

Determination of some physicochemical and biochemical parameters of hazelnut (*Corylus avellana* L.) cultivars

Necati ÇETİN¹ , Mehmet YAMAN² , Kevser KARAMAN^{3,*} , Bünyamin DEMİR⁴ 

¹Department of Biosystems Engineering, Faculty of Agriculture, Erciyes University, Kayseri, Turkey

²Department of Horticulture, Faculty of Agriculture, Erciyes University, Kayseri, Turkey

³Department of Agricultural Biotechnology, Faculty of Agriculture, Erciyes University, Kayseri, Turkey

⁴Department of Mechanical and Metal Technologies, Vocational School of Technical Sciences, Mersin University, Mersin, Turkey

Received: 31.05.2019 • Accepted/Published Online: 29.11.2019 • Final Version: 02.10.2020

Abstract: Hazelnut is one of the most popular nuts consumed by people; it has different cultivars in Turkey. The aim of the current study was to characterize some physicochemical characteristics, shape features, color, and biochemical properties of 6 standard and 3 local hazelnut cultivars grown in Turkey. The shape and size properties of the samples were determined using image processing techniques as an alternative to conventional measurement methods. Additionally, principal component analysis (PCA) was used to classify the hazelnut samples in terms of the biochemical parameters of the hazelnut cultivars. According to the findings, the highest crude oil (63.25%) and lowest protein contents (13.63%) were observed in the Kalınkara cultivar. Oleic and linoleic acids were the major fatty acids for all hazelnut samples. While local Devediş and standard Çakıldak cultivars had the highest oleic acid levels, the highest linoleic acid level was observed for the Dağ findığı cultivar. The cultivars of Foşa had the highest Zn and Mn, while the highest Cu was found in the Tombul cultivar. The greatest surface and projected areas were calculated for the Kara findık and Dağ findığı samples, while the greatest hardness value was measured for the Devediş cultivar. PCA revealed some positive and negative correlations between the physicochemical and biochemical parameters. The present analyses revealed significant correlations between hardness and internal shell b* values and between Cu content and internal L*. Such correlations should be taken into consideration in food processing applications and machine design for these hazelnut cultivars.

Key words: PCA, shape, size, fatty acids, image processing

1. Introduction

Hazelnut (*Corylus avellana* L.) is a member of the *Betulaceae* family and it is one of the most consumed tree nuts worldwide. Hazelnut trees are largely distributed in Turkey, Italy, Spain, Portugal, France, and in some parts of the USA (Ozkutlu et al., 2011). Turkey is the leading hazelnut producer in the world and alone constitutes about 63% (675.000 tons in 2017) of world production (FAOSTAT, 2019). Hazelnut plays an important role in human diets due to its rich fat, protein, carbohydrate, vitamin, mineral, dietary fiber, and phenolic compound contents (Cosmulescu et al., 2013).

Lipids are the major constituent (60%) of hazelnut kernels; thus, hazelnut kernels are used in various industries. It has also been reported that hazelnut kernels are rich in copper and manganese; thus, they are commonly used in the daily diets of adults (Cosmulescu et al., 2013). Alasalvar et al. (2009) stated that a daily amount of 42.5 g of hazelnut provided 44.4%–83.6% of the recommended copper and 40.1%–44.8% of the recommended manganese intake for

adults. In addition, Ciemnińska-Żytkiewicz et al. (2015) stated that hazelnuts were a good source of fiber and phenolics, which are considered significant quality criteria. Hazelnut fruits are different in terms of morphological characteristics and nutrient composition, and they exhibit quite broad variation among the genotypes (Ferreira et al., 2010; Rovira et al., 2005).

In recent years, researchers have largely focused on physical properties of agricultural products to investigate the relationship between the physical and chemical parameters (Ercişli et al., 2011; 2012; Sayıncı et al., 2015a; 2015b; Bahrami et al., 2017; Demir et al., 2018; 2019). For agricultural products, appearance, shape, and size are important parameters for engineered systems. Such parameters also greatly influence consumer preferences. Physical properties of agricultural commodities are largely used in various processes and operations such as storage, classification, drying, packaging, sizing, and transportation of these products.

* Correspondence: kevserkaraman@erciyes.edu.tr

Color is a significant parameter in designing mechanical equipment to be used in the sorting and grading processes of agricultural products (Mohsenin, 1984; Pathare et al., 2013; Mahawar et al., 2017). In addition, shell thickness, kernel size, and kernel color are indicated as significant quality properties of the nuts (Warmund, 2008). Color is one of the main criteria for the appearance of the product and it represents a basic attribute for the selection of storage, marketing, utilization, and the entire market production chain (Antonucci et al., 2012). Kaleoğlu et al. (2004) reported that the white kernel color is important because the seed coat of the hazelnut after toasting adds a bitter taste, which causes a decrease in the overall preference for the product; thus, kernels should be produced by removing the testa to provide a uniform white color.

Shape and dimensional characteristics are commonly used to assess quality properties and to correlate them with other chemical quality parameters (Sadri et al., 2007; Sun et al., 2012; Sayinci et al., 2012; Bayrakdar et al., 2015; Demir et al., 2018; Alibabic et al., 2018; Gunduz and Ozbay, 2018). Shape and size are the primary designators of the variety and the primary indicators of quantity and quality (Brewer et al., 2007; Fıratlıgil-Durmuş et al., 2010; Costa et al., 2011; Milošević and Milošević, 2017; Sorkheh et al., 2018). On the other hand, color, flavor, and texture are also significant quality characteristics of fruits and vegetables; thus, they constitute the major factors related to sensory perception and consumer preference for foodstuffs (Oey et al., 2008; Titova et al., 2015).

The aim of the present work was to determine some physicochemical, color, and biochemical properties, as well as shape/dimension-based characteristics, of local and standard hazelnut cultivars of Turkey, and classify them using principal component analyses depending on their studied parameters. As a novelty, an image-based processing approach, which is a popular technique for the determination of some shape and dimensional characteristic parameters of food samples, was used to calculate the related physical parameters (mass, volume, surface area, length, width, sphericity, etc.) instead of conventional measurement procedures.

2. Materials and methods

2.1. Materials

In the current study, 6 standard (Çakıldak, Kalınkara, Kara findık, Foşa, Tombul, and Palaz) and 3 local (Devediş, Dağ findığı, and Hanımeli) hazelnut cultivars commonly consumed in Turkey were used as the experimental material. Hazelnut samples were collected from the orchards in Giresun Province (Turkey) during the regular harvest times. Images of the collected hazelnut cultivars are presented in Figure 1.



Figure 1. Images of the studied hazelnut cultivars.

2.2. Proximate composition

Dry matter, ash, protein, and crude oil content of the hazelnut samples were determined according to the methodologies in AOAC (2000).

2.3. Fatty acid composition

Fatty acid methyl esters (FAME) of hazelnut oils were prepared using a 1-step extraction–transesterification process (Sukhija and Palmquist, 1988). The FAME composition for a 0.6-µL sample at a split ratio of 1:50 was generated using a gas chromatography device (Schimadzu, GC 2010 Plus, Kyoto, Japan) equipped with a flame ionization detector (Schimadzu, Kyoto, Japan), a 100-m fused silica capillary column (i.d. 0.25 mm), and H₂ as the carrier gas. The FAMES were separated using a temperature gradient program (Chilliard et al., 2013), and the peaks were identified based on comparison of retention times with authentic standards (Supelco #37, Supelco Inc., Bellefonte, PA, USA; L8404 and O5632, Sigma-Aldrich, St. Louis, MO, USA).

2.4. Microelement composition

To prepare the samples for the microelement analysis, 0.5 g of milled hazelnut sample was weighed and 10 mL of nitric + perchloric acid mixture was incorporated into the sample; the samples were then subjected to wet ashing until 1 mL of sample remained. Following the ashing procedure, the samples were diluted with distilled water and analyzed in an ICP-OES spectrometer (Perkin-Elmer, Optima 4300 DV, ICP/OES, Shelton, CT, USA). Fe, Mn, Zn, and Cu content of the samples were determined (Mertens, 2005).

2.5. Color properties

Color properties of the samples were determined using a chroma meter (CR-400; Konica Minolta, Japan). The measurements were performed both over the outer surface and on the inside of the shells. The values of CIE-L*, a*, and b* were recorded for all samples; these parameters were also used to calculate color index (CI), hue angle (h*), and chroma (C*) values for the studied samples (McGuire, 1992; Demir, 2018).

2.6. Image acquisition and processing

The mass of each hazelnut sample was measured using a precise balance (± 0.001 g). In order to reveal the size and shape of the hazelnut images, an acquisition system described in the study of Kara et al. (2013) was used. This system consists of a digital SLR camera (Nikon D300, Tokyo, Japan) and illumination equipment. The images of the hazelnut cultivars were recorded in a dark room to acquire an image without a shadow on the background. The samples were carefully placed on a white fiberglass surface with 2 orientations (horizontal and vertical). Putty was used to hold the samples in a stable position in the 2 orientations on the fiberglass. The camera was vertically positioned at a constant height of approximately 50 cm. For each of the hazelnut cultivars, 75 samples from the collected hazelnut cultivars were randomly selected for the image processing analysis.

The unit conversion ratio of the images was determined with the aid of a ruler on the fiberglass plate as 38.7 pixels/mm. The captured images were transferred to a computer and saved as image files with the *.tiff extension for descriptive analysis. SigmaScan[®] Pro 5.0 software was used in order to process the hazelnut images. The length (L, mm), width (W, mm), thickness (T, mm), projected area (PA, mm²), equivalent diameter (mm), perimeter (mm), shape factor (mm), aspect ratio, and roundness at both the horizontal and vertical orientation of each hazelnut were determined using image processing operations.

The equations used for calculation of the volume (mm³), shape index (SI), roundness (R), geometric mean diameter (D_g, mm), surface area (S, mm²), and sphericity (ϕ , %) are given in Table 1 (Sayinci et al., 2015a; Demir et al., 2018).

2.7. Hardness properties

Hardness values of the samples were measured by a texture analyzer (TA.XT Plus, Stable Micro System Ltd., Surrey, UK) using a 100 kg load cell and a cylindrical probe (36 mm P/36). Measurement conditions were as follows: pre-test speed = 2.0 mm/s; test speed = 2.0 mm/s; post-test speed = 10 mm/s; distance = 2.5 mm. All measurements were replicated 5 times.

2.8. Statistical analysis and cultivar classification

Principal component analysis technique was used to classify the samples according to the same analyzed parameters. PCA was performed using XLSTAT Software (XLSTAT, Addinsoft, New York, NY, USA). Correlations among the biochemical and physicochemical data were determined using Pearson correlations with XLSTAT Software. Statistical analyses of the samples were carried out using SAS statistical software (SAS, 2000). One-factor variance analysis was applied to the assessed parameters, and the differences among the means were tested with Tukey’s multiple comparison test at 95% significance level.

3. Results and discussion

In this study, 6 standard and 3 local hazelnut cultivars were evaluated in terms of biochemical composition, physical (shape, size, and mechanical), and color properties. Table 2 shows the proximate composition of hazelnut cultivars. As expected, crude oil was the greatest compound for all samples. Crude oil contents varied between 57.25% and 63.25%; the highest oil content was determined for Kalinkara, while the lowest value was in the Dağ findiği cultivar. Alasalvar et al. (2010) reported that the crude

Table 1. Equations used to calculate the size and shape properties of the hazelnut cultivars.

Variables	Equations*	Literature
Shape index (SI)	$SI = (2 \times L) / (W + T)$	Ozkan and Koyuncu, 2005
Volume (V, mm ³)	$V = (\pi / 6) \times D_g^3$	Aydın, 2003
Surface area (S, mm ²)	$S = \pi D_g^2$	Sayinci et al., 2015a
Sphericity (ϕ)	$\phi = (D_g / L) \times 100$	Mohsenin, 1986
Geometric mean diameter (D _g , mm)	$D_g = (L \times W \times T)^{(1/3)}$	Mohsenin, 1986
Roundness (R)	$R = A_p / A_c$	Mohsenin, 1980

*L: Length (mm); W: Width (mm); T: Thickness (mm); D_g: Geometric mean diameter (mm); A_p: Projected area (mm²) A_c: The biggest circular area (mm²).

oil contents of 18 hazelnut cultivars were in the range of 57.85%–68.31%; the values determined in this study are quite similar to those earlier ones. In contrast to crude oil contents, the highest protein content was observed in the Dağ findığı cultivar ($P < 0.05$). Similar variations were not observed in ash contents. Koksall et al. (2006) investigated the chemical composition of 17 different hazelnut cultivars and reported the crude oil contents as between 56.07% and 68.52%, with the highest value in the Kalıncara cultivar, as in the current study. Additionally, the lowest protein content (11.7%) was reported by the same researchers for

the Kalıncara cultivar (Koksall et al., 2006), similar to the present study's results. The fatty acid composition of the hazelnut cultivars is tabulated in Table 3. Oleic acid was the major fatty acid for all cultivars; the highest oleic acid values, 85.11% and 85.08%, were observed in Devediş and Çakıldak, respectively. Linoleic acid was the second most abundant fatty acid for the samples, with the highest value (12.17%) in the Dağ findığı cultivar. It was observed that palmitic acid was the third most abundant fatty acid; Kalıncara was the cultivar having the highest palmitic acid level. On the other hand, the Kara findık cultivar

Table 2. Proximate composition of the hazelnut cultivars.

Cultivars	Dry matter (%)	Ash (%)	Crude protein (%)	Crude oil (%)
Devediş	97.40 ± 0.30 ^{abc}	2.70 ± 0.50 ^a	17.85 ± 0.66 ^c	60.80 ± 0.40 ^c
Çakıldak	97.21 ± 0.20 ^{bc}	2.22 ± 0.02 ^{bcd}	19.52 ± 0.36 ^b	60.80 ± 0.40 ^c
Kalıncara	98.25 ± 0.14 ^a	1.89 ± 0.09 ^d	13.63 ± 0.32 ^e	63.25 ± 0.25 ^a
Dağ findığı	96.90 ± 0.20 ^{dc}	2.59 ± 0.01 ^{ab}	22.53 ± 1.65 ^a	57.25 ± 0.05 ^e
Kara Findık	97.11 ± 0.30 ^{bcd}	2.19 ± 0.20 ^{bcd}	17.35 ± 0.18 ^c	61.85 ± 0.25 ^b
Foşa	97.21 ± 0.00 ^{bc}	2.19 ± 0.01 ^{bcd}	19.29 ± 0.31 ^b	59.50 ± 0.00 ^d
Tombul	97.95 ± 1.24 ^{ab}	2.48 ± 0.28 ^{ab}	19.92 ± 0.25 ^b	60.55 ± 0.15 ^c
Hanımeli	96.91 ± 0.79 ^{dc}	1.98 ± 0.19 ^{cd}	17.43 ± 0.49 ^c	61.95 ± 0.65 ^b
Palaz	96.16 ± 0.04 ^d	2.34 ± 0.06 ^{abc}	15.31 ± 1.15 ^d	61.75 ± 0.35 ^b
F values	4.08**	4.55**	35.78*	78.66**

Different superscript letters in each column show the significant differences ($P < 0.05$).

*: significant at $P < 0.05$.

** : significant at $P < 0.01$.

Table 3. Fatty acid composition (%) of the hazelnut cultivars.

Cultivars	Stearic acid	Oleic acid	Linoleic acid	Gama linoleic acid	Arachidic acid	Eicosanoic acid	Palmitic acid	Palmitoleic acid
Devediş	2.68 ± 0.00 ^d	85.11 ± 0.01 ^a	6.58 ± 0.00 ^f	0.14 ± 0.00 ^{bc}	0.17 ± 0.00 ^b	0.12 ± 0.01 ^c	5.02 ± 0.00 ^{fg}	0.16 ± 0.00 ^{cd}
Çakıldak	3.02 ± 0.01 ^c	85.08 ± 0.02 ^a	6.16 ± 0.01 ^g	0.16 ± 0.00 ^a	0.15 ± 0.00 ^{cd}	0.22 ± 0.01 ^a	5.07 ± 0.07 ^f	0.12 ± 0.01 ^e
Kalıncara	2.65 ± 0.00 ^e	83.55 ± 0.01 ^b	6.07 ± 0.01 ^h	0.15 ± 0.01 ^{abc}	0.13 ± 0.01 ^e	0.10 ± 0.01 ^d	7.06 ± 0.02 ^a	0.28 ± 0.00 ^a
Dağ findığı	1.76 ± 0.01 ^g	80.36 ± 0.01 ^h	12.17 ± 0.02 ^a	0.13 ± 0.02 ^c	0.18 ± 0.01 ^a	0.19 ± 0.01 ^b	5.04 ± 0.04 ^{fg}	0.14 ± 0.01 ^{de}
Kara Findık	6.33 ± 0.00 ^a	81.07 ± 0.01 ^g	6.04 ± 0.01 ^h	0.16 ± 0.02 ^{ab}	0.15 ± 0.00 ^c	0.22 ± 0.01 ^a	5.86 ± 0.02 ^c	0.15 ± 0.01 ^{cd}
Foşa	2.60 ± 0.01 ^f	83.02 ± 0.00 ^c	7.64 ± 0.00 ^e	0.14 ± 0.00 ^{abc}	0.13 ± 0.00 ^{de}	0.22 ± 0.00 ^a	6.02 ± 0.02 ^b	0.20 ± 0.00 ^b
Tombul	2.60 ± 0.00 ^f	82.97 ± 0.01 ^d	8.02 ± 0.02 ^d	0.13 ± 0.00 ^c	0.14 ± 0.00 ^{cd}	0.22 ± 0.01 ^a	5.72 ± 0.00 ^d	0.16 ± 0.00 ^c
Hanımeli	2.66 ± 0.02 ^e	81.73 ± 0.04 ^f	10.06 ± 0.06 ^b	0.14 ± 0.00 ^{bc}	0.15 ± 0.00 ^c	0.09 ± 0.01 ^d	5.01 ± 0.01 ^g	0.15 ± 0.01 ^{cd}
Palaz	3.21 ± 0.00 ^b	81.96 ± 0.02 ^e	8.82 ± 0.01 ^c	0.14 ± 0.00 ^{bc}	0.15 ± 0.00 ^c	0.18 ± 0.00 ^b	5.36 ± 0.03 ^e	0.16 ± 0.01 ^{cd}
F values	46369.10*	21772.60*	21342.70*	3.23**	13.95*	85.36*	1393.41*	58.68*

Different superscript letters in each column show the significant differences ($P < 0.05$).

*: significant at $P < 0.05$.

** : significant at $P < 0.01$.

was quite different from the others in terms of stearic acid value. Koyuncu et al. (2005) investigated the fatty acid composition of Tombul, Palaz, and Kalinkara cultivars and reported oleic acid contents of 78.52%–79.30%; the values in the present study were greater than those earlier ones. In contrast, linoleic acid values of Tombul, Palaz, and Kalinkara cultivars (11.70%–13.06%) reported by Koyuncu et al. (2005) were greater than those of the present work (6.07%–8.82%) for the same cultivars. The remaining fatty acids (everything except for oleic, linoleic, palmitic, and stearic acids) constituted less than 1% of the total fatty acids. Alasalvar et al. (2010) indicated the ratio of oleic acid to linoleic acid to be an important quality indicator; higher values indicate better oxidative stability. According to Table 3, the highest ratio of oleic acid to linoleic acid was observed in Çakıldak, Kalinkara, and Karafındık cultivars. The authors have expressed that different factors such as cultivar, geographic origin, growing conditions, harvest maturity and time, fertilization, soil type, climate, latitude, and storage conditions could affect the fatty acid composition of hazelnuts (Parcerisa et al., 1995; 1999; Savage et al., 1997; Alasalvar et al., 2010).

In Table 4, microelement composition of the hazelnut cultivars is given. Significant differences were observed for Fe, Zn, Cu, and Mn contents of the cultivars ($P < 0.05$). The highest Zn and Mn contents were determined in the Foşa cultivar, and the highest Cu and Fe contents were determined in the Tombul sample. Simsek and Aykut (2007) investigated the microelement composition of hazelnut cultivars and reported Cu, Fe, and Zn contents to be in the range of 16.23–32.23 mg/kg, 31.60–51.60 mg/kg, and 22.03–44.03 mg/kg, respectively. Present values generally comply with those earlier ones. However,

Ozdemir and Akinci (2004) reported higher Mn and Cu contents than the present values.

Significant differences were observed in color parameters of the hazelnut cultivars ($P < 0.05$, Table 5). For external color parameters, Kalinkara and Palaz cultivars had the highest L^* (brightness) values among the samples. The greatest average a^* value was observed in Dağ findığı, and the lowest value was recorded for Hanımeli samples. The b^* values (yellowness) ranged between 13.15 and 26.95; the highest value was determined for the Hanımeli cultivar.

There were significant differences in physicochemical properties of the hazelnut cultivars ($P < 0.01$). The highest average mass values were observed in Karafındık and Dağ findığı samples, while the lowest values were observed in Hanımeli and Çakıldak samples (Table 6). Güner et al. (2003) reported that the mass of Çakıldak nut (1.34 g) was lower than that reported in this study (1.65 g). The greatest surface area and projected area (both horizontal and vertical orientations) were determined for Karafındık and Dağ findığı cultivars. In the present study, surface area values were determined to be 914.45–1369.13 mm², while Ozdemir and Akinci (2004) reported these values as 8.34–10.32 cm² for different hazelnut cultivars. Tombul (2612.2 mm³) and Çakıldak (2666.9 mm³) cultivars had the lowest volume values. In contrast, the volume value (1.92 cm³) of the Tombul cultivar reported by Aydın (2003) was lower than the present study's values. The highest average length and width values were measured for the Devediş and Kara findık cultivars. The greatest average thickness, geometric mean diameter, equivalent diameter, and perimeter (both horizontal and vertical orientations) were observed in Kara findık and Dağ

Table 4. Microelement composition (mg/kg) of the hazelnut cultivars.

Cultivars	Zn	Cu	Mn	Fe
Devediş	28.12 ± 0.40 ^c	15.59 ± 0.12 ^d	5.22 ± 0.10 ^f	14.62 ± 0.26 ^b
Çakıldak	15.70 ± 0.21 ^f	16.73 ± 0.15 ^b	9.11 ± 0.11 ^c	44.28 ± 0.65 ^b
Kalinkara	5.69 ± 0.21 ^g	8.56 ± 0.08 ^{fg}	3.41 ± 0.03 ^g	15.50 ± 0.35 ^g
Dağ findığı	18.30 ± 0.57 ^e	16.69 ± 0.15 ^b	5.34 ± 0.10 ^f	34.27 ± 0.75 ^d
Kara Findık	5.87 ± 0.24 ^g	8.68 ± 0.08 ^f	7.22 ± 0.10 ^d	7.26 ± 0.35 ^e
Foşa	34.42 ± 2.27 ^a	16.31 ± 0.17 ^c	15.59 ± 0.25 ^a	24.19 ± 0.14 ^f
Tombul	31.35 ± 1.09 ^b	20.18 ± 0.11 ^a	11.46 ± 0.30 ^b	60.20 ± 0.26 ^a
Hanımeli	14.72 ± 0.17 ^f	9.23 ± 0.10 ^e	2.82 ± 0.05 ^h	43.40 ± 0.50 ^c
Palaz	19.99 ± 0.11 ^d	8.37 ± 0.06 ^g	6.30 ± 0.21 ^e	29.11 ± 0.58 ^e
F values	407.89*	4109.98*	1795.10*	3877.24*

Different superscript letters in each column show the significant differences ($P < 0.05$).

*: significant at $P < 0.05$.

** : significant at $P < 0.01$.

Table 5. Color properties of the hazelnut cultivars.

Cultivars	External shell						Internal shell			Internal		
	L*	a*	b*	Hue	C*	CI	L*	a*	b*	L*	a*	b*
Devediş	44.72 ± 3.92 ^b	16.38 ± 0.79 ^{ab}	26.95 ± 2.0 ^a	58.60 ± 2.73 ^b	31.57 ± 1.60 ^a	13.98 ± 3.53 ^c	41.73 ± 1.88 ^{bc}	16.11 ± 0.64 ^a	21.19 ± 1.43 ^{ab}	79.29 ± 2.14 ^{ab}	0.38 ± 0.30 ^d	24.00 ± 4.55 ^{ab}
Çakıldak	42.14 ± 1.87 ^{cd}	16.27 ± 2.34 ^{ab}	22.60 ± 3.70 ^b	54.15 ± 2.47 ^c	27.87 ± 4.23 ^b	17.27 ± 2.22 ^{cd}	39.10 ± 1.05 ^{bc}	15.21 ± 0.90 ^{ab}	16.57 ± 2.29 ^{cd}	81.97 ± 1.58 ^a	0.21 ± 0.31 ^d	21.32 ± 0.84 ^b
Kalınkara	47.43 ± 2.36 ^a	9.81 ± 1.92 ^e	16.02 ± 1.76 ^f	58.75 ± 3.13 ^{ab}	18.82 ± 2.41 ^f	12.92 ± 2.09 ^e	43.66 ± 1.27 ^{ab}	17.29 ± 0.99 ^a	21.90 ± 0.75 ^a	74.80 ± 1.92 ^b	2.46 ± 0.81 ^b	27.54 ± 2.65 ^a
Dağ fındığı	44.55 ± 2.49 ^b	16.65 ± 1.35 ^a	23.12 ± 2.31 ^b	54.13 ± 3.07 ^c	28.53 ± 2.21 ^b	16.41 ± 2.50 ^d	46.95 ± 2.48 ^a	14.32 ± 0.95 ^{ab}	21.98 ± 0.34 ^a	80.83 ± 0.17 ^a	-0.02 ± 0.10 ^d	23.13 ± 0.38 ^{ab}
Kara Fındık	42.40 ± 2.63 ^c	13.07 ± 2.11 ^c	16.75 ± 1.88 ^{ef}	52.20 ± 3.71 ^d	21.29 ± 2.52 ^e	18.58 ± 3.16 ^{bc}	41.43 ± 2.10 ^{bc}	11.88 ± 0.70 ^b	18.64 ± 1.26 ^{ab}	74.50 ± 3.21 ^b	1.54 ^b ± 0.28 ^c	24.98 ± 1.78 ^{ab}
Foşa	40.82 ± 2.10 ^{de}	16.22 ± 1.28 ^{ab}	20.74 ± 2.57 ^c	51.81 ± 2.39 ^d	26.35 ± 2.65 ^c	19.43 ± 2.52 ^{ab}	41.87 ± 1.60 ^{bc}	14.08 ± 0.14 ^{ab}	18.30 ± 1.98 ^{ab}	78.44 ± 1.15 ^{ab}	1.50 ± 0.11 ^c	23.56 ± 0.34 ^{ab}
Tombul	40.16 ± 1.40 ^e	15.62 ± 1.54 ^b	19.12 ± 2.12 ^d	50.70 ± 1.65 ^d	24.70 ± 2.52 ^d	20.45 ± 1.81 ^a	37.93 ± 1.58 ^c	15.31 ± 0.77 ^{ab}	15.43 ± 0.71 ^{cd}	80.24 ± 1.27 ^a	0.51 ± 0.09 ^d	22.72 ± 0.44 ^{ab}
Hanımeli	42.03 ± 2.68 ^{cd}	7.61 ± 1.75 ^f	13.15 ± 1.45 ^g	60.23 ± 4.54 ^a	15.24 ± 1.93 ^g	13.90 ± 3.34 ^e	32.34 ± 0.76 ^d	11.81 ± 2.69 ^b	12.14 ± 2.97 ^d	68.96 ± 0.65 ^c	3.59 ± 0.12 ^a	26.04 ± 1.06 ^{ab}
Palaz	46.83 ± 3.17 ^a	11.32 ± 2.65 ^d	17.57 ± 2.33 ^e	57.58 ± 3.86 ^b	20.94 ± 3.26 ^e	13.80 ± 2.69 ^e	38.12 ± 1.51 ^c	16.13 ± 1.47 ^a	16.77 ± 0.48 ^{bc}	77.66 ± 1.04 ^{ab}	0.41 ± 0.12 ^d	22.76 ± 0.94 ^{ab}
F values	72.44*	252.94*	249.52	90.95*	282.70*	78.89*	18.50*	6.97*	12.54**	17.35**	39.74*	2.87*

Different superscript letters in each column show the significant differences (P < 0.05).

*: significant at P < 0.05.

** : significant at P < 0.01.

Table 6. Gravitational, mechanical, and area values of the hazelnut cultivars.

Cultivars	Mass (M, g)	Volume (V, mm ³)	Hardness (N)	Projected area at horiz. orient. (PA _h , mm ²)	Projected area at vert. orient. (PA _v , mm ²)	Surface area (SA, mm ²)
Devediş	2.15 ± 0.22 ^{bc}	3691.75 ± 496.56 ^c	519.56 ± 52.24 ^a	260.12 ± 21.56 ^c	243.77 ± 22.88 ^c	1152.93 ± 102.38 ^c
Çakıldak	1.65 ± 0.31 ^e	2666.99 ± 453.64 ^g	191.24 ± 32.70 ^e	227.10 ± 28.83 ^{de}	196.24 ± 23.70 ^e	927.07 ± 105.54 ^g
Kalınkara	2.25 ± 0.46 ^b	3293.91 ± 572.17 ^{de}	286.39 ± 29.09 ^{cd}	281.21 ± 34.49 ^b	227.30 ± 29.43 ^d	1066.97 ± 124.87 ^{de}
Dağ fındığı	2.90 ± 0.34 ^a	4192.17 ± 527.67 ^b	458.70 ± 66.49 ^b	319.26 ± 25.92 ^a	281.13 ± 24.52 ^b	1255.08 ± 106.22 ^b
Kara Fındık	3.02 ± 0.37 ^a	4774.93 ± 571.61 ^a	308.65 ± 26.12 ^c	329.21 ± 27.24 ^a	314.67 ± 29.56 ^a	1369.13 ± 109.45 ^a
Foşa	2.11 ± 0.33 ^{bc}	3331.32 ± 469.45 ^d	246.51 ± 17.04 ^{de}	263.17 ± 22.78 ^c	224.77 ± 24.11 ^d	1076.36 ± 100.89 ^d
Tombul	1.84 ± 0.25 ^d	2612.23 ± 441.09 ^g	203.06 ± 46.08 ^e	214.38 ± 23.77 ^e	192.40 ± 24.15 ^e	914.45 ± 102.35 ^g
Hanımeli	1.18 ± 0.26 ^f	2925.68 ± 475.65 ^f	230.97 ± 40.50 ^e	220.90 ± 24.84 ^e	190.30 ± 21.96 ^e	986.25 ± 108.86 ^f
Palaz	1.99 ± 0.31 ^{cd}	3054.36 ± 471.52 ^{ef}	204.48 ± 36.43 ^e	234.56 ± 26.73 ^d	227.45 ± 23.60 ^d	1015.44 ± 103.81 ^{ef}
F values	228.45*	154.65*	295.40*	188.25*	210.63*	149.05*

Different superscript letters in each column show the significant differences (P < 0.05).

*: significant at P < 0.05.

** : significant at P < 0.01.

findığı cultivars. The lowest geometric mean diameters were measured for Çakıldak and Tombul samples (Table 7). These physical properties are important for hazelnut cracking and separation machines; they are used to adjust the dimensions between cylinders in breaker systems (Demir et al., 2018). Furthermore, these properties could prove convenient for hazelnut drying and processing (Milošević and Milošević, 2017).

Roundness value close to unity indicates an almost circular fruit shape. While Karafındık and Dağ findığı samples had the closest shape to circular in horizontal orientation, the Palaz cultivar was found to be almost circular in vertical orientation (Table 8). Palaz and Karafındık had the closest shape to a sphere, with sphericity values of 96.43% and 96.14%, respectively. Hosseinpour et al. (2013) reported that nut sphericity values varied

Table 7. Dimensional properties of the hazelnut cultivars.

Cultivars	Length (L, mm)	Width (W, mm)	Thickness (T, mm)	Geometric mean diam. (D_g , mm)	Perimeter at horiz. orient. (P_h , mm)	Perimeter at vert. orient. (P_v , mm)	Equivalent diameter at horiz. orient (mm)	Equivalent diameter at vert. orient. (mm)
Devediş	23.26 ± 1.17 ^a	23.84 ± 1.15 ^a	12.66 ± 0.77 ^f	19.14 ± 0.84 ^e	63.48 ± 2.76 ^{bc}	62.99 ± 2.83 ^b	18.18 ± 0.75 ^c	17.60 ± 0.82 ^c
Çakıldak	18.84 ± 1.20 ^e	18.60 ± 1.10 ^f	14.43 ± 1.16 ^e	17.15 ± 0.98 ^e	57.19 ± 3.59 ^{de}	53.75 ± 3.09 ^e	16.97 ± 1.08 ^{de}	15.78 ± 0.95 ^e
Kalınkara	20.19 ± 1.23 ^d	19.43 ± 1.22 ^e	15.90 ± 1.31 ^c	18.4 ± 1.09 ^{de}	63.67 ± 4.00 ^b	58.14 ± 3.74 ^c	18.89 ± 1.17 ^b	16.98 ± 1.11 ^d
Dağ findığı	21.68 ± 0.92 ^{bc}	21.35 ± 1.03 ^c	17.24 ± 1.20 ^b	19.97 ± 0.85 ^e	68.20 ± 2.74 ^a	64.57 ± 2.69 ^b	20.14 ± 0.83 ^a	18.90 ± 0.83 ^b
Kara Fındık	21.87 ± 0.97 ^b	22.59 ± 1.06 ^b	18.41 ± 1.23 ^a	20.86 ± 0.84 ^a	69.00 ± 2.95 ^a	68.16 ± 3.26 ^a	20.46 ± 0.84 ^a	19.99 ± 0.94 ^a
Foşa	20.38 ± 0.98 ^d	20.12 ± 1.24 ^d	15.44 ± 0.99 ^{cd}	18.49 ± 0.87 ^d	62.01 ± 2.64 ^c	58.34 ± 3.17 ^c	18.29 ± 0.78 ^c	16.89 ± 0.90 ^d
Tombul	18.10 ± 1.12 ^f	18.28 ± 1.11 ^f	14.97 ± 1.11 ^{de}	17.04 ± 0.95 ^e	55.92 ± 3.02 ^e	54.19 ± 2.97 ^{de}	16.50 ± 0.92 ^f	15.62 ± 0.97 ^e
Hanımeli	21.28 ± 1.25 ^c	17.69 ± 1.00 ^c	12.31 ± 0.95 ^f	17.69 ± 1.00 ^f	58.07 ± 3.17 ^d	55.58 ± 3.09 ^d	16.74 ± 0.96 ^{ef}	15.54 ± 0.92 ^e
Palaz	18.70 ± 1.24 ^e	17.96 ± 0.91 ^f	16.90 ± 0.89 ^b	17.96 ± 0.91 ^{ef}	58.38 ± 3.40 ^d	57.67 ± 2.97 ^c	17.25 ± 0.98 ^d	17.00 ± 0.88 ^d
F values	172.29*	227.51*	265.34*	141.89*	168.57*	190.16*	180.88*	199.26*

Different superscript letters in each column show the significant differences (P < 0.05).

*: significant at P < 0.05.

** : significant at P < 0.01.

Table 8. Sphericity, shape, and aspect ratio values of the hazelnut cultivars.

Cultivars	Sphericity (S, %)	Shape index (SI)	Shape description	Shape factor at horiz. orient. (SF _h)	Shape factor at vert. orient. (SF _v)	Roundness at horiz. orient. (R _h)	Roundness at vert. orient. (R _v)	Aspect ratio at horiz. orient. (AR _h)	Aspect ratio at vert. orient. (AR _v)
Devediş	82.35 ± 1.95 ^e	1.27 ± 0.03 ^a	Oval	0.81 ± 0.01 ^e	0.77 ± 0.02 ^d	0.61 ± 0.03 ^e	0.55 ± 0.03 ^d	0.98 ± 0.01 ^{de}	1.89 ± 0.11 ^a
Çakıldak	91.13 ± 2.87 ^{cd}	1.14 ± 0.05 ^{bc}	Spherical	0.87 ± 0.01 ^a	0.85 ± 0.01 ^{ab}	0.81 ± 0.06 ^{cd}	0.72 ± 0.06 ^c	1.01 ± 0.03 ^b	1.29 ± 0.09 ^c
Kalınkara	91.14 ± 2.34 ^{cd}	1.14 ± 0.04 ^{bc}	Spherical	0.87 ± 0.02 ^a	0.84 ± 0.02 ^b	0.88 ± 0.06 ^a	0.77 ± 0.07 ^b	1.04 ± 0.04 ^a	1.23 ± 0.10 ^d
Dağ findığı	92.13 ± 2.18 ^c	1.12 ± 0.04 ^c	Spherical	0.86 ± 0.01 ^{bc}	0.85 ± 0.02 ^b	0.86 ± 0.04 ^a	0.79 ± 0.05 ^b	1.02 ± 0.03 ^b	1.24 ± 0.09 ^d
Kara Fındık	95.43 ± 2.36 ^a	1.07 ± 0.04 ^e	Spherical	0.87 ± 0.01 ^{ab}	0.85 ± 0.02 ^{ab}	0.88 ± 0.04 ^a	0.79 ± 0.07 ^b	0.97 ± 0.04 ^e	1.23 ± 0.09 ^d
Foşa	90.76 ± 2.47 ^d	1.15 ± 0.04 ^b	Spherical	0.86 ± 0.01 ^c	0.83 ± 0.02 ^c	0.81 ± 0.06 ^d	0.71 ± 0.06 ^e	1.01 ± 0.03 ^b	1.31 ± 0.09 ^c
Tombul	94.19 ± 2.39 ^b	1.09 ± 0.04 ^d	Spherical	0.86 ± 0.02 ^c	0.82 ± 0.02 ^c	0.83 ± 0.06 ^{bc}	0.73 ± 0.07 ^c	0.99 ± 0.03 ^{cd}	1.23 ± 0.09 ^d
Hanımeli	83.18 ± 2.14 ^e	1.27 ± 0.04 ^a	Oval	0.82 ± 0.02 ^d	0.77 ± 0.02 ^d	0.62 ± 0.05 ^e	0.54 ± 0.04 ^d	1.01 ± 0.02 ^{bc}	1.73 ± 0.12 ^b
Palaz	96.14 ± 2.78 ^a	1.06 ± 0.05 ^c	Spherical	0.86 ± 0.01 ^{abc}	0.86 ± 0.01 ^a	0.85 ± 0.04 ^{ab}	0.86 ± 0.05 ^a	1.02 ± 0.05 ^b	1.08 ± 0.06 ^e
F values	313.33*	275.61*	-	182.21*	246.86*	322.33*	294.14*	37.54*	569.52*

Different superscript letters in each column show the significant differences (P < 0.05).

*: significant at P < 0.05.

** : significant at P < 0.01.

between 81% and 94% for all hazelnut cultivars, similar to the results of present study. The shape of Devediş and Hanımeli cultivars was described as oval because their average value of shape index was greater than 1.25. The average values of sphericity and roundness proportionally decreased as the average values of shape index increased. There was a relative increase tendency for the aspect ratio at the vertical orientation in association with the shape index averages. However, there was a negative correlation between aspect ratio at the horizontal orientation and shape index. Çakıldak and Kalınkara had the greatest shape factor at the horizontal orientation, and Palaz cultivar had the greatest shape factor at the vertical orientation. The lowest shape factors (at both horizontal and vertical orientations) were observed in Devediş and Hanımeli cultivars. Aspect ratio is defined by the major and minor axes of an ellipse. An aspect ratio close to unity indicates increasing circularity of the object in 2-dimensional views. In the present study, decreased sphericity was observed with increased aspect ratio. According to the shape description, it can be concluded that most of the hazelnut cultivars were spherical.

The present study also focused on some size and shape features of hazelnut cultivars, and a detailed comparison for the samples in terms of the physicochemical properties was carried out. In general, the highest dimensional, gravitational, mechanical, and area values

were observed in the Dağ fındığı and Karafındık cultivars. In terms of the general features, Hanımeli had the lowest averages excluding mass, volume, hardness, thickness, and projected area in vertical orientation. Ozdemir and Akıncı (2004) reported lower dimensional, mass, volume, and surface area averages for Palaz, Çakıldak, and Kara cultivars compared to values reported in the present study; however, projected area values at vertical orientation (Palaz, 238.87 mm²; Tombul, 206.84 mm²; Çakıldak, 231.01 mm²) were similar to the current values. Increasing sphericity was observed with decreasing shape index because the relation between both variables was significant. The results of some scientific studies conducted on walnut and hazelnut cultivars or genotypes by Demir et al. (2018), Sayıncı et al. (2015a), Ercisli et al. (2012), and Ozkan and Koyuncu (2005) supported the findings of the current study. The surface area of agricultural products is closely related to evaporation from the product surfaces. George et al. (2007) reported that drying rate increased due to increased surface area of the product.

Principal component analysis (PCA) results are also illustrated in Figure 2. According to this analysis, two PCs explained 51.98% of the total variance. Palaz–Foşa and Çakıldak–Tombul cultivars displayed similarities in terms of characterized properties. Foşa separated from the other cultivars in terms of Fe, Mn, Zn, and linoleic acid contents. However, the Devediş cultivar differentiated from the

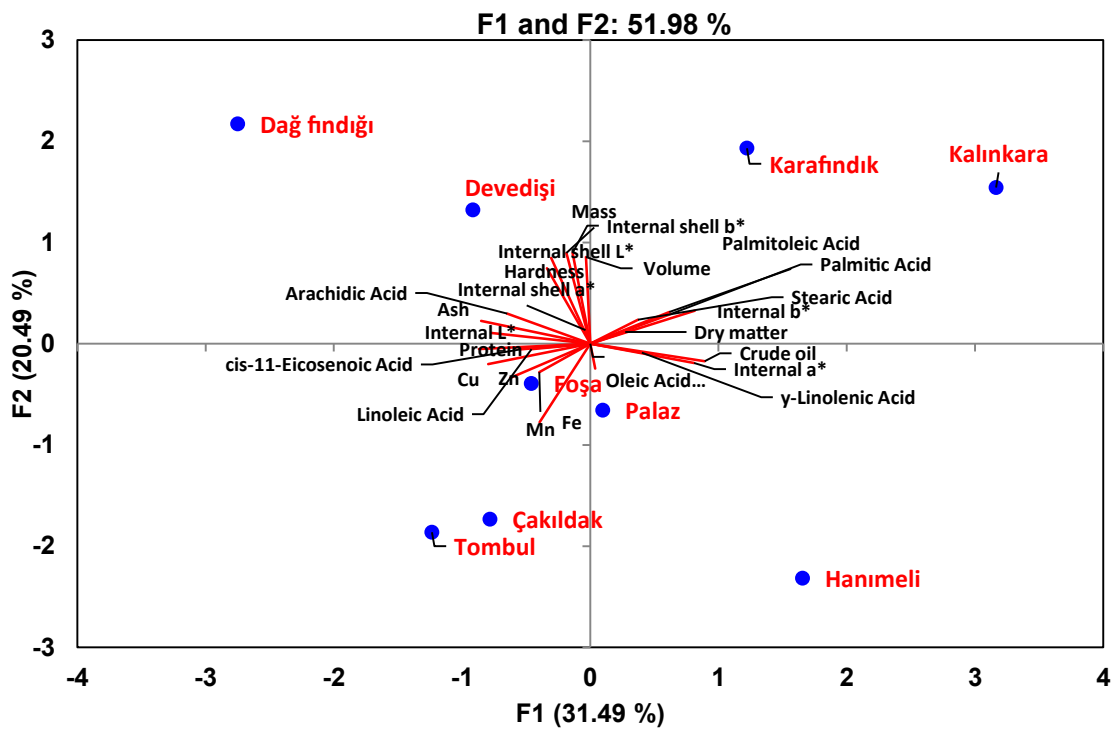


Figure 2. Principal component analysis results among some physicochemical and biochemical features of the hazelnut cultivars.

Table 9. Correlation matrix for some physicochemical properties and biochemical features of the hazelnut cultivars.

Variables	Internal Shell L*	Internal Shell a*	Internal Shell b*	Internal L*	Internal a*	Internal b*	Dry Matter	Ash	Protein	Crude Oil	Palmitic Acid	Palmitoleic Acid	Stearic Acid	Oleic Acid	Linoleic Acid	Linolenic Acid	Arachidic Acid	Eicosenoic Acid	Zn	Cu	Mn	Fe	Mass	Volume	Hardness	
Internal Shell L*	1																									
Internal Shell a*	0.352	1																								
Internal Shell b*	0.945	0.487	1																							
Internal L*	0.518	0.508	0.407	1																						
Internal a*	-0.467	-0.415	-0.380	-0.929	1																					
Internal b*	-0.012	-0.098	0.151	-0.791	0.819	1																				
Dry Matter	0.224	0.351	0.281	0.063	0.188	0.389	1																			
Ash	0.328	0.197	0.308	0.670	-0.807	-0.605	-0.180	1																		
Protein	0.237	-0.317	0.000	0.543	-0.501	-0.624	-0.121	0.586	1																	
Crude Oil	-0.473	0.133	-0.257	-0.593	0.574	0.567	0.241	-0.644	-0.910	1																
Palmitic Acid	0.306	0.327	0.344	-0.193	0.366	0.587	0.630	-0.564	-0.560	0.466	1															
Palmitoleic Acid	0.314	0.477	0.429	-0.238	0.425	0.692	0.631	-0.494	-0.602	0.430	0.912	1														
Stearic Acid	-0.083	-0.461	-0.076	-0.289	0.130	0.142	-0.127	-0.223	-0.291	0.419	0.168	-0.136	1													
Oleic Acid	-0.088	0.564	0.074	0.354	-0.173	-0.179	0.431	0.061	-0.189	0.278	0.044	0.164	-0.213	1												
Linoleic Acid	0.006	-0.271	-0.132	-0.052	-0.053	-0.130	-0.472	0.272	0.504	-0.621	-0.475	-0.348	-0.506	-0.670	1											
Linolenic Acid	-0.132	-0.191	-0.145	-0.068	0.120	-0.052	-0.015	-0.512	-0.284	0.448	0.184	-0.059	0.662	0.272	-0.689	1										
Arachidic Acid	0.217	-0.217	0.189	0.225	-0.442	-0.318	-0.471	0.702	0.578	-0.622	-0.780	-0.663	-0.170	-0.325	0.623	-0.436	1									
Eicosenoic Acid	0.235	-0.164	-0.023	0.615	-0.593	-0.720	-0.174	0.283	0.540	-0.476	-0.074	-0.387	0.297	-0.139	-0.068	0.303	-0.032	1								
Zn	-0.060	0.166	-0.121	0.477	-0.394	-0.529	-0.025	0.570	0.462	-0.501	-0.278	-0.173	-0.477	0.274	0.165	-0.486	0.056	0.301	1							
Cu	0.211	0.166	0.063	0.756	-0.596	-0.653	0.284	0.620	0.791	-0.687	-0.297	-0.292	-0.468	0.322	0.123	-0.305	0.215	0.481	0.722	1						
Mn	0.071	-0.035	-0.121	0.497	-0.325	-0.544	0.082	0.149	0.409	-0.367	0.113	-0.062	0.012	0.176	-0.200	0.148	-0.370	0.781	0.671	0.600	1					
Fe	-0.482	-0.029	-0.629	0.219	-0.136	-0.477	0.027	0.122	0.465	-0.257	-0.373	-0.397	-0.487	0.025	0.405	-0.270	0.057	0.191	0.374	0.546	0.226	1				
Mass	0.826	-0.038	0.752	0.254	-0.359	0.062	0.007	0.296	0.166	-0.333	0.246	0.105	0.402	-0.434	0.001	0.000	0.286	0.353	-0.253	-0.055	0.004	-0.603	1			
Volume	0.593	-0.369	0.574	-0.094	-0.070	0.252	-0.149	0.192	0.107	-0.224	0.056	-0.032	0.535	-0.499	0.041	0.053	0.408	0.118	-0.358	-0.265	-0.194	-0.725	0.882	1		
Hardness	0.608	0.095	0.710	0.182	-0.280	0.133	0.047	0.602	0.251	-0.407	-0.228	-0.023	-0.138	-0.018	0.178	-0.439	0.675	-0.277	0.053	0.143	-0.350	-0.479	0.540	0.632	1	

The correlation values in bold are statistically significant at the level of alpha = 0.05.

others in terms of physical properties such as internal shell L* value, internal shell hardness, and mass. Table 9 shows the correlation matrix between some studied parameters of hazelnut samples. The correlation between internal L* value and Cu content was found to be significant (r = 0.756). Similar correlations were also reported by Nayik and Nanda (2015). There were significant correlations between internal b* value and palmitoleic acid–eicosenoic acid contents. A positive correlation was monitored between palmitoleic acid and internal b* values, while a negative correlation was determined between eicosenoic acid and internal b* values. At the same time, some significant correlations were also observed between some fatty acids (palmitic acid–palmitoleic acid, palmitic acid–arachidic acid, oleic acid–linoleic acid). Significant negative correlations between linoleic and oleic acid were also reported by Fernández-Martinez et al. (1993), Johnson et al. (1999), and Rudolphi et al. (2012). Shell color is indicative of hazelnut appearance, defects, and external quality. According to chroma values, Devediş is more attractive for consumers in terms of skin color intensity.

Additionally, there were highly significant correlations between hardness and internal shell b* values (r = 0.710). Similar to the present findings, Konopka et al. (2005) stated that correlations between hardness and color of wheat endosperm indicated only a tendency for increasing endosperm hardness along with increasing b* values. While there was a positive correlation between ash content

and internal L* values, there were negative correlations between ash content and internal a* values.

4. Conclusion

In this study, 9 common hazelnut cultivars of Turkey were characterized based on color, physicochemical, and biochemical properties, and relationships between some physicochemical and biochemical parameters were assessed by using principal component analysis. As an alternative to the conventional measurement techniques, the shape and size parameters were determined using the image processing procedure; it was observed that the images of the hazelnut samples could be used effectively to determine the shape and size characteristics. There were significant positive and negative correlations between the characterized parameters of hazelnut cultivars. Such parameters should also be taken into consideration in food processing (cleaning, cracking, drying, packaging, separating, and transporting) and machine design technologies for these hazelnut cultivars. In addition, these properties can be utilized to determine the quality and abnormality of the hazelnut samples.

Acknowledgments

The authors are grateful to Prof. Dr. Zeki GÖKALP for his critical reading and thorough syntactic corrections of the manuscript. The authors also would like to thank Dr. Rusen Metin YILDIRIM for her technical assistance in textural analysis of the hazelnut samples.

References

- Alasalvar C, Amaral JS, Satir G, Shahidi F (2009). Lipid characteristics and essential minerals of native hazelnut varieties (*Corylus avellana* L.). *Food Chemistry* 113: 919-925. doi: 10.1016/j.foodchem.2008.08.019
- Alasalvar C, Pelvan E, Amarowicz R (2010). Effects of roasting on taste-active compounds of hazelnut varieties (*Corylus avellana* L.). *Journal of Agricultural Food Chemistry* 58: 8674-8679. doi: 10.1021/jf101039f
- Alibabic A, Skender A, Orascanin M, Sertovic E, Bajric E (2018). Evaluation of morphological, chemical, and sensory characteristics of raspberry cultivars grown in Bosnia and Herzegovina. *Turkish Journal of Agriculture and Forestry* 42: 67-74. doi:10.3906/tar-1702-59
- Antonucci F, Costa C, Pallottino F, Paglia G, Rimatori V et al. (2012). Quantitative method for shape description of almond cultivars (*Prunus amygdalus* Batsch). *Food and Bioprocess Technology* 5 (2): 768-785. doi.org/10.1007/s11947-010-0389-2
- AOAC (2000). *Official Methods of Analysis of AOAC International* (17th ed.). Gaithersburg, MD, USA: AOAC International.
- Aydin C (2003). Physical properties of almond nut and kernel. *Journal of Food Engineering* 60: 315-320. doi: 10.1016/S0260-8774(03)00053-0
- Bahrami ME, Honarvar M, Ansari K (2017). Feasibility of using digital image processing and colorimetric measurements to estimate the physicochemical properties of raw cane sugars. *Sugar Technology* 19: 305-316. doi: 10.1007/s12355-016-0467-5
- Bayrakdar S, Comak, B, Basol D, Yücedag İ (2015). Determination of type and quality of hazelnut using image processing techniques. *The 23rd Signal Processing and Communications Applications Conference (SIU); Malatya, Turkey*, pp. 616-619. doi: 10.1109/SIU.2015.7129899
- Brewer MT, Moysenko JB, Monforte AJ, Van Der Knaap E (2007). Morphological variation in tomato: a comprehensive study of quantitative trait loci controlling fruit shape and development. *Journal of Experimental Botany* 58: 1339-1349. doi: 10.1093/jxb/erl301
- Chilliard Y, Rouel, J, Guillouet P (2013). Goat alpha-s1 casein genotype interacts with the effect of extruded linseed feeding on milk fat yield, fatty acid composition and post-milking lipolysis. *Animal Feed Science and Technology* 185: 140-149. doi:10.1016/j.anifeedsci.2013.08.002
- Ciemińska-Żytkiewicz H, Verardo V, Pasini F, Bryś J, Koczkoń P et al. (2015). Determination of lipid and phenolic fraction in two hazelnut (*Corylus avellana* L.) cultivars grown in Poland. *Food Chemistry* 168: 615-622. doi: 10.1016/j.foodchem.2014.07.107
- Cosmulescu S, Botu M, Trandafir I (2013). The mineral source for human nutrition of nuts in different hazelnut (*Corylus avellana* L.) cultivars. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 41 (1): 250-254. doi: 10.15835/nbha4118307
- Costa C, Antonucci F, Pallottino F, Aguzzi J, Sun DW et al. (2011). Shape analysis of agricultural products: a review of recent research advances and potential application to computer vision. *Food and Bioprocess Technology* 4: 673-692. doi: 10.1007/s11947-011-0556-0
- Demir B (2018). Application of data mining and adaptive neuro-fuzzy structure to predict color parameters of walnuts (*Juglans regia* L.). *Turkish Journal of Agriculture and Forestry* 42 (3): 216-225. doi:10.3906/tar-1801-78
- Demir B, Sayıncı B, Çetin N, Yaman M, Çömlek R et al. (2018). Elliptic Fourier based analysis and multivariate approaches for size and shape distinctions of walnut (*Juglans regia* L.) cultivars. *Grasas y Aceites* 69 (4): 1-12. doi: 10.3989/gya.0104181
- Demir B, Sayıncı B, Çetin N, Yaman M, Çömlek R (2019). Shape discrimination of almond cultivars by Elliptic Fourier Descriptors. *Erwerbs-Obstbau* 61 (3): 245-256. doi: 10.1007/s10341-019-00423-7
- Ercisli S, Kara M, Ozturk I, Sayıncı B, Kalkan F (2011). Comparison of some physico-mechanical properties of nut and kernel of two walnut (*Juglans regia* L.) cultivars. *Notulae Botanicae Horti Agrobotanici Cluj-Napuca* 39 (2): 227-231. doi: 10.15835/nbha3926045
- Ercisli S, Sayıncı B, Kara M, Yildiz C, Ozturk I (2012). Determination of size and shape features of walnut (*Juglans regia* L.) cultivars using image processing. *Scientia Horticulturae* 133: 47-55. doi: 10.1016/j.scienta.2011.10.014
- FAOSTAT (2019). <http://faostat.fao.org/> (Access date 27.08.2019).
- Fernández-Martínez J, del Rio M, Haro A (1993). Survey of safflower (*Carthamus tinctorius* L.) germplasm for variants in fatty acid composition and other seed characters. *Euphytica* 69: 115-122. doi: 10.1007/BF00021734
- Ferreira JJ, Garcia-González C, Tous J, Rovira M (2010). Genetic diversity revealed by morphological traits and ISSR markers in hazelnut germplasm from northern Spain. *Plant Breeding* 129: 435-441. doi: 10.1111/j.1439-0523.2009.01702.x
- Fıratlıgil-Durmuş E, Sárka E, Bubník Z, Schejbal M, Kadlec P (2010). Size properties of legume seeds of different varieties using image analysis. *Journal of Food Engineering* 99 (4): 445-451. doi: 10.1016/j.jfoodeng.2009.08.005
- George C, McGruder R, Torgerson K (2007). Determination of optimal surface area to volume ratio for thin-layer drying of breadfruit (*Artocarpus altilis*). *The International Journal for Service Learning in Engineering* 2: 76-88. doi: 10.24908/ijse.v2i2.2093
- Gunduz K, Ozbay H (2018). The effects of genotype and altitude of the growing location on physical, chemical, and phytochemical properties of strawberry. *Turkish Journal of Agriculture and Forestry* 42: 145-153. doi:10.3906/tar-1706-65
- Güner M, Dursun E, Dursun, IG (2003). Mechanical behaviour of hazelnut under compression loading. *Biosystems Engineering* 85 (4): 485-491. [https://doi.org/10.1016/S1537-5110\(03\)00089-8](https://doi.org/10.1016/S1537-5110(03)00089-8)

- Hosseinpour A, Seifi E, Javadi D, Ramezanzpour SS, Molnar TJ (2013). Nut and kernel characteristics of twelve hazelnut cultivars grown in Iran. *Scientia Horticulturae* 150: 410-413. doi:10.1016/j.scienta.2012.11.028
- Johnson RC, Bergmann JW, Flynn CR (1999). Oil and meal characteristics of core and non-core safflower accessions from USDA collection. *Genetic Resources and Crop Evolution* 46: 611-618. doi: 10.1023/A:10087566
- Kaleoglu M, Bayindirli L, Bayindirli A (2004). Lye peeling of ‘Tombul’ hazelnuts and effect of peeling on quality. *Food and Bioprocess Processing* 82 (3): 201-206. doi:10.1205/ fbio.82.3.201.44184.
- Kara M, Sayıncı B, Elkoca E, Öztürk İ, Özmen TB (2013). Seed size and shape analysis of registered common bean (*Phaseolus vulgaris* L.) cultivars in Turkey using digital photography. *Tarım Bilimleri Dergisi* 19: 219-234.
- Koksal Aİ, Artık N, Şimsek A, Gunes N (2006). Nutrient composition of hazelnut (*Corylus avellana* L.) varieties cultivated in Turkey. *Food Chemistry* 99: 509-515. doi: 10.1016/j.foodchem.2005.08.013
- Konopka I, Kozirok W, Tańska M (2005). Wheat endosperm hardness. Part I. Relationships to colour of kernel cross-section. *European Food Research and Technology* 220: 11-19. doi: 10.1007/s00217-004-1037-8
- Koyuncu MA, Islam A, Küçük M (2005). Fat and fatty acid composition of hazelnut kernels in vacuum packages during storage. *Grasas y Aceites* 56 (4): 263-266. doi: 10.3989/gya.2005.v56.i4.91
- Mahawar MK, Jalgaonkar K, Kumar M, Meena VS, Bhushan B (2017). Determination of some physical properties of date palm fruits (cv. Khadrawy and Medjool). *Acta Agroph* 24: 217-223.
- McGuire RG (1992). Reporting of objective color measurements. *HortScience* 27: 1254-1255.
- Mertens D. AOAC Official Method 975.03. Metal in Plants and Pet Foods: Official Methods of Analysis. Horwitz W, Latimer GW, editors. 18th ed. Gaithersburg, MD, USA: AOAC International, pp. 3-4.
- Milošević T, Milošević N (2017). Determination of size and shape features of hazelnuts using multivariate analysis. *Acta Scientiarum Polonorum-Hortorum Cultus* 16 (5): 49-61. doi: 10.24326/asphc.2017.5.6
- Mohsenin NN (1980). *Physical Properties of Plant and Animal Materials: Structure, Physical Characteristics and Mechanical Properties*. New York, London, Paris: Gordon and Breach Science Publishers. doi: 10.1002/food.19870310724
- Mohsenin NN (1984). *Electromagnetic Radiation Properties of Foods and Agricultural Products*. New York: Gordon and Breach Science Publishers.
- Mohsenin NN (1986). *Physical Properties of Plant and Animal Materials: Structure, Physical Characteristics and Mechanical Properties*. New York: Gordon and Breach Science Publishers.
- Nayik GA, Nanda V (2015) Physico-chemical, enzymatic, mineral and colour characterization of three different varieties of honeys from Kashmir valley of India with a multivariate approach. *Polish Journal of Food and Nutrition Sciences* 65 (2): 101-108. doi:10.1515/pjfn-2015-0022
- Oey I, Lille M, Van Loey A, Hendrickx, M (2008). Effect of high-pressure processing on colour, texture and flavour of fruit- and vegetable-based food products: a review. *Trends in Food Science & Technology* 19 (6): 320-328. doi: 10.1016/j.tifs.2008.04.001
- Ozdemir F, Akinci I (2004). Physical and nutritional properties of four major commercial hazelnut varieties. *Journal of Food Engineering* 63 (3): 341-347. doi: 10.1016/j.jfoodeng.2003.08.006
- Ozkan G, Koyuncu MA (2005). Physical and chemical composition of some walnut (*Juglans regia* L.) genotypes grown in Turkey. *Grasas y Aceites* 56: 141-146. doi: 10.3989/gya.2005.v56.i2.122
- Ozkutlu F, Doğru YZ, Özenç N, Yazıcı G, Turan M et al. (2011). The importance of hazelnut trace and heavy metal contents for human nutrition. *Journal of Soil Science and Environmental Management* 2 (1): 25-33.
- Parcerisa J, Boatella J, Codony R, Rafecas M, Castellote AI et al. (1995). Comparison of fatty acid and triacylglycerol compositions of different hazelnut varieties (*Corylus avellana* L.) cultivated in Catalonia (Spain). *Journal of Agricultural Food Chemistry* 43: 13-16. doi: 10.1021/jf00049a004
- Parcerisa J, Codony R, Boatella J, Rafecas M (1999). Triacylglycerol and phospholipid composition of hazelnut (*Corylus avellana* L.) lipid fraction during fruit development. *Journal of Agricultural Food Chemistry* 47: 1410-1415. doi: 10.1021/jf980879q
- Pathare PB, Opara UL, Al-Said FAJ (2013). Colour measurement and analysis in fresh and processed foods: a review. *Food and Bioprocess Technology* 6: 36-60. doi: 10.1007/s11947-012-0867-9
- Rovira M, Ferreira JJ, Tous J, Ciordia M (2005). Hazelnut diversity in Asturias (Northern Spain). *Acta Horticulturae* 686: 41-46. doi: 10.17660/ActaHortic.2005.686.3
- Rudolphi S, Becker HC, Schierholt A, Witzke-Ehbrecht S (2012). Improved estimation of oil, linoleic and oleic acid and seed hull fractions in safflower by NIRS. *Journal of the American Oil Chemists’ Society* 89 (3): 363-369. doi: 10.1007/s11746-011-1920-y
- Sadrnia H, Rajabipour A, Jafari A, Javadi A, Mostofi Y (2007). Classification and analysis of fruit shapes in long type watermelon using image processing. *International Journal of Agriculture and Biology* 9: 68-70.
- SAS (2000). SAS Institute Inc.: SAS Version 8.02: SAS/STAT Software: Changes and Enhancements Through Release 8.02. Cary, NC, USA: SAS Institute Inc.
- Savage GP, McNeil DL, Dutta PC (1997). Lipid composition and oxidative stability of oils in hazelnuts (*Corylus avellana* L.) grown in New Zealand. *Journal of the American Oil Chemists’ Society* 74: 755-759.
- Sayıncı B, Erciqli S, Akbulut M, Şavşatlı Y, Baykal H (2015a). Determination of shape in fruits of cherry laurel (*Prunus laurocerasus*) accessions by using Elliptic Fourier analysis. *Acta Scientiarum Polonorum, Hortorum Cultus* 14 (1): 63-82.

- Sayinci B, Ercisli S, Ozturk I, Eryilmaz Z, Demir B (2012). Determination of size and shape in the 'Moro' blood orange and 'Valencia' sweet orange cultivar and its mutants using image processing. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 40: 234-242. <https://doi.org/10.15835/nbha4016645> doi: 10.15835/nbha4016645
- Sayinci B, Kara M, Ercişli S, Duyar Ö, Ertürk Y (2015b). Elliptic Fourier analysis for shape distinction of hazelnut cultivars. *Erwerbs-Obstbau* 57: 1-11. doi: 10.1007/s10341-014-0221-7
- Simsek A, Aykut O (2007). Evaluation of the microelement profile of hazelnut (*Corylus avellana* L.) varieties for human nutrition and health. *International Journal of Food Sciences and Nutrition* 58: 677-688. doi: 10.1080/09637480701403202
- Sorkheh K, Kazemifard A, Rajabpoor S (2018). A comparative study of fuzzy linear regression and multiple linear regression in agricultural studies: a case study of lentil yield management. *Turkish Journal of Agriculture and Forestry* 42: 402-411. doi:10.3906/tar-1709-57
- Sukhija PS, Palmquist DL (1988). Rapid method for determination of total fatty acid content and composition of feedstuffs and feces. *Journal of Agricultural Food Chemistry* 36: 1202-1206.
- Sun D, Costa C, Menesatti P (2012). Advantages of using quantitative shape descriptors in protocols for plant cultivar and postharvest product quality assessment. *Food and Bioprocess Technology* 5: 1-2. doi: 10.1007/s11947-011-0715-3
- Titova TP, Nachev VG, Damyanov CI (2015). Food quality evaluation according to their color characteristics. *FU Automatic Control and Robotics* 14: 1-10.
- Warmund MR (2008). Kernel color of three black walnut cultivars after delayed hulling at five successive harvest dates. *HortScience* 43: 2256-2258. doi: 10.21273/HORTSCI.43.7.2256