QE kg ⁻¹)	DPPH (μmol TE kg ⁻¹)	FRAP (μmol TE kg ⁻¹)
Tombul	4483.3 ± 0.12 ^{a-k}	340.1 ± 0.01-b	2465.1 ± 0.13-cd	12189.3 ± 0.13-g
Palaz	4689.6 ± 0.09-ı	131.8 ± 0.15-h	2416.2 ± 0.15-ef	12821.3 ± 0.16-g
Çakıldak	7410.6 ± 0.14-c	126.9 ± 0.25-h	2536.5 ± 0.13-a	19502.8 ± 0.14-cd
Foşa	3412.6 ± 0.21-n	73.4 ± 0.03-m	1736.9 ± 0.14-j	2979.6 ± 0.22-o
Mincane	3422.4 ± 0.22-n	82.7 ± 0.04-l	1859.3 ± 0.16-ı	5236.9 ± 0.07-l
Sivri	6172.9 ± 0.23-d	165.7 ± 0.02-f	2489.6 ± 0.12-bc	12460.1 ± 0.06-g
İncekara	3432.2 ± 0.13-n	217.3 ± 0.10-e	2293.8 ± 0.14-h	3972.8 ± 0.12-mn
Kalinkara	4365.4 ± 0.20-l	125.9 ± 0.21-h	2373.3 ± 0.13-g	20496.0 ± 0.17-b
Cavcava	3451.9 ± 0.25-n	88.1 ± 0.07-kl	1298.3 ± 0.15-l	10383.4 ± 0.05-h
Yuvarlak Badem	3835.0 ± 0.17-m	235.5 ± 0.23-d	2391.7 ± 0.13-fg	26996.9 ± 0.23-a
Yassı Badem	5357.6 ± 0.11-f	92.0 ± 0.03-k	1481.9 ± 0.12-k	3160.2 ± 0.11-no
Kargalak	10662.1 ± 0.22-b	130.4 ± 0.12-h	2475.3 ± 15-bcd	14807.7 ± 0.17-f
Kara	5485.3 ± 0.13-e	110.2 ± 0.07-ı	2516.1 ± 0.13- ab	8126.2 ± 0.06-j
Uzunmusa	4561.9 ± 0.23-j	222.2 ± 0.02-e	2438.6 ± 0.21-de	9299.9 ± 0.12-ı
Kuş	5072.7 ± 0.14-g	107.3 ± 0.11-ıj	2518.2 ± 0.14-ab	7042.7 ± 0.25-k
Acı	4336.0 ± 0.12-l	108.3 ± 0.16-ıj	2450.8 ± 0.22-cde	18870.8 ± 0.14-d
Kan	3893.9 ± 0.17-m	650.0 ± 0.25-a	2420.2 ± 0.02-ef	16523.2 ± 0.04-e
Allahverdi	11300.6 ± 0.25-a	278.2 ± 0.06-c	2510.0 ± 0.04- ab	20315.4 ± 0.09-bc
Okay 28	5121.8 ± 0.22-g	147.1 ± 0.18-g	2375.4 ± 0.19-fg	17335.8 ± 0.16-e
Giresun Melezi	4778.0 ± 0.15-h	102.4 ± 0.04-j	2412.1 ± 0.08-efg	5868.9 ± 0.03-l
Turkish hazel (<i>C. colurna</i>)	2803.5 ± 0.21-o	73.4 ± 0.31-m	1220.8 ± 0.11-m	4243.7 ± 0.07-m

*: mean ± standard deviation. Means indicated with the same letter in the same column are not significantly different according to Tukey's test at $P < 0.05$.

GAE kg⁻¹. Göncüoğlu Taş and Gökmen (2015) reported total phenolics of Turkish hazelnut cultivars as between 5190 mg GAE kg⁻¹ (Foşa) and 20300 mg GAE kg⁻¹ (Çakıldak); Ghirardello et al. (2013) reported total phenolics of Italian 'Nocciola Piemonte PGI' cultivar as 1400 mg GAE kg⁻¹. Özyurt and Otles (2018) reported that total phenolics of hazelnut skin varied with the extraction method and varied as between 1413.32 and 2057.72 GAE mg GAE g⁻¹ or between 3072.7 and 4533.98 mg CE g⁻¹.

Total flavonoid contents of the hazelnut cultivars are provided in Table 3. The lowest total flavonoid content was obtained from 'Foşa' and *C. colurna* L. (73.4 mg QE kg⁻¹) and the greatest value was obtained from 'Kan' cultivar (650 mg QE kg⁻¹). *C. colurna* L. species with a natural spread in Northwest Anatolia have low flavonoid content and low market value, thus they are mostly used as rootstock in hazelnut cultivation. However, 'Foşa' is a high productivity cultivar, thus quite widespread recently and new hazelnut plantations are established with 'Foşa' cultivar in Central and Western Black Sea regions. 'Kan' hazelnut cultivar with the greatest flavonoid content bears *C. maxima* gene, a form of *C. avellana*, but it is rarely seen in grower orchards. 'Kan' has a red testa and can easily be distinguished from the other hazelnut cultivars. 'Tombul' cultivar, mostly preferred by the consumers as roasted, had a total flavonoid content of 340.1 mg QE kg⁻¹ and 'Allahverdi', a new cultivar, had a total flavonoid content of 278.2 mg QE kg⁻¹. 'Allahverdi' hazelnut cultivar, with a high total phenolic and flavonoid content, is prominent as an appetizer. Göncüoğlu Taş and Gökmen (2015) reported total flavonoid contents of Turkish hazelnut cultivars as between 30.9 mg CE/g (Foşa) and 112.4 mg CE/g (Uzunmusa).

Total antioxidant capacity of hazelnut cultivars determined based on DPPH and FRAP methods are provided in Table 3. DPPH total antioxidant capacities of hazelnut cultivars varied between 1220.8 µmol TE kg⁻¹ (*C. colurna* L.) and 2536.5 µmol TE kg⁻¹ (Çakıldak). FRAP total antioxidant capacities varied between 2979.6 µmol TE kg⁻¹ (Foşa) and 26996.9 µmol TE kg⁻¹ (Yuvarlak Badem). 'Çakıldak' cultivar with the greatest DPPH antioxidant capacity the second most widely cultivated cultivar of Turkey after the Tombul cultivar. Time of leaf bud burst of 'Çakıldak' is late because of this fact it is mostly preferred at high altitudes with the risk of spring late frosts. 'Yuvarlak Badem' cultivar with the greatest FRAP antioxidant capacity has limited production, but it is among the earliest cultivars served to markets because of early harvest maturity. It is mostly cultivated in the Western Black Sea Region, consumed as inshell and finds a place in markets of Marmara region from the middle of July. Göncüoğlu Taş and Gökmen (2015) reported the total antioxidant capacity of Turkish hazelnut cultivars as between 5.4 and 8.8 mmol TE/g. Özyurt and Otles (2018) reported DPPH total antioxidant capacity of nut skin as between 148.27 and 155.67 mg GAE/kg. Ghirardello et al. (2013) reported the FRAP antioxidant capacity of hazelnuts as between 0.14 and 0.94 mmol-g⁻¹. Güleşçi and Aygül (2016) indicated that antioxidant capacity and bioavailability varied with the cultivars, harvest time and method, storage or preservation temperature, light, climate and humidity, postharvest processes, and even consumptive habits of the individuals and society.

Conclusions

There are several studies conducted about the biochemical characteristics of Turkish hazelnut cultivars. However, fatty acid components, total phenolics, flavonoids, and antioxidant capacity of new hazelnut cultivars (Okay 28, Giresun Melezi and Allahverdi) were determined and compared with the values of other cultivars for the first time in the present study. Present findings revealed that there were significant differences in protein and oil ratios of Turkish hazelnut cultivars. Oleic, linoleic, palmitic, stearic, and palmitoleic acid values were able to be identified. Oleic acid, desired to be at high quantities in nuts, was the major fatty acid. High oleic acid contents increase the resistance of oil against deterioration and improve the nutritional value of the oil. Total phenolics, flavonoids, and antioxidant capacity of hazelnut cultivars were quite high. Among the new hazelnut cultivars, 'Okay 28' and 'Giresun Melezi' were found to be prominent for protein and oil ratio and 'Allahverdi' was found to be prominent for phenolics.

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Compliance With Ethical Standards

Conflict of Interest: The author declares that they have no conflict of interest.

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