

## Elliptic Fourier based analysis and multivariate approaches for size and shape distinctions of walnut (*Juglans regia* L.) cultivars

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**SUMMARY:** Size and shape data of agricultural crops provide great sources for food processing technologies. The physical attributes of different fruits should be known for the design, developing and innovation of food technologies. In this study, the size and shape distinctions of fifteen national and international walnut cultivars (Midland, Sütyemez-1, Serr, Maraş-18, Maraş-12, Sütyemez-2, Kaman-1, Kaman-5, Pedro, Howard, Chandler, Şebin, Şen-2, Bilecik and KR-1) were determined using elliptic Fourier and multivariate approaches. Firstly, the gravitational features of walnut cultivars were determined, and their dimensional, area and shape attributes were revealed by image processing. Cluster analysis was used to designate the walnut cultivars. Elliptic Fourier descriptors obtained from walnut outlines provided the comparisons among walnut cultivars in shape. The shape index indicated that Serr, Sütyemez-2, Midland and Şen-2 cultivars were oval-shaped, and the others were spherical. The cluster analysis divided the walnut cultivars into four subgroups. Elliptic Fourier descriptors perfectly distinguished the walnut cultivars according to shape.

**KEYWORDS:** Dimensional analysis; Image processing; Physical attribute; Projected area; Shape descriptor; Shape index

**RESUMEN:** *Análisis mediante elíptica de Fourier y multivariante para diferenciar tamaño y forma de cultivos de nogal (*Juglans regia* L.).* Los datos de tamaño y forma de los cultivos agrícolas proporcionan grandes fuentes para las tecnologías de procesamiento de alimentos. Los atributos físicos de diferentes frutas deben conocerse para el diseño, desarrollo e innovación de tecnologías alimentarias. En este estudio, las diferencias de tamaño y forma de quince cultivares de nueces nacionales e internacionales (Midland, Sütyemez-1, Serr, Maraş-18, Maraş-12, Sütyemez-2, Kaman-1, Kaman-5, Pedro, Howard, Chandler, Şebin, Şen-2, Bilecik y KR-1) se realizaron mediante elípticas de Fourier y multivariantes. En primer lugar, se determinaron las características gravitacionales de los cultivares de nogal, y sus atributos dimensionales de área y de forma se revelaron mediante el procesamiento de imágenes. El análisis de clusters se utilizó para designar los cultivares de nueces. Los descriptores de elípticas de Fourier obtenidos a partir de contornos de nogal proporcionaron las comparaciones de formas entre los cultivares de nueces. El índice de forma indicó que los cultivares Serr, Sütyemez-2, Midland y Şen-2 tenían forma ovalada, y los otros eran esféricos. El análisis de conglomerados dividió los cultivares de nueces en cuatro subgrupos. Los descriptores de elípticas de Fourier distinguían de manera excelente las formas de las variedades de nueces.

**PALABRAS CLAVE:** *Análisis dimensional; Área proyectada; Atributo físico; Descriptor de forma; Índice de forma; Procesamiento de imágenes*

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## 1. INTRODUCTION

Turkey is the oldest walnut (*Juglans regia* L.) growing country and is accepted as one of the primary gene centers for walnuts (Bayazit *et al.*, 2007). There are 21 species of *Juglans* known worldwide up to now. Among the species, *Juglans regia* (L), with a great commercial value, is expanding to a great deal of the regions all over the world and is the most popular one. Walnuts have quite diverse features and attributes and all these differences are mostly originated from the genetic structure of the seeds used in the walnut culture (Şen and Tekintaş, 1992).

FAO (2014) resources showed that Turkey was the fourth largest walnut producer in the world after China, the United States and Iran, and the annual walnut production of Turkey was reported as 180.807 tones. Walnut fruits are quite rich in oils (56.4%–70.6%) and proteins (13.6%–22.3%). Therefore, walnuts are considered as a significant source of nutrition and suggested as a dietary nutrient against cardiovascular diseases. Walnut fruits are also rich in vitamin A, group B vitamins (thiamin-B1, riboflavin-B2, niacin-B6) and minerals (P, K, Mg, Fe, Na and Ca) (Şahin and Akbaş, 2001; Patel, 2005; Cosmulescu *et al.*, 2009).

The physical features, especially the visual appearance of agricultural products, are significant engineering parameters. These features are composed of size and shape attributes (dimensions, area, gravitational, elongation, roundness and spherical parameters). In order to design a processing system or develop a method for processing of any agricultural product, these descriptive variables should be known. In addition, the physical attributes of a product play a great role in designing postharvest processes or industrial purposes such as handling, storage, sizing, fracturing, classifying, packaging, drying and transportation (Sadriani *et al.*, 2007; Sun *et al.*, 2012; Sayıncı *et al.*, 2012). The size and shape attributes of any product are essential descriptive data used to identify plant cultivars, assess marketing quality, analyze shape abnormalities and investigate the heritability of the product (Brewer *et al.*, 2007; Costa *et al.*, 2011).

Several studies have been conducted about the physical attributes of different fruit species and cultivars and the results and outcomes of these studies yielded a crucial database for the physical attributes of the fruits. Such studies involve size and shape attributes of different fruit species or genotypes such as orange (Sayıncı *et al.*, 2012), walnut (Ozkan and Koyuncu 2005; Ercisli *et al.*, 2012), bean (Kara *et al.*, 2013), cherry laurel (Sayıncı *et al.*, 2015b), hazelnut (Sayıncı *et al.*, 2015a), strawberry (Liming and Yanchao 2010), almond (Antonucci *et al.*, 2012), pistachio (Ghazanfari *et al.*, 1997) and loquat (Boydas *et al.*, 2012).

As indicated by some researchers (Costa *et al.*, 2011; Antonucci *et al.*, 2012; Sun *et al.*, 2012), there are disharmonies among different semantic or visual evaluations used for shape description. While shape descriptions such as elongation, roundness, circularity and symmetry were used for classifying or identifying agricultural products, Sayıncı *et al.*, (2015a) reported that these descriptors were not able to distinguish the cultivars sufficiently. Instead of semantic or visual descriptions, most of the researchers applied the Elliptic Fourier Analysis (EFA), using shape descriptors for the shape analysis of agricultural products such as cereal grains (Mebatsion *et al.*, 2012), hazelnut (Sayıncı *et al.*, 2015a), orange (Costa *et al.*, 2009), apple (Currie *et al.*, 2000) and almond (Antonucci *et al.* 2012). EFA using shape descriptors dissociates the boundary contour of a fruit into a set of harmonically closed curves and at the end of the set the original outline of the fruit view is generated (Costa *et al.*, 2011). The EFA method is widely used to determine the shape discrimination among cultivars.

The aim of this study was to contribute to the walnut database involving size and shape attributes of walnut cultivars, to comprise data required for the design of walnut processing systems and to reveal distinctions among fifteen different walnut cultivars in terms of shape attributes by means of Elliptic Fourier descriptors using an image processing operation.

## 2. MATERIALS AND METHODS

### 2.1. Sample preparation

In this study, 5 international (Midland, Serr, Pedro, Howard and Chandler) and 10 national walnut (*Juglans regia* L.) cultivars (Sütyemez-1, Maraş-18, Maraş-12, Sütyemez-2, Kaman-1, Kaman-5, Şebin, Şen-2, Bilecik and KR-1) were used as the plant material (Table 1). The walnut cultivars were provided from the Nuts Research and Application Center of Kahramanmaraş Sütçü İmam University in the Kahramanmaraş province of Turkey.

### 2.2. Image acquisition system

In order to reveal the size and shape attributes of walnut cultivars, an imaging system, details of which were explained by Kara *et al.*, (2013), consisting of a digital camera (Nikon D300, JP) and illumination equipment (paraflashes with softbox) was used. The digital images of the walnut cultivars were taken in a dark room. The camera was fixed on a frame in a position perpendicular to a white-colored fiberglass surface at a constant height of 50.5 cm. The walnut samples were kept in a fridge (−4 °C) until subsequent analyses. For each of the cultivars, 100 samples were randomly selected from a box where they were kept. Firstly, a digital balance

TABLE 1. Walnut cultivars at horizontal and vertical orientations

Cultivars	Horizontal orientation	Vertical orientation	Cultivars	Horizontal orientation	Vertical orientation
Midland			Pedro		
Sütyemez-1			Howard		
Serr			Chandler		
Maraş-18			Şebin		
Maraş-12			Şen-2		
Sütyemez-2			Bilecik		
Kaman-1			KR-1		
Kaman-5					

(Shimadzu TW423L Model, JP) ( $\pm 0.001$  g) was used to determine fruit mass. After that, the walnut samples were placed on a transparent fiberglass plate in a matrix form of  $3 \times 6$  at two orientations, namely horizontal and vertical. Putty was used to position the walnuts on the fiberglass plates. A ruler on the fiberglass surface centered at the bottom of the image area surface was used to convert the unit from pixel to millimeter. The conversion ratio was found as  $15.54\text{-pixel}\cdot\text{mm}^{-1}$ . A cable release was used to prevent vibration during the imaging. For the moisture content of the walnut samples used in present study, 20 samples randomly selected from each cultivar were dried at  $105^\circ\text{C}$  for 24 hours and their mass was measured again. The images captured by the camera were saved as a color \*.tiff extension image files for descriptive analysis and \*.bmp extension image files for the EFA. During the experiments, mean temperature and relative humidity of the laboratory were recorded as  $24.0^\circ\text{C}$  and  $24\%$ , respectively.

### 2.3. Descriptive variables of walnut cultivars

SigmaScan<sup>®</sup>Pro 5.0 software was used in order to process the walnut images, and projected area, perimeter, length, width, thickness, maximum and minimum diameters and aspect ratio variables were determined for each walnut at horizontal and vertical orientations by means of the image processing operation (Figure 1). The variables of shape index, geometric mean diameter, surface area, sphericity and volume were calculated using the equations given in Table 2. A shape index of lower than 1.25 was considered as spherical and a value over 1.25 was considered as oval (Ozkan and Koyuncu, 2005).

### 2.4. Shape analysis based on Elliptic Fourier Analysis

The walnut images were saved as color bitmap image files for the EFA. The aim of the EFA was to reveal the shape variation among the walnut cultivars. For this purpose, the outlines of each walnut image were firstly digitized using SHAPE version 1.3 software (Iwata and Ukai 2002). All data were

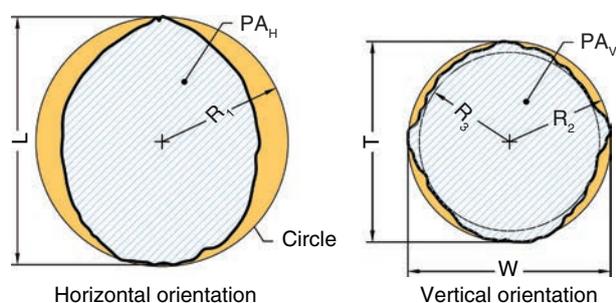


FIGURE 1. Imaging orientations and dimensions of walnut samples

TABLE 2. Equations used to calculate the size and shape attributes of walnut cultivars

Variables	Equations*	Literatures
Shape index ( $SI$ )	$SI = (2 \cdot L)/(W + T)$	Ozkan and Koyuncu (2005)
Geom. mean diameter ( $D_g$ , mm)	$D_g = (L \cdot W \cdot T)^{(1/3)}$	Mohsenin (1986)
Surface area ( $S$ , $\text{mm}^2$ )	$S = \pi \cdot D_g^2$	Sayıncı <i>et al.</i> (2015a)
Sphericity ( $\phi$ , %)	$\phi = (D_g/L) \cdot 100$	Mohsenin (1986)
Volume ( $V$ , $\text{cm}^3$ )	$V = (4/3) \cdot \pi (R_1 \cdot R_2 \cdot R_3)$	Volume of ellipse

\*  $L$ : length (mm);  $W$ : width (mm);  $T$ : thickness (mm);  $D_g$ : geometric mean diameter (mm);  $R_1$ : maximum diameter at horizontal orientation (cm);  $R_2$ : maximum diameter at width orientation (cm);  $R_3$ : minimum diameter at width orientation (cm)

recorded as chain codes to describe the geometrical information about outlines ranging from 0–7. The data obtained from the chain code were normalized using a module of the software based on the ellipse of the first harmonic in order to be independent from orientation, size, or location. In order to describe the outlines of walnut samples, 20 harmonic numbers were used (Iwata and Ukai 2002; Mebatsion *et al.*, 2012; Vasallo *et al.*, 2013).

### 2.5. Statistical analysis

In this study, approximately 100 walnuts of each cultivar, totaling 1492 walnut samples were used, and their mass, volume, length, width, thickness, geometric mean diameter, surface area, sphericity, shape index values, and projected area, perimeter and aspect ratio values at two orientations were determined as descriptive variables. A correlation matrix created for descriptive data showed the relationships among the variables. The resultant data were subjected to analysis of variance (ANOVA) with a 95% confidence level using SPSS version 20. Differences among the means were determined with Tukey's comparison test at 5% significance level. In reference to the descriptive variables of walnut cultivars, similar cultivars were determined using a hierarchical cluster analysis. For this analysis, Ward's method algorithm was used. The cluster analysis was performed by using the squared Euclidean distance method with arithmetic averages of walnut cultivars.

Shape descriptors obtained from EFA were also used to perform principle component analysis (PCA) based on the variance-covariance matrix. The resulting PC scores for each walnut cultivar were used as observed values of shape features. MANOVA was carried out using PAST version 3.01 (Hammer *et al.*, 2001). Wilks' Lambda and Pillai trace values

and p values were determined. The matrix of differences among walnut cultivars was obtained from Hotelling's pairwise comparisons with Bonferroni correction and squared Mahalanobis distances which make two-cultivar comparisons possible. Differences in walnut outlines were evaluated using a discriminant analysis (Sayinci *et al.*, 2015a). Group centroids of walnut cultivars obtained from discriminant analysis were presented in a scatter plot with canonical discrimination functions.

### 3. RESULTS

#### 3.1. Relationships among variables describing walnut cultivars

The correlation matrix is provided in Table 3. Correlation greater than 0.70 were marked. While correlations between mass (*M*) and the other variables were not found to be significant, volume (*V*) significantly correlated with the area variables (*SA*, *PA<sub>h</sub>* and *PA<sub>v</sub>*) of the walnut cultivars. Similarly, the correlations between length and the other dimensional variables (*W*, *T*, *D<sub>g</sub>*, *P<sub>h</sub>* and *P<sub>v</sub>*) were not found to be significant. As for the descriptive shape attributes of the walnut cultivars, sphericity and shape index showed a significant negative correlation. The correlations between aspect ratio variables measured at horizontal and vertical orientations (*AR<sub>h</sub>* and *AR<sub>v</sub>*) were not found to be significant.

#### 3.2. Gravitational and area attributes

The mass, volume, surface area and projected area averages are provided in Table 4. While the KR-1 cultivar had the highest gravitational and area averages, the lowest averages were observed for the Serr and Maraş-12 cultivars. Surface area to volume ratio averages varied between 1.42 and 1.89 and the ratio decreased with increasing volumes. Projected area values at two orientations positively correlated with the volume values of the walnuts. However, the projected area averages of the walnut cultivars at two orientations were significantly different. The lowest projected area ratio was observed for the KR-1 and Sütyemez-1 cultivars. The projected area averages measured at the horizontal orientation of the Sütyemez-2 and Serr cultivars were significantly higher than those of vertical orientation. This ratio was considerably close to 1.00 for the KR-1 and Sütyemez-1 cultivars.

#### 3.3. Dimensional attributes

The dimensional attributes of the walnut cultivars are provided in Table 5. While the KR-1 and Şen-2 cultivars had the longest dimensions, the Maraş-12 cultivar had the lowest length average. As the width of the walnuts increased, the other dimensional attributes (*T*, *D<sub>g</sub>*, *P<sub>h</sub>* and *P<sub>v</sub>*) also increased because of the positive correlations among size variables, except for length. As seen from the averages,

TABLE 3. Correlation matrix for size, shape and gravitational variables

Variables <sup>1</sup>	<i>M</i> (g)	<i>V</i> (cm <sup>3</sup> )	<i>PA<sub>h</sub></i> (mm <sup>2</sup> )	<i>PA<sub>v</sub></i> (mm <sup>2</sup> )	<i>SA</i> (cm <sup>2</sup> )	<i>L</i> (mm)	<i>W</i> (mm)	<i>T</i> (mm)	<i>D<sub>g</sub></i> (mm)	<i>P<sub>h</sub></i> (mm)	<i>P<sub>v</sub></i> (mm)	<i>S</i> (%)	<i>SI</i>	<i>AR<sub>h</sub></i>	<i>AR<sub>v</sub></i>
<i>M</i> (g)	1	0.552	0.495	0.551	0.560	0.446	0.528	0.531	0.562	0.493	0.553	0.068	-0.084	0.011	0.015
<i>V</i> (cm <sup>3</sup> )	0.552	1	<b>0.904</b>	<b>0.951</b>	<b>0.990</b>	<b>0.820</b>	<b>0.906</b>	<b>0.895</b>	<b>0.977</b>	<b>0.888</b>	<b>0.932</b>	0.024	-0.041	0.027	0.022
<i>PA<sub>h</sub></i> (mm <sup>2</sup> )	0.495	<b>0.904</b>	1	<b>0.799</b>	<b>0.914</b>	<b>0.920</b>	<b>0.750</b>	<b>0.771</b>	<b>0.911</b>	<b>0.992</b>	<b>0.794</b>	-0.238	0.230	0.034	-0.051
<i>PA<sub>v</sub></i> (mm <sup>2</sup> )	0.551	<b>0.951</b>	<b>0.799</b>	1	<b>0.952</b>	0.652	<b>0.946</b>	<b>0.944</b>	<b>0.945</b>	<b>0.778</b>	<b>0.988</b>	0.265	-0.274	-0.162	0.033
<i>SA</i> (cm <sup>2</sup> )	0.560	<b>0.990</b>	<b>0.914</b>	<b>0.952</b>	1	<b>0.839</b>	<b>0.918</b>	<b>0.914</b>	<b>0.996</b>	<b>0.905</b>	<b>0.948</b>	0.02	-0.038	0.032	0.024
<i>L</i> (mm)	0.446	<b>0.820</b>	<b>0.920</b>	0.652	<b>0.839</b>	1	0.627	0.625	<b>0.842</b>	<b>0.941</b>	0.656	-0.486	0.471	0.381	0.014
<i>W</i> (mm)	0.528	<b>0.906</b>	<b>0.750</b>	<b>0.946</b>	<b>0.918</b>	0.627	1	<b>0.847</b>	<b>0.920</b>	<b>0.739</b>	<b>0.957</b>	0.276	-0.282	-0.125	0.267
<i>T</i> (mm)	0.531	<b>0.895</b>	<b>0.771</b>	<b>0.944</b>	<b>0.914</b>	0.625	<b>0.847</b>	1	<b>0.920</b>	<b>0.756</b>	<b>0.944</b>	0.287	-0.304	-0.198	-0.221
<i>D<sub>g</sub></i> (mm)	0.562	<b>0.977</b>	<b>0.911</b>	<b>0.945</b>	<b>0.996</b>	<b>0.842</b>	<b>0.920</b>	<b>0.920</b>	1	<b>0.909</b>	<b>0.951</b>	0.025	-0.042	0.028	0.022
<i>P<sub>h</sub></i> (mm)	0.493	<b>0.888</b>	<b>0.992</b>	<b>0.778</b>	<b>0.905</b>	<b>0.941</b>	<b>0.739</b>	<b>0.756</b>	<b>0.909</b>	1	<b>0.781</b>	-0.278	0.271	0.088	-0.040
<i>P<sub>v</sub></i> (mm)	0.553	<b>0.932</b>	<b>0.794</b>	<b>0.988</b>	<b>0.948</b>	0.656	<b>0.957</b>	<b>0.944</b>	<b>0.951</b>	<b>0.781</b>	1	0.273	-0.285	-0.162	0.054
<i>S</i> (%)	0.068	0.024	-0.238	0.265	0.020	-0.486	0.276	0.287	0.025	-0.278	0.273	1	<b>-0.951</b>	-0.651	-0.009
<i>SI</i>	-0.084	-0.041	0.230	-0.274	-0.038	0.471	-0.282	-0.304	-0.042	0.271	-0.285	<b>-0.951</b>	1	0.614	0.020
<i>AP<sub>h</sub></i>	0.011	0.027	0.034	-0.162	0.032	0.381	-0.125	-0.198	0.028	0.088	-0.162	-0.651	0.614	1	0.190
<i>AR<sub>v</sub></i>	0.015	0.022	-0.051	0.033	0.024	0.014	0.267	-0.221	0.022	-0.040	0.054	-0.009	0.020	0.190	1

<sup>1</sup> *M*: mass; *V*: volume; *PA<sub>h</sub>*: projected area at horizontal orientation; *PA<sub>v</sub>*: projected area at vertical orientation; *SA*: surface area; *L*: length; *W*: width; *T*: thickness; *D<sub>g</sub>*: geometric mean diameter; *P<sub>h</sub>*: perimeter at horizontal orientation; *P<sub>v</sub>*: perimeter at vertical orientation; *S*: sphericity; *SI*: shape index; *AR<sub>h</sub>*: aspect ratio at horizontal orientation; *AR<sub>v</sub>*: aspect ratio at vertical orientation

TABLE 4. Gravitational and area attributes

Cultivars	Mass (M, g)	Cultivars	Volume (V, cm <sup>3</sup> )	Surface area (SA, cm <sup>2</sup> )	Ratio of SA to V (cm <sup>-1</sup> )	Projected area at horiz. orient. (PA <sub>h</sub> , mm <sup>2</sup> )	Projected area at vert. orient. (PA <sub>v</sub> , mm <sup>2</sup> )	Cultivars	Ratio of PA <sub>h</sub> to PA <sub>v</sub>
Serr	8.41±1.30k*	Maraş-12	17.68±2.23j	33.28±2.82	1.89±0.08	847.1±75.7	735.7±62.1	Sütyemez-2	1.38±0.06a
Maraş-12	9.05±1.45j	Serr	18.63±2.54ij	34.78±3.12	1.88±0.09	945.9±86.2	701.5±62.2	Serr	1.35±0.06a
Pedro	9.76±1.40i	Kaman-1	18.99±2.72i	35.09±3.38	1.86±0.09	863.9±80.0	762.5±74.2	Midland	1.30±0.26b
Kaman-1	10.86±1.49h	Maraş-18	21.01±4.33h	37.28±5.20	1.80±0.14	1010.4±139.7	793.6±119.5	Maraş-18	1.28±0.06b
Howard	11.20±1.85gh	Bilecik	21.89±2.38gh	38.43±2.85	1.76±0.07	973.3±77.1	834.2±64.3	Şen-2	1.22±0.04c
Midland	11.48±2.06g	Pedro	21.90±3.93gh	38.47±4.73	1.78±0.12	983.3±123.2	853.7±107.0	Chandler	1.21±0.04cd
Sütyemez-2	11.70±1.46fg	Şebin	22.22±3.09g	38.81±3.66	1.76±0.09	1044.5±98.4	865.6±85.1	Şebin	1.21±0.05cd
Bilecik	11.80±1.61efg	Midland	22.39±3.32g	39.18±3.86	1.76±0.09	1042.4±142.7	814.5±106.7	Howard	1.17±0.03de
Şebin	12.11±1.49def	Howard	22.92±2.10fg	39.95±2.49	1.75±0.06	1028.2±57.9	878.0±54.5	Bilecik	1.17±0.05e
Maraş-18	12.35±2.71de	Sütyemez-2	23.58±3.38ef	40.40±3.72	1.73±0.09	1142.0±102.9	830.7±81.5	Maraş-12	1.15±0.05e
Chandler	12.69±1.37d	Sütyemez-1	24.54±3.85de	41.51±4.23	1.71±0.09	1012.3±103.6	1003.7±106.8	Pedro	1.15±0.05e
Şen-2	14.80±2.10c	Chandler	24.92±2.98d	41.73±3.32	1.68±0.07	1104.3±85.2	914.4±75.1	Kaman-1	1.13±0.05e
Kaman-5	15.37±2.02b	Şen-2	27.88±3.10c	45.08±3.30	1.62±0.06	1177.2±87.5	962.9±70.1	Kaman-5	1.08±0.05f
Sütyemez-1	15.44±2.66b	Kaman-5	29.35±3.82b	46.94±4.15	1.61±0.07	1190.7±109.6	1104.1±101.9	Sütyemez-1	1.01±0.07g
KR-1	17.84±3.39a	KR-1	41.59±6.72a	58.49±6.33	1.42±0.08	1402.5±154.9	1425.3±153.1	KR-1	0.98±0.03g
Mean±SD	12.31±3.17	Mean±SD	23.93±6.59	40.59±7.06	1.73±0.14	1050.5±169.9	897.3±194.7	Mean±SD	1.19±0.14
Range	(1.94–25.43)	Range	(9.84–61.95)	(22.61–77.12)	(1.24–2.30)	(618.5–1837.9)	(469.9–1865.2)	Range	(0.85–2.18)
F (P, sigma)	168.03 (0.000)**	F (P, sigma)	264.93 (0.000)**					F (P, sigma)	176.41 (0.000)**

\* one hundred repetitive means (n = 100) for each cultivar followed by the same letter in the same column are not different as determined by the Tukey test at 5% significance level  
 \*\* highly significant (p < 0.01)

TABLE 5. Dimensional attributes

Cultivars	Length ( <i>L</i> , mm)	Cultivars	Width ( <i>W</i> , mm)	Thickness ( <i>T</i> , mm)	Geometric mean diam. ( <i>D<sub>g</sub></i> , mm)	Perimeter at horiz.orient. ( <i>P<sub>h</sub></i> , mm)	Perimeter at vert. orient. ( <i>P<sub>v</sub></i> , mm)
Maraş-12	36.7±1.9j*	Maraş-12	32.1±1.5k	29.2±1.2	32.5±1.4	104.2±4.7	97.3±4.1
Sütyemez-1	37.4±2.4i	Serr	32.2±1.4k	28.3±1.4	33.3±1.5	110.9±5.3	97.0±4.2
Kaman-1	37.5±2.0i	Kaman-1	33.2±1.7j	29.9±1.6	33.4±1.6	105.6±4.9	99.9±5.0
Şebin	38.2±1.8h	Maraş-18	33.7±2.5j	30.3±2.3	34.4±2.5	113.6±8.2	101.6±7.6
Pedro	39.0±2.7g	Midland	34.4±2.4i	30.7±2.1	35.3±1.7	116.2±8.1	103.3±6.8
Howard	39.7±1.6f	Bilecik	34.7±1.5hi	30.7±1.3	35.0±1.3	111.8±4.5	103.7±4.0
Maraş-18	39.8±2.9f	Pedro	35.0±2.1gh	31.3±2.2	34.9±2.2	112.0±7.1	104.8±6.6
Bilecik	40.1±1.8ef	Sütyemez-2	35.1±1.7gh	30.9±1.5	35.8±1.7	120.7±5.5	105.0±4.8
Serr	40.3±2.4ef	Şebin	35.5±1.9fg	32.0±1.7	35.1±1.7	115.1±5.6	106.8±5.3
Kaman-5	40.6±2.0de	Howard	35.7±1.4ef	32.0±1.0	35.7±1.1	114.8±3.4	107.2±3.3
Chandler	41.0±1.9d	Chandler	36.0±1.6e	32.7±1.4	36.4±1.5	118.7±4.7	108.9±4.5
Midland	41.8±3.2c	Şen-2	37.3±1.7d	32.9±1.2	37.9±1.4	123.3±4.8	111.2±4.1
Sütyemez-2	42.5±2.1b	Sütyemez-1	38.0±2.1c	33.7±1.9	36.3±1.9	112.9±5.8	113.7±6.0
Şen-2	44.2±2.0a	Kaman-5	39.7±1.8b	35.7±1.8	38.6±1.7	122.8±5.7	120.0±5.6
KR-1	44.3±2.6a	KR-1	45.1±2.5a	40.0±2.2	43.1±2.3	132.9±7.4	134.7±7.4
Mean±SD	40.2±3.2	Mean±SD	35.8±3.7	32.0±3.2	35.8±3.0	115.7±9.1	107.6±10.7
Range	(30.4–51.3)	Range	(25.6–53.3)	(23.5–45.5)	(26.8–49.6)	(89.0–152.9)	(78.3–155.0)
F ( <i>P</i> , sigma)	102.86 (0.000)**	F ( <i>P</i> , sigma)	294.37 (0.000)**				

\* one hundred repetitive means ( $n = 100$ ) for each cultivar followed by the same letter in the same column are not different as determined by the Tukey test at 5% significance level

\*\* highly significant ( $p < 0.01$ )

the KR-1 cultivar also had considerably higher averages in terms of width, thickness, geometric mean diameter and perimeter. In any case, the lowest width and thickness values were observed for the Maraş-12 and Serr cultivars.

### 3.4. Shape attributes describing walnut cultivars

The walnut cultivar KR-1 had the closest shape to a sphere with a sphericity average of 96.7% (Table 6). The shape of Serr, Sütyemez-2, Midland and Şen-2 cultivars were described as oval because their shape index average was greater than 1.25, and their sphericity averages ranged between 82.6% and 85.7%. While the aspect ratios determined at the horizontal orientation of the walnuts which had a high sphericity average were low in general; the averages at the vertical orientation varied, regardless of the horizontal orientation.

### 3.5. Results of cluster analysis based on dimensional and shape attributes

As seen in Figure 2, the hierarchical cluster analysis divided the walnut cultivars into two main groups. The first main group had two subgroups (shown with green triangle). While the 1<sup>st</sup> subgroup was composed

of two clusters (cluster 1 and cluster 2), the 2<sup>nd</sup> subgroup constituted cluster 3. The second main group consisted of a single walnut cultivar comprised of cluster 4. Consequently, cluster 1 involved six walnut cultivars (Howard, Şebin, Pedro, Bilecik, Midland and Maraş-18), similar to each other with regard to size and descriptive shape attributes. The Maraş-12, Kaman-1 and Serr cultivars were in cluster 2. Cluster 3 had five walnut cultivars (Chandler, Şen-2, Sütyemez-2, Sütyemez-1 and Kaman-5). KR-1, due to different size and descriptive attributes, was grouped separately into the 4<sup>th</sup> cluster.

### 3.6. Shape distinction based on Elliptic Fourier Analysis

The Elliptic Fourier analysis (EFA) revealed that the first seven variables shown in Figure 3 explained 92.7% of the total variance. The corresponding principle components PC1, PC2, PC3, PC4, PC5, PC6 and PC7 constituted 65.3%, 11.9%, 5.1%, 4.1%, 2.6%, 2.1% and 1.6% of the total variation, respectively. Each significant principle component (PC) was derived from the chain codes of the walnut contours illustrated, regardless of the shape variation in the cultivars. PC1 was the component which explained the greatest variation among the walnut

TABLE 6. Sphericity, shape index and aspect ratio attributes

Cultivars	Sphericity (S, %)	Shape Index (SI)	Shape description	Cultivars	Aspect ratio at horiz. orient. (AR <sub>h</sub> )	Cultivars	Aspect ratio at vertical orient. (AR <sub>v</sub> )
Serr	82.55±2.53 k*	1.333±0.060	Oval	Kaman-5	1.071±0.036 j	Şebin	1.054±0.032 e
Sütyemez-2	84.44±1.92 i	1.287±0.044	Oval	Şebin	1.072±0.037 j	Maraş-18	1.067±0.032 d
Midland	84.79±6.05 i	1.292±0.138	Oval	Sütyemez-1	1.078±0.050 ij	Sütyemez-2	1.068±0.034 d
Şen-2	85.70±1.85 h	1.259±0.041	Oval	KR-1	1.090±0.036 i	Chandler	1.073±0.032 d
Maraş-18	86.41±2.40 h	1.245±0.052	Spherical	Howard	1.175±0.051 h	Maraş-12	1.097±0.030 c
Bilecik	87.20±2.19 g	1.227±0.047	Spherical	Chandler	1.179±0.044 fg	Kaman-1	1.098±0.040 c
Maraş-12	88.59±2.11 f	1.199±0.043	Spherical	Maraş-12	1.190±0.042 ef	Midland	1.100±0.044 c
Chandler	88.79±1.98 f	1.195±0.040	Spherical	Maraş-18	1.191±0.047 ef	Kaman-5	1.101±0.040 c
Kaman-1	89.03±2.18 ef	1.190±0.043	Spherical	Kaman-1	1.198±0.046 e	Serr	1.103±0.039 c
Pedro	89.62±2.34 de	1.179±0.042	Spherical	Pedro	1.201±0.049 e	Howard	1.106±0.038 c
Howard	89.93±1.95 d	1.172±0.039	Spherical	Sütyemez-2	1.220±0.041 d	Pedro	1.117±0.038 b
Şebin	92.03±1.90 c	1.132±0.035	Spherical	Bilecik	1.250±0.045 c	KR-1	1.128±0.038 ab
Kaman-5	95.01±2.10 b	1.087±0.030	Spherical	Midland	1.273±0.050 b	Bilecik	1.128±0.047 ab
Sütyemez-1	95.62±2.95 b	1.095±0.033	Spherical	Şen-2	1.282±0.044 b	Sütyemez-1	1.129±0.041 a
KR-1	96.87±1.52 a	1.076±0.021	Spherical	Serr	1.295±0.056 a	Şen-2	1.136±0.042 a
Mean±SD	89.07±4.85	1.198±0.092	-	Mean±SD	1.185±0.086	Mean±SD	1.100±0.045
Range	69.75–99.99	1.029–1.715	-	Range	1.000–1.440	Range	1.003–1.268
F (P, sigma)	262.25(0.000)**			F (P, sigma)	280.86(0.000)**	F (P, sigma)	44.40(0.000)**

\* one hundred repetitive means (n = 100) for each cultivar followed by the same letter in the same column are not different as determined by the Tukey test at 5% significance level  
 \*\* highly significant (p < 0.01)

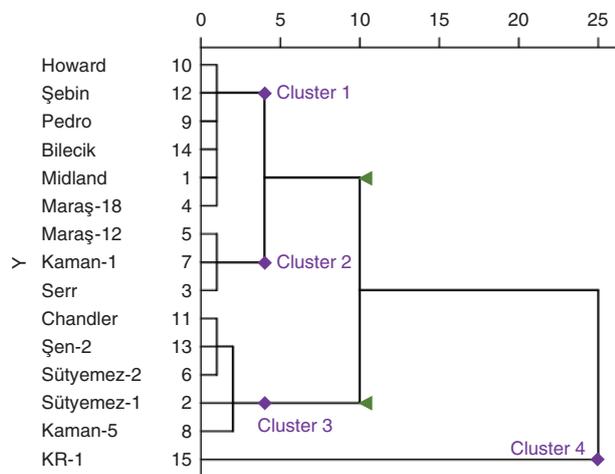


FIGURE 2. Dendrogram of the walnut cultivars

cultivars and showed the width alteration in the walnut cultivars. This alteration resulted in a variation in dimensional and shape attributes such as length, sphericity and aspect ratio. The principle components PC2 - PC7 described the smaller variations in the outlines of the walnut cultivars. For instance, PC2 originated from the swelling of the walnut base.

Flatness and tapering at the bottom of the walnut was revealed by PC3. There was a one-sided tapering at the bottom of the walnut at PC4. At PC5, the slight, centripetal tapering was found at the walnut base. At PC6, tapering and flatness form both the top and the bottom of the walnut were determined. PC7, which was the lowest component of total variance, constituted the reason for the flatness at the bottom and tapering at the top of the walnut.

### 3.7. Results of discriminant analysis based on Elliptic Fourier descriptors and pairwise comparison in shape

According to results from the discriminant analysis illustrated in Table 7, six canonical discriminant functions were obtained from the significant principle components (PC1-PC7) derived from EFA based on walnut outlines. Discriminant analysis showed that the first seven PC scores explained a major part of the variance among the PCs. The first two canonical functions explained 86.9% of the total variance. In reference to the Wilk's Lambda and Pillai Trace statistics, significant differences were observed in the shapes of the walnut cultivars. The Hotelling's pairwise comparison results revealed the distinctions and showed similarities among the outlines of the walnut cultivars. Mahalanobis

PC's		- 2 SD	Mean	+ 2 SD	Shape evaluation
PC1 65.3% of total variance					width alteration
PC2 11.9% of total variance					swelling of bottom
PC3 5.1% of total variance					flatness and tapering form at bottom
PC4 4.1% of total variance					one-sided tapering form at bottom
PC5 2.6% of total variance					centripetal tapering form at bottom
PC6 2.1% of total variance					tapering form or flatness at top and bottom
PC7 1.6% of total variance					flatness at bottom and tapering form at top

FIGURE 3. Principal components (PCs) of the walnut cultivars

distances in the lower triangle account for the variance of each walnut outline and the covariance between the cultivars. As the distance increased, the distinctions among the cultivars grew. The lowest distances marked in the lower triangle showed the cultivars which were similar to each other. Bonferroni-corrected P values were given in the upper triangle and the walnut cultivars which were identical were colored as pairwise. The uncolored cells showed the significant ( $p < 0.01$  and  $p < 0.05$ ) distinctions among the pairwise walnut cultivars.

The results of the Hotelling's pairwise comparisons were found to be compatible with the scatter plot shown in Figure 4. The scatter plot showed the cultivar centroids with regard to their canonical discriminant functions. The loadings of the first two canonical functions explained 86.9% of the total variance and they were presented as standardized canonical discriminant function coefficients in Table 7. According to these loadings, the canonical function 1 had the highest loading of the PC1, while the canonical function 2 explained the variation caused by PC3, PC6 and PC7. The similarities or distinctions among the cultivars should be evaluated based on the results of the Hotelling's pairwise comparison in addition to the centroids in the scatter plot. Because Kaman-5 had a different characteristic in shape, it remained alone in its own group. The centroid coordinates shown in Figure 4 indicated that the Howard and Maraş-12 cultivars

had different shape attributes, because their coordinates on the function 2 axis were different. However, their coordinates were close to the origin of the discriminant function 1 axis, and the results of the pairwise comparison test determined the similarity between them. Serr and Midland were the cultivars which comparatively stayed on the left of the function 1 axis. Chandler, Pedro, Kaman-1 and Maraş-18 were similar cultivars in shape due to their centralizing at the origin. Sütyemez-2, Bilecik and Şen-2 cultivars together constituted a separate group in shape attributes.

#### 4. DISCUSSION

The surface area attribute of agricultural products is closely related to evaporation. Hence, Mohseni and Peters (2016) reported that an increasing ratio of 360% at the surface area of a particle caused the drying rate to be enhanced by more than twice. George *et al.*, (2007) reported that the drying rate was accelerated due to increased surface area of the product and recommended a surface area to volume ratio of  $12 \text{ cm}^{-1}$  for the optimal ratio of surface area to volume for thin-layer drying of breadfruit with sun drying. Dursun (2001) indicated that the projected area of a product is a crucial engineering parameter for classification and clearing with regard to the principles of hydrodynamic and aerodynamic. Sayıncı *et al.*, (2015a) determined that the projected area average of

TABLE 7. Results of the discriminant analysis and pairwise comparison

A. Eigenvalue statistics of discriminant functions						
Eigenvalue statistics	Function 1	Function 2	Function 3	Function 4	Function 5	Function 6
Eigenvalues	3.166	0.967	0.556	0.047	0.013	0.008
% of variance	66.6	20.3	11.7	1.0	0.3	0.2
% cumulative variance	66.6	86.9	98.6	99.5	99.8	100.0
Canonical correlation	0.872	0.701	0.598	0.211	0.115	0.091

B. MANOVA results (computed in PAST ver. 3.01)						
Effects	Statistics	Value	Hypothesis df	Error df	F	P (sigma)
Cultivars	Wilks' Lambda	0.2482	28	2952	106.2	0.000**
	Pillai Trace	0.7871	28	2954	68.46	2.406E-295**

C. Standardized canonical discriminant function coefficients						
PC's obtained from EFA	1	2	3	4	5	6
PC1	<b>1.012</b>	-0.178	0.012	0.054	0.01	0.02
PC2	-0.128	0.182	0.207	0.773	-0.345	0.462
PC3	0.295	<b>0.758</b>	0.606	-0.147	0.066	-0.025
PC5	0.018	-0.173	0.06	-0.592	-0.376	0.694
PC6	0.13	<b>0.485</b>	-0.557	0.04	0.572	0.432
PC7	-0.295	<b>-0.605</b>	0.603	0.057	0.502	0.208

D. The results of the Hotelling's pairwise comparisons. Bonferroni-corrected P values in upper triangle, Mahalanobis distances in lower triangle (computed in PAST ver. 3.01)															
Cultivars	Midland	Sütyemez-1	Serr	Maraş-18	Maraş-12	Sütyemez-2	Kaman-1	Kaman-5	Pedro	Howard	Chandler	Şebın	Şen-2	Bilecik	KR-1
Midland		0.000	1.416	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.480	0.019	0.000
Sütyemez-1	21.00		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	57.897	0.000	0.000	0.028
Serr	0.18	24.62		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.390	0.000	0.000
Maraş-18	3.05	8.20	4.44		89.253	0.027	22.498	0.000	16.022	0.918	0.432	0.000	0.000	0.000	0.000
Maraş-12	2.80	8.58	4.15	0.01		0.142	28.751	0.000	39.537	0.373	0.383	0.000	0.000	0.000	0.000
Sütyemez-2	1.43	11.92	2.34	0.35	0.28		2.606	0.000	0.277	0.000	0.000	0.000	0.000	0.000	0.010
Kaman-1	2.50	9.47	3.68	0.06	0.05	0.15		0.000	4.657	0.001	0.001	0.000	0.000	0.000	0.000
Kaman-5	21.38	0.69	25.29	9.11	9.42	12.94	10.62		0.000	0.000	0.000	0.002	0.000	0.000	0.001
Pedro	2.40	9.21	3.72	0.08	0.04	0.25	0.13	9.77		0.049	0.403	0.000	0.000	0.000	0.000
Howard	4.47	6.09	6.22	0.20	0.24	1.03	0.48	6.67	0.32		30.746	0.000	0.000	0.000	0.000
Chandler	3.97	6.76	5.70	0.23	0.24	0.94	0.51	7.03	0.23	0.05		0.000	0.000	0.000	0.000
Şebın	20.94	0.02	24.61	8.25	8.62	11.98	9.57	0.46	9.19	6.08	6.69		0.000	0.000	0.154
Şen-2	0.22	21.81	0.18	3.27	3.04	1.48	2.54	22.96	2.78	4.93	4.59	21.89		0.016	0.000
Bilecik	0.36	16.58	0.82	1.46	1.31	0.39	1.03	17.50	1.12	2.61	2.35	16.63	0.37		0.000
KR-1	16.66	0.36	20.01	5.78	6.07	8.96	6.95	0.51	6.48	3.94	4.37	17.69	12.96		

\*\* highly significant (p < 0.01)

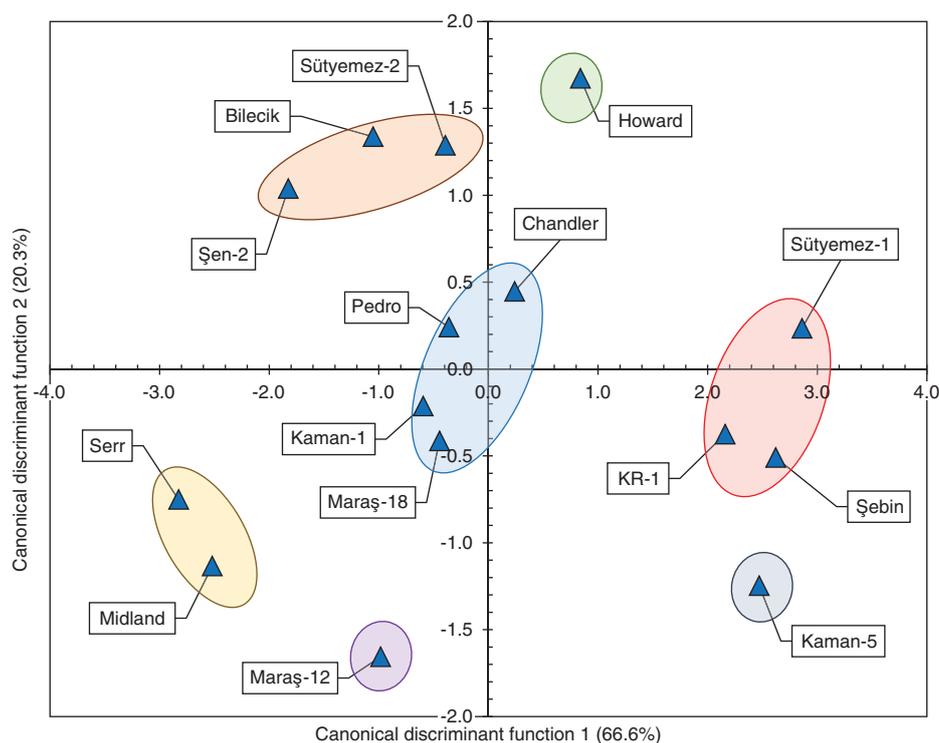


FIGURE 4. Group centroids of the walnut cultivars

hazelnut cultivars was to be  $2.69 \text{ cm}^2$ . This average showed that the projected area average of  $10.5 \text{ cm}^2$  of the walnut cultivars used in present study were 3.9-fold higher than that of the hazelnut cultivars.

In a study conducted by Ercisli *et al.*, (2012), the variation interval of the dimensional averages for walnut cultivars were determined as between 40.5–48.8 mm for length, between 34.0–46.4 mm for width and between 32.0–42.7 mm for thickness. For the walnut cultivars used in present study, the length, width and thickness averages varied between 37.6–44.3 mm, between 32.1–45.1 mm, and between 28.3–40.0 mm, respectively. These dimensional attributes are crucial engineering parameters for walnut cracking systems and separation, and used to adjust the dimensions between cylinder pairs in breaker systems designed to crack walnut shells. Similarly, the pore dimensions for the separation processing of the walnut cultivars should be determined by taking dimensional attributes into account.

Aspect ratio is defined by the major axis and minor axis of an ellipse equivalent to an object. Aspect ratios close to 1 indicate increasing circularity of the object on a two dimensional view. But, in the present study, decreasing sphericity was observed with increasing aspect ratios. Such a finding indicates that the relation between aspect ratio and sphericity or shape index was insignificant. According to the shape description, it can be concluded that most of the walnut cultivars were

spherical-shaped. The studies conducted on walnut cultivars or genotypes by Ercisli *et al.*, (2012) and Ozkan and Koyuncu (2005) support the present findings. While shape index average decreased, the sphericity of the walnuts increased because the relation between both variables was significant.

Sayıncı *et al.*, (2015a) noted that the EFA method provided a superior distinction among hazelnut cultivars. The size and shape attributes of the walnut cultivars were quite well distinguished with the EFA method in the present study. Cluster analysis is also an easy method used to distinguish cultivars. Cluster analysis revealed similar walnut cultivars. All these findings provide crucial information for walnut processing technologies such as cracking, separation, cleaning, packaging and transporting.

Shape distinctions for walnut cultivars originates predominantly from width alteration. The other significant distinctions among the cultivars were the swelling, flatness or tapering form of the walnut base. These typical distinctions can be beneficial to distinguish the cultivars, to determine the abnormality or quality of the product, and to design separators for product classification processes.

## 5. CONCLUSIONS

In the present study, walnut shapes were analyzed with the EFA method through closed-counter modelling of the products and the method revealed

distinctions among the walnut cultivars quite well. Both the centroid distributions on scatter plot and pairwise comparisons revealed similarities among them and allowed for classifying the walnut cultivars.

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