Erwerbs-Obstbau (2019) 61:245–256
https://doi.org/10.1007/s10341-019-00423-7

ORIGINAL ARTICLE

Shape Discrimination of Almond Cultivars by Elliptic Fourier Descriptors

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Received: 26 October 2017 / Accepted: 7 February 2019 / Published online: 27 February 2019
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Abstract

Knowledge is required about shape and size features of almonds before the design of machines, equipment and systems used in harvest and postharvest processes such as classifying, drying, packaging, grading, transportation and quality assessments of almonds. Such attributes are also required for assessing consumer preferences, cultivar registration, security of plant variety rights, investigating heritability and analyzing shape abnormalities. In present study, seven almond cultivars ('Bertina', 'Ferragnes', 'Ferradual', 'Ferrostar', 'Glorieta', 'Lauranne' and 'Marta') grown in Turkey were used in order to determine the longitudinal, surface and gravitational features and to compare their shapes with elliptic Fourier descriptors. 'Bertina', 'Glorieta' and 'Ferragnes' had the greatest longitudinal, surface and gravitational averages. 'Marta' cultivars had the lowest averages in all parameters except for mass, thickness and projected area in suture orientation. Among the almond cultivars, 'Lauranne' and 'Ferrostar' had the lowest mass and thickness averages. Sphericity averages varied between 60.6–71.6% with the greatest value in 'Ferradual' cultivar. Among the cultivars again, 'Ferrostar' had the greatest elongation, roundness and aspect ratio averages. In terms of the nut shape, elliptic Fourier descriptors revealed that the greatest difference was observed in width dimension in horizontal orientation and thickness dimension in suture orientation. MANOVA results revealed that almond cultivars were significantly different from each other in terms of the nut shape. The results of the Bonferroni pairwise comparison test revealed that all almond cultivars was different in shape.

Keywords Almond features · *Amygdalus communis* L. · Elliptic Fourier · Physical properties · Shape analysis

Unterscheidung der Fruchtform von verschiedenen Mandelsorten mit Hilfe von elliptischen Fourier-Deskriptoren

Schlüsselwörter Merkmale der Mandel · *Amygdalus communis* L. · Elliptische Fourier-Transformation · Physikalische Eigenschaften · Formanalyse

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Abbreviations

M	mass, g
V	volume, mm^3
PA_H	projected area at horizontal orientation, mm^2
PA_S	projected area at suture orientation, mm^2
SA	surface area, mm^2
D_g	geometric mean diameter, mm
L	length, mm
W	width, mm
T	thickness, mm
P	perimeter, mm
φ	sphericity, %
SI	shape index
AR_H	aspect ratio at horizontal orientation
AR_S	aspect ratio at suture orientation

E_H	elongation at horizontal orientation
E_S	elongation at suture orientation
R_H	roundness at horizontal orientation
R_S	roundness at suture orientation
El_H	ellipticity at horizontal orientation
El_S	ellipticity at suture orientation
R_1	min radius at horizontal orientation, mm
R_2	max radius at horiz.or suture orient., mm
R_3	min radius at suture orientation, mm

Introduction

Almond (*Amygdalus communis* L.) is a crucial agricultural product for food industry and peeled forms constitute greater proportion of almond production (Valverde et al. 2006). Almond kernels contain about 6.0 kcal/g energy and 15.64% protein. Kernels have quite high oil contents varying between 35.27–40.00%. Oleic acid is the major component (around 40%) of almond kernel oil (Aydin 2003).

Almond is a perennial plant and widely grown in Central Anatolia, Mediterranean and Marmara regions of Turkey (Aydin 2003). Turkey is an important producer country with an annual production of 73.230 tones and average yield of 2.710 kg/ha (FAO 2014).

Shape and size are significant physical attributes. They are also used as an indicator for marketing quality of the agricultural products and for identification of plant cultivars. A knowledge is required about such attributes before the design of machines, equipment and systems used in harvest and postharvest processes such as classifying, packaging, grading, transportation and quality assessments of agricultural products (Beyer et al. 2002; Sadrnia et al. 2007; Costa et al. 2011; Sayıncı et al. 2015a). Besides, such descriptive features are also used for different commercial and industrial purposes (Costa et al. 2011) including cultivar description (Khanizadeh 1994; Beyer et al. 2002), assessing consumer choices (Kays 1999), investigating heritability of product shape attributes (Cannon and Manos 2001) or analyzing shape abnormalities (Brewer et al. 2007).

In order to describe an agricultural product in terms of the size, several variables such as length, width, thickness, geometric mean diameter and perimeter are used. These variables designate visual appearance of the product and significantly influence consumer preferences (Kays 1999; Jahns et al. 2001). Shape variables such as sphericity, aspect ratio, elongation, circularity, shape index and roundness are some of the independent variables describing the shape of agricultural products (Sayinci et al. 2015a).

Agricultural products are commonly compared with each other just based on psychophysical subjective assessments (Mohsenin 1986). Thus, some descriptive classes recalling shape characteristics such as long, round, oblong have been developed instead of these subjective assessments (Sayıncı et al. 2015a). Unshelled almonds are categorized as round, ovate, oblong, cordate and extremely narrow (Gülcan 1985; Antonucci et al. 2012). In other studies, hazelnuts (Bostan and Islam 1999; Aydin 2002; Cristofori et al. 2008), plums (Bayazit and Yılmaz 2011), walnuts (Ozkan and Koyuncu 2005; Ercisli et al. 2012), apples (Kazankaya et al. 2009), rosehips (Ekincialp and Kazankaya 2012), potatoes (Altuntas et al. 2012) and onions (Bahnasawy et al. 2004) were classified or named based on their shape index values.

The studies about the physical attributes of Almond cultivars are quite limited (Valverde et al. 2006). Kalyoncu (1990) determined the size and rupture strength of 10 almond cultivars and revealed the relationship between rupture strength and the size of the almond cultivars. Aydin (2003) assessed some physical features of almond cultivars as a function of moisture content. Altuntas et al. (2010) investigated the effect of compression force at different axes and speeds on mechanical features and geometrical features of almond cultivars. Loghavi et al. (2011) determined physical and mechanical properties of Iranian almond varieties.

Elliptic Fourier Analysis (EFA) have been widely used in shape description of agricultural products. EFA generates the descriptors based on boundary contour of an object into a set of harmonically closed curves (Carlo et al. 2011; Costa et al. 2010, 2011). The evaluation of shape distinctions and classifications between cultivars are able to successfully make by EFA. Antonucci et al. (2012) used an EFA-based image processing method and carpological measurements to discriminate shape features of 18 almond cultivars. Similarly, EFA was used for cereal grains (Mebatsion et al. 2012a; 2012b), cherry laurel accessions (Sayıncı et al. 2015b), in plant leaf shape analyses (Du et al. 2007; Soares et al. 2011; Demandante et al. 2014), Italian hazelnut shape analyses (Menesatti et al. 2008), orange fruit shape assessments (Costa et al. 2009; Sayıncı et al. 2012) and apple shape assessments (Currie et al. 2000). Besides, EFA-based image processing was also used for evaluation of geometrical uniformity of spray nozzle orifices by Sayıncı (2016a, 2016b). In brief, EFA provided an excellent tool for shape discrimination of several agricultural products.

This study was conducted to investigate the size and shape features describing the physical attributes of seven almond cultivars and to reveal shape distinctions with elliptic Fourier descriptors modelling the closed-contour of the cultivars.

Material and Method

Almond Cultivars and Test Preparations

This study was conducted for disclosing the shape distinctions among seven almond cultivars. The almond nuts were obtained from the Pistachio Research Institute in Gaziantep province of Turkey in 2016 growing season. The almond cultivars were selected as 'Bertina', 'Ferragnes', 'Ferradual', 'Ferrostar', 'Glorieta', 'Lauranne' and 'Marta' (Fig. 1). Following the harvest, 100 almonds were randomly sampled from each cultivar. Samples were then transferred to Biological Material Laboratory. Shelled almonds were numbered separately and fruit mass was determined with a digital balance (Shimadzu TW423L Model, Japan) (±0.001 g).

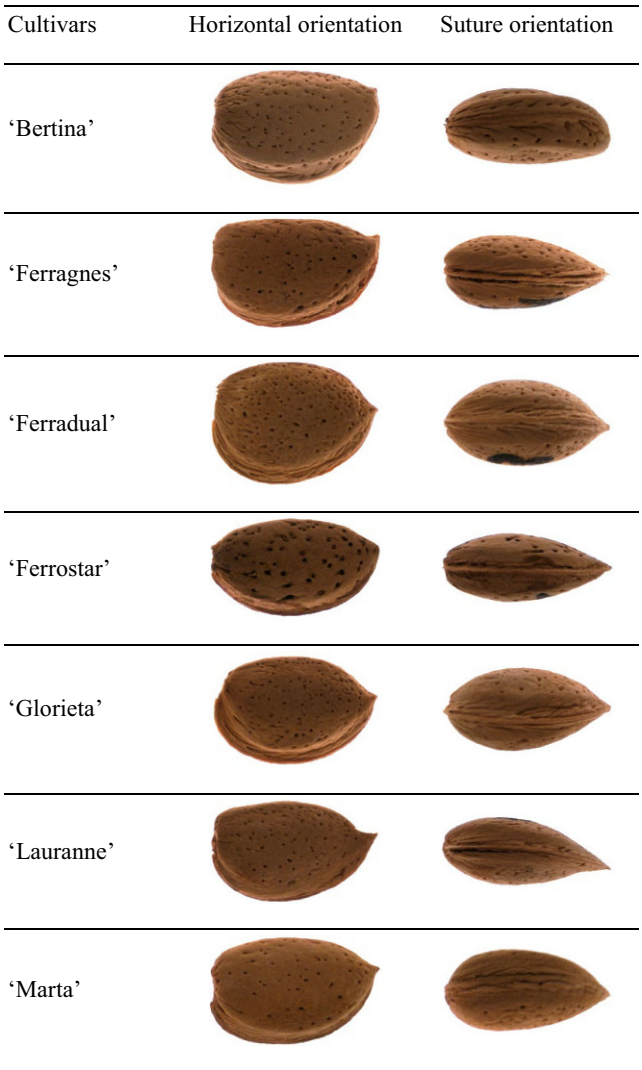


Fig. 1 Almond cultivars

Image Acquisition System

An acquisition system constituted by Kara et al. (2013) was used to obtain the almond images. This system equipped with a digital SLR camera (Nikon D300, JP) was placed in a dark room and privately acquired with the aim of obtaining no-shade image on a background. The image without shadow on the back ground was supplied with three paraflashes in the softbox. Two paraflashes with reflector were positioned to the height of 2.2 meters, and positioned towards to the sample surface with the angle of 45°. The other paraflash was placed under the sample surface at 100 cm from floor. Before taking the image, the light intensity on the transparent surface after the flash shot was adjusted using an exposure meter (Sekonic L758D Dijitalmaster, JP). The sample surface was placed over a white fiberglass plate and the almond samples were carefully located on it in the matrix form of 5 × 8 at two different orientations (horizontal and suture). In order to keep the almond samples at a stabile position on the fiberglass in two orientations, putty was used. The horizontal orientation represents the natural position of the almond cultivars on the transparent surface. The digital camera was vertically positioned at 51-cm height above the samples on the surface. In order to prevent the hand–vibration on the camera, an external shutter button with a fixed cable was used during the test. The captured images were obtained as color *.tiff extension. A ruler used on the transparent surface before the experiment provided a pixel unit to convert into millimeter. The conversion value was determined as 0.0770 mm per pixel after the calibration. During the experiments, temperature and relative humidity of the laboratory was recorded as 22.4 °C and 26%, respectively.

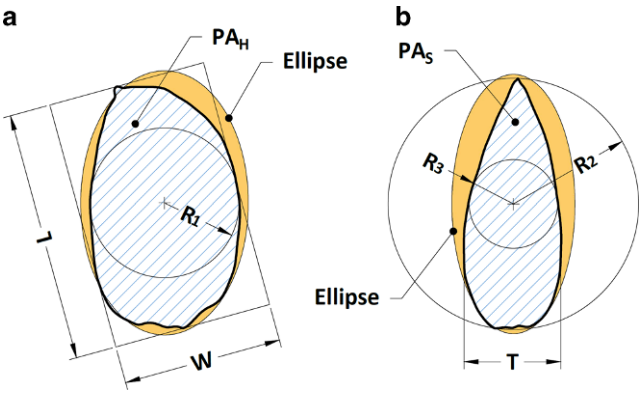


Fig. 2 Basic sizes and notations for any almond cultivars (R_1, R_2, R_3: the length of the line that can be drawn to pass through the centroid position and join two points on each object's perimeter; L, W, T: caliper (feret) length in terms of their orientation). **a** Horizontal orientation; **b** Suture orientation

Table 1 Equations used for size and shape features of almond cultivars

Size and shape features	Equations	References
Volume (V)	$V = (4/3) \cdot \pi \cdot (R_1 \cdot R_2 \cdot R_3)$	Volume of ellipse
Geometric mean diameter (D_g)	$D_g = \sqrt[3]{(L \cdot W \cdot T)}$	Kara (2017)
Surface area (SA)	$SA = \pi \cdot D_g^2$	Olajide and Ade-Omowaye (1999)
Sphericity (φ)	$\varphi = (D_g / L) \cdot 100$	Mohsenin (1986)
Shape index (SI)	$SI = L/\sqrt{W \cdot T}$	Loghavi et al. (2011)
Elongation at hor. orient. (E_H)	$E_H = L/W$	Fıratlıgil-Durmuş et al. (2010)
Elongation at sut. orient. (E_S)	$E_S = L/T$	–
Aspect ratio at hor. orient. (AR_H)	$AR_H = R_2/R_1$	Kara (2017)
Aspect ratio at sut. orient. (AR_S)	$AR_S = R_2/R_3$	–
Ellipticity at hor. orient. (El_H)	$El_H = (3.14 \cdot R_2 \cdot R_1) / PA_H$	Similarity to ellipse
Ellipticity at sut. orient. (El_S)	$El_S = (3.14 \cdot R_2 \cdot R_3) / PA_S$	–
Roundness at hor. orient. (R_H)	$R_H = P^2 / (4 \cdot \pi \cdot PA_H)$	Sayinci et al. (2015b)
Roundness at sut. orient. (R_S)	$R_S = P^2 / (4 \cdot \pi \cdot PA_S)$	–

Determination of Size and Shape Features

In order to determine the size and shape features of the almond cultivar from the images obtained in horizontal and suture orientations, SigmaScan®Pro 5.0 software was used. After calibrating the pixel unit for any images in this software, each of the almond samples on the image were measured respectively. The measurements presented in Fig. 2 relating the size and shape features of the almond samples were obtained and recorded on MS Excel spreadsheet.

Some features were calculated by using the equations given in Table 1. In order to test the almond cultivars in terms of their size and shape features, SPSS version 20.0 was employed for One-way ANOVA with a 95% confidence level. The differences among the means were tested with Tukey's multiple comparison test at 95% significance level (IBM SPSS® 2010).

Elliptic Fourier Analysis

SHAPE software (version 1.3) was used for Elliptic Fourier (EF) analysis to digitize the outlines of each almond contour (Iwata and Ukai 2002). Initially, almond images were converted into *.bmp (bitmap) extension file of 24-bit and gray level of the images were acquired by using the first module of the software tool. In this module, the images were filtered to reduce the noise level on the overall image. Chain codes were generated then to geometrically describe the closed-contour of the almond samples. These codes ranging from 0 to 7 described the outline of the almond samples. These data acquired from the chain code were normalized by using the second module of the software based on the ellipse of the first harmonic so as to be independent of orientation, size or location. The outlines of the almond were described with 20 harmonic numbers (Kuhl and Giardina 1982; Lootens et al. 2007; Tabugo et al. 2012; Mebatsion et al. 2012a; Vasallo et al. 2013; Sayinci et al. 2015a). In the third module of the software, principal component analysis was performed by using the normalized chain codes so as to reduce the shape descriptors, and a smaller number of independent shape variables was obtained. These variables, the best describing the contour of the almonds were principle component (PC) scores. The PC scores of the almond cultivars constituted as observed values of the multivariate analysis of variance (MANOVA). MANOVA was carried out with SPSS version 20.0 statistical software. Discriminant analysis was performed for correctly classification of almond cultivar PCs. The acquired discriminant scores were the coordinates of the almond cultivars presented in two axis, which were the canonic discriminant functions. The scores enabled to compare the differences among the almond cultivars via Hotelling's pairwise comparisons with Bonferroni correction and squared Mahalanobis distances.

Results

Size and Shape Features of the Almond Cultivars

In this section, the results of gravimetric, surface, longitudinal and shape features of almond cultivars were summarized. The estimates of the ANOVA performed for the data related to gravimetric, surface, longitudinal and shape of the almond cultivars are provided in Table 2 and 3. All longitudinal, surface, shape, and gravimetric variables were found to be highly significant ($p < 0.01$). Among the almond cultivars, 'Glorieta' and 'Bertina' had the greatest fruit mass averages as seen in Table 2. Although the lowest average mass was observed in 'Ferrostar' and 'Lauranne', their projected area and surface area averages were higher than 'Marta'. In terms of both surface and volume features, 'Marta' had the lowest averages. As for the longitudinal

Table 2 Gravimetric, surface and longitudinal features of the almond cultivars (mean ± SD)

Cultivars	Gravitational features		Surface features		
	Mass	Volume	Projected area	Projected area	Surface area
	M (g)	(V, cm^3)	PA_H (cm^2)	PA_S (cm^2)	(SA, cm^2)
'Bertina'	4.73 ± 0.61 a*	6.88 ± 1.00 b	6.73 ± 0.65 a	4.26 ± 0.40 a	17.55 ± 1.71 a
'Ferragnes'	4.24 ± 0.71 b	6.74 ± 1.07 b	6.50 ± 0.87 a	4.19 ± 0.48 a	17.69 ± 2.00 a
'Ferradual'	4.05 ± 0.45 b	6.07 ± 0.74 c	5.52 ± 0.49 bc	3.72 ± 0.32 b	16.08 ± 1.32 b
'Ferrostar'	2.60 ± 0.36 d	5.36 ± 0.68 d	5.68 ± 0.59 b	3.57 ± 0.37 b	14.77 ± 1.39 c
'Glorieta'	4.79 ± 0.76 a	7.30 ± 1.31 a	6.57 ± 0.87 a	4.13 ± 0.49 a	18.21 ± 2.22 a
'Lauranne'	2.75 ± 0.40 d	5.04 ± 0.94 d	5.28 ± 0.74 c	3.22 ± 0.39 d	14.31 ± 1.82 c
'Marta'	3.04 ± 0.40 c	4.53 ± 0.67 e	4.62 ± 0.52 d	3.40 ± 0.29 c	13.34 ± 1.30 d
F (*p*, sigma)	288.0 (0.000)**	122.4 (0.000)**	128.9 (0.000)**	108.7 (0.000)**	122.1 (0.000)**
All	3.74 ± 1.02	5.99 ± 1.34	5.84 ± 1.00	3.78 ± 0.55	16.00 ± 2.45
Min–max	1.51–6.56	3.15–10.27	3.62–8.62	2.39–5.31	10.56–23.03
Cultivars	**Longitudinal features of the almond cultivars**				
	Geom. mean dia.	Length	Width	Thickness	Perimeter
	(Dg, mm)	(L, mm)	(W, mm)	(T, mm)	(P, mm)
'Bertina'	23.62 ± 1.15 a*	35.66 ± 1.60 a	23.84 ± 1.46 ab	15.51 ± 0.89 b	95.61 ± 4.47 a
'Ferragnes'	23.69 ± 1.36 a	35.79 ± 2.15 a	23.28 ± 1.84 b	16.00 ± 1.00 a	95.37 ± 6.41 a
'Ferradual'	22.61 ± 0.93 b	31.58 ± 1.46 c	22.62 ± 1.11 c	16.20 ± 0.72 a	85.43 ± 3.86 c
'Ferrostar'	21.67 ± 1.03 c	35.77 ± 2.21 a	20.32 ± 1.10 d	14.01 ± 0.77 d	90.37 ± 5.05 b
'Glorieta'	24.03 ± 1.50 a	35.59 ± 2.50 a	24.16 ± 1.76 a	16.16 ± 0.97 a	94.32 ± 6.37 a
'Lauranne'	21.30 ± 1.36 c	32.89 ± 2.41 b	20.93 ± 1.60 d	14.06 ± 0.83 cd	85.91 ± 6.62 c
'Marta'	20.59 ± 1.00 d	31.88 ± 1.61 c	19.05 ± 1.44 e	14.40 ± 0.65 c	81.00 ± 4.20 d
F (*p*, sigma)	123.4 (0.000**)	92.8 (0.000)**	168.1 (0.000)**	141.8 (0.000)**	112.5 (0.000)**
All	22.51 ± 1.73	34.17 ± 2.72	22.03 ± 2.34	15.19 ± 1.25	89.73 ± 7.55
Min–max	18.34–27.08	26.49–41.51	15.95–28.43	11.59–18.31	70.85–113.03

*Means followed by the same letter in the same column are not different as determined by the Tukey test at 5% significance level
**Highly significant ($p < 0.01$)

features, size features of 'Bertina', 'Ferragnes' and 'Glorieta' cultivars were higher than those of the other cultivars. The lowest thickness was observed in 'Ferrostar' and 'Lauranne' cultivars. But, 'Marta' generally had the lowest size features. The average perimeter increased with increasing geometric mean diameters.

A roundness value close to 1 indicates that cultivar was similar to circular. As can be seen from the roundness values in Table 3, 'Ferradual' had the closest circular shape in both horizontal and suture orientations. 'Ferrostar' appeared to be longer than the other cultivars with regard to elongation feature in both orientations. These findings were also confirmed for the aspect ratio of the samples. Elongation values increased proportionally with increasing aspect ratios. Ellipticity was calculated as the similarity variable to ellipse for both orientations. 'Ferragnes' and 'Ferrostar' cultivars with ellipticity values close to 1 were similar to ellipse geometry as compared to the other cultivars, while 'Bertina' cultivar had the lowest ellipticity in horizontal orientation. But, in general, shape of the cultivars were all seems to be elliptical.

Sphericity can be used as a comparison criterion for spherical products such a hazelnut and walnut etc. As can be seen in Fig. 3a, while 'Ferradual' had the greatest sphericity value, the sphericity of 'Ferrostar' was dramatically lower than the sphericity of the other cultivars. Similar findings were also observed in shape index values of the cultivars (Fig. 3b). Increasing shape index values were observed with increasing sphericity values.

Elliptic Fourier Analysis

In this section, the results of principle component analysis (PCA) performed by using Elliptic Fourier descriptors were presented. The independent shape variations obtained from PC scores of almond outlines are presented in Fig. 4. Each of the PCs found by EFA were determined in two different orientations of the cultivars. The first component PC1 in horizontal and suture orientations was the most important primary source of the variation. PC1 displayed the greatest difference between length and width or length and thickness of the cultivars for horizontal and suture orientations, respectively. For the second principle component PC2 in horizontal orientation, the crucial difference was observed in tip of the almond shell. As for PC2 in suture orientation, the differences between minimum and maximum standard

Table 3 Shape features of the almond cultivars (mean ± SD)

Cultivars	Horizontal orientation			
	Roundness (R)	Elongation (E)	Aspect ratio (AR)	Ellipticity (El)
'Bertina'	1.084 ± 0.016 d*	1.499 ± 0.065 e	1.481 ± 0.062 e	0.983 ± 0.018 d
'Ferragnes'	1.118 ± 0.021 c	1.541 ± 0.068 d	1.549 ± 0.069 d	0.997 ± 0.022 c
'Ferradual'	1.055 ± 0.010 e	1.397 ± 0.043 f	1.398 ± 0.044 f	1.015 ± 0.010 b
'Ferrostar'	1.148 ± 0.027 a	1.761 ± 0.079 a	1.753 ± 0.078 a	0.999 ± 0.019 c
'Glorieta'	1.082 ± 0.020 d	1.474 ± 0.054 e	1.476 ± 0.054 e	1.028 ± 0.014 a
'Lauranne'	1.118 ± 0.040 c	1.572 ± 0.060 c	1.578 ± 0.063 c	1.022 ± 0.018 ab
'Marta'	1.134 ± 0.029 b	1.680 ± 0.109 b	1.661 ± 0.093 b	1.020 ± 0.022 ab
F (p, sigma)	174.7 (0.000)**	305.6 (0.000)**	318.0 (0.000)**	85.1 (0.000)**
All	1.106 ± 0.039	1.560 ± 0.135	1.557 ± 0.131	1.009 ± 0.023
Min–max	1.034–1.445	1.317–1.946	1.287–1.942	0.930–1.068
Cultivars	**Suture orientation**			
	Roundness (R)	Elongation (E)	Aspect ratio (AR)	Ellipticity (El)
'Bertina'	1.285 ± 0.034 d	2.271 ± 0.106 b	2.259 ± 0.100 c	1.008 ± 0.026 e
'Ferragnes'	1.315 ± 0.039 c	2.199 ± 0.105 c	2.250 ± 0.121 c	1.023 ± 0.028 d
'Ferradual'	1.195 ± 0.026 e	1.937 ± 0.083 d	1.931 ± 0.086 e	1.073 ± 0.015 b
'Ferrostar'	1.452 ± 0.073 a	2.546 ± 0.137 a	2.508 ± 0.140 a	1.111 ± 0.061 a
'Glorieta'	1.285 ± 0.045 d	2.180 ± 0.119 c	2.177 ± 0.123 d	1.077 ± 0.024 b
'Lauranne'	1.385 ± 0.056 b	2.298 ± 0.130 b	2.312 ± 0.147 b	1.098 ± 0.032 a
'Marta'	1.285 ± 0.040 d	2.193 ± 0.108 c	2.187 ± 0.112 d	1.041 ± 0.027 c
F (p, sigma)	309.7 (0.000)**	252.2 (0.000)**	208.0 (0.000)**	136.4 (0.000)**
All	1.314 ± 0.089	2.232 ± 0.203	2.232 ± 0.200	1.062 ± 0.049
Min–max	1.138–1.657	1.740–2.968	1.730–2.861	0.920–1.410

*Means followed by the same letter in the same column are not different as determined by the Tukey test at 5% significance level
**Highly significant ($p < 0.01$)

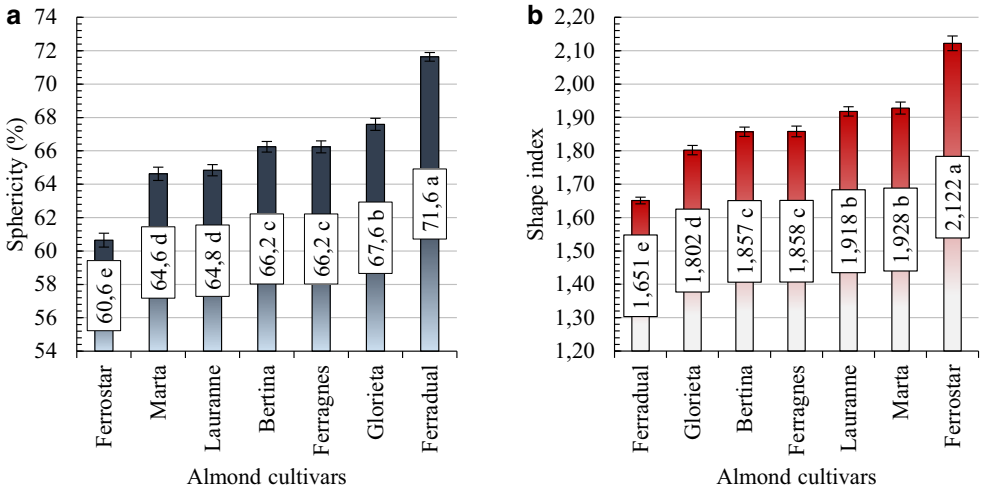


Fig. 3 **a** Sphericity (%) and **b** shape index of the almond cultivars (mean ±2 · SE) (means followed by the same letter in the box chart are not different as determined by the Tukey test at 5% significance level)

deviation originated from the shape differences ranged from drop form to ellipse form. In PC3 which is third component, the shape differences among the cultivars was at minimum level for both orientations. In horizontal orientation, principles components explained 89.45 of total variations in shape futures (PC1 explained 71.71%, PC2 explained 10.00% and PC3 explained 7.665 of total variation). In suture orientation, PC1 explained 66.8%, PC2 explained 12.695 and PC3 explained 6.10% of total variation (three principle components explained 85.7% of total variation in shape futures).

The results for discriminant analysis are provided in Table 4. The first, second and third functions explaining variance among the cultivars, constituted 43.6, 27.1 and 22.0%, respectively, and these functions explained 92.7% of total

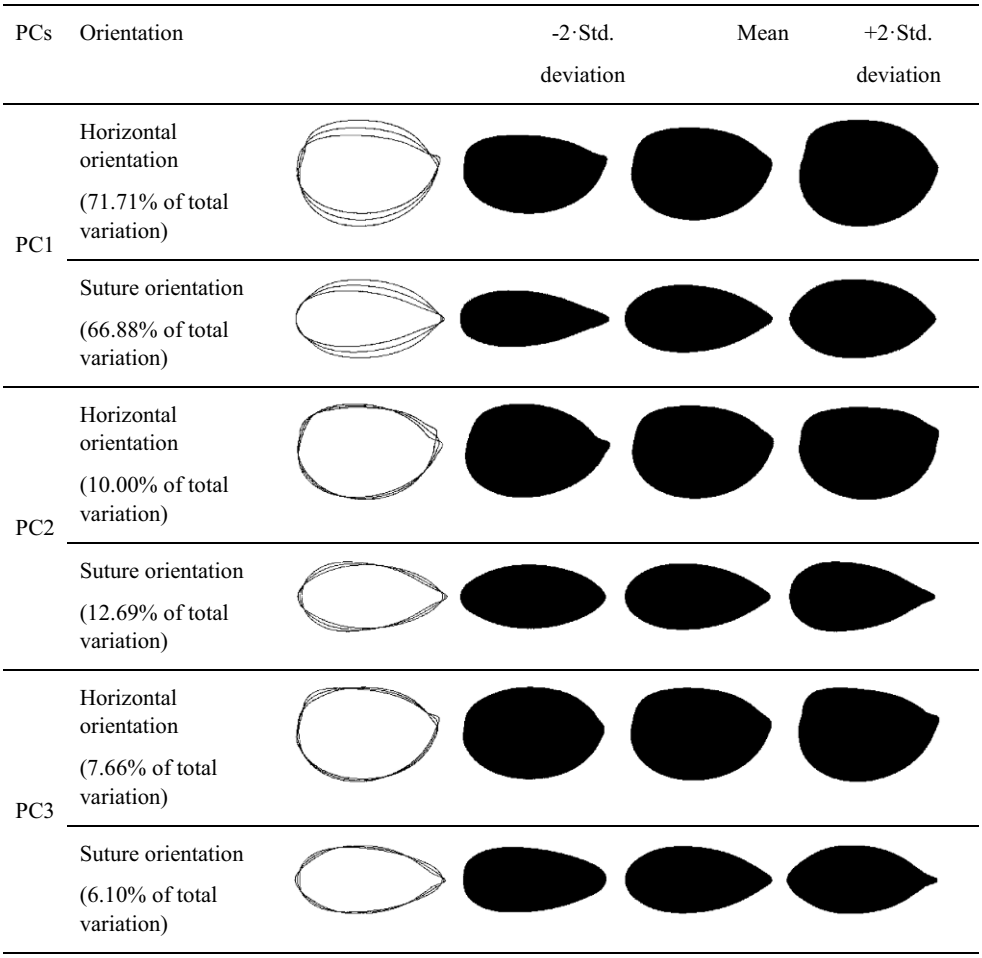


Fig. 4 The first three principal components (PC) obtained from closed-contours of almond cultivars based on a PC analysis of 699 nut sample outlines, each of which has 20-harmonic reconstructions from elliptic Fourier descriptors. The first three PCs explained 89.4% of the total variation in almond images at horizontal orientation and 85.7% of the total variation in almond images at suture orientation. Each PC shows the shape variation of the almond cultivars

variation. The canonical correlation, which was the multiple correlation relation between the predictors and the discriminant functions, was considerably high for function 1, function 2 and function 3. According to the Wilks' Lambda statistics, the effect of the all discriminant functions were found to be highly significant. For the function 1, PC1 in suture orientation was the strongest predictor while PC2 was next in significance as a predictor because of their large coefficients. As to the function 2, PC3 in suture orientation and PC2 in horizontal orientation had the greatest function coefficients. For function 3, PC3 in horizontal orientation had the greatest coefficient. The canonical discriminant function coefficients were unstandardized coefficients, and used to create the discriminant equations.

All almond cultivars were found to be significantly different in terms of the shape (Table 5). In the reference of Mahalanobis distances among the almond cultivars, the closest distances were observed between 'Glorieta' and 'Ferradual' cultivars, and between 'Ferragnes' and 'Lauranne' cultivars, while the distance among the 'Bertina' and 'Lauranne' cultivars had the highest value. Pairwise comparisons revealed that there were not similarities among the almond cultivars.

The classification results of the discriminant analysis are provided in Table 6. Analysis predicted almond group membership with 94.0% accuracy. Because the group membership was predicted in reference to both horizontal and suture orientations of the cultivars, it could be concluded that the power of estimation of the classification increased.

Scatter plots shown in Fig. 5 presented highly significant information about similarities in shapes of almond cultivars. Canonical function 1 had the greatest load in suture orientation for PC1 and PC2 (Table 4). With regard to shape distinction among the principle components, width was identified as a significant distinguishing feature. Appearance of the cultivars gradually turned into round with increasing widths in suture orientation (Fig. 4). According to PC2 in suture orientation, the differences in shape were originated from the geometrical variations in shapes of the cultivars. 'Ferradual' was located farther from the canonical function 1 axis origin (Fig. 5a). The features of elongation and aspect ratio with lower averages for 'Ferradual' confirmed the location of canonical function 1. In contrast, 'Lauranne' and 'Ferragnes' cultivars in shape could be prominently associated with drop form rather than elliptical form as compared to the other cultivars.

Table 4 Discriminant analysis results

Eigen value statistics		**Functions**					
		1	**2**	**3**	**4**	**5**	**6**
Eigen values		7.021	4.370	3.535	0.874	0.200	0.102
% of variance		43.6	27.1	22.0	5.4	1.2	0.6
Cumulative variance, %		43.6	70.7	92.7	98.1	99.4	100.0
Canonical correlation		0.936	0.902	0.883	0.683	0.409	0.304
Statistics		**Significance test of canonical functions**					
		1	**2**	**3**	**4**	**5**	**6**
Wilks' Lambda		0.002	0.017	0.089	0.403	0.756	0.908
df		54	40	28	18	10	4
p (sigma)		0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
Variables		**Standardized canonical discriminant function coefficients**					
		1	**2**	**3**	**4**	**5**	**6**
Horizontal orientation	PC1	0.435	0.015	0.447	**0.701**	–0.244	0.034
	PC2	0.048	**–0.511**	–0.053	0.312	0.363	0.571
	PC3	–0.343	–0.083	**0.539**	0.052	–0.203	–0.300
	PC4	–0.011	–0.051	–0.129	0.046	0.451	**–0.607**
	PC5	0.181	–0.055	0.083	–0.367	**–0.644**	0.264
Suture orientation	PC1	**0.673**	0.145	0.312	–0.600	0.344	–0.038
	PC2	**–0.587**	0.537	0.274	0.091	0.282	0.447
	PC3	0.316	**0.659**	–0.346	0.280	0.016	0.102
	PC4	–0.083	–0.202	0.156	–0.045	0.156	0.015
Variables		**Canonical discriminant function coefficients**					
		1	**2**	**3**	**4**	**5**	
Horizontal orientation	PC1	16.178	0.572	16.617	26.061	–9.075	
	PC2	3.816	–40.826	–4.206	24.898	29.04	
	PC3	–34.627	–8.361	54.463	5.210	–20.461	
	PC4	–1.165	–5.591	–14.124	5.018	49.469	
	PC5	25.106	–7.588	11.453	–50.978	–89.328	
Suture orientation	PC1	27.686	5.951	12.825	–24.690	14.142	
	PC2	–54.717	50.065	25.570	8.513	26.333	
	PC3	38.911	81.174	–42.660	34.465	1.956	
	PC4	–5.994	–14.647	11.322	–3.251	11.334	

**Highly significant ($p < 0.01$)

Table 5 Differences among the almond cultivars based on nut outlines

A. MANOVA results (computed in PAST version 3.01)

Effect	*Statistics*	*Value*	*df1*	*df2*	*F*	*p (sigma)*
Cultivars	Wilks' Lambda	0.002065	36	3020	259	0.000**
–	Pillai's trace	3.194	36	4152	131.3	0.000**

B. Hotelling's pairwise comparisons. Bonferroni corrected *p* values in lower triangle, Mahalanobis distances in upper triangle (computed in PAST version 3.01)

Cultivars	*'Bertina'*	*'Ferragnes'*	*'Ferrostar'*	*'Glorieta'*	*'Ferradual'*	*'Lauranne'*	*'Marta'*
'Bertina'	–	39.7	51.4	35.2	51.2	65.2	36.5
'Ferragnes'	2.37E-96**	–	44.9	38.9	61.8	11.1	15.3
'Ferrostar'	2.67E-106	4.29E-101	–	32.1	62.7	33.4	24.8
'Glorieta'	7.54E-92	1.22E-95	1.99E-88	–	8.0	33.8	19.3
'Ferradual'	3.64E-106	1.51E-113	4.31E-114	1.64E-42	–	59.4	37.4
'Lauranne'	1.19E-115	5.09E-52	7.50E-90	2.27E-90	5.84E-112	–	18.4
'Marta'	1.09E-92	8.29E-62	1.47E-78	1.31E-69	1.31E-93	4.98E-68	–

**Highly significant ($p < 0.01$)

Table 6 Classification results (Predicted almond cultivar membership; 94.0% of original groups were correctly classified)

Cultivars	'Bertina'	'Ferragnes'	'Ferrostar'	'Glorieta'	'Ferradual'	'Lauranne'	'Marta'	Total
'Bertina'	100	0	0	0	0	0	0	100
'Ferragnes'	1	88	0	1	0	3	7	100
'Ferrostar'	0	0	98	1	0	0	1	100
'Glorieta'	0	0	0	89	9	1	1	100
'Ferradual'	0	0	0	3	97	0	0	100
'Lauranne'	0	7	0	1	0	92	0	100
'Marta'	0	2	0	2	0	2	93.9	100

Canonical function 2 had the greatest load for PC2 with negative correlation in horizontal orientation, and for PC3 in suture orientation. Variations of horizontal orientation were originated from the sharp pointed shells. There were slight differences in PC3. 'Bertina' cultivar under the canonical function 2 axis showed dissimilarity with its elliptical form in suture orientation (Fig. 5a). 'Bertina' also had the lowest ellipticity in both orientations (Table 4). Moreover, 'Bertina' had a distinguishing shape feature in terms of the peak point form of the almond shell in horizontal orientation.

Considering the canonical function 3, it was observed that PC3 in horizontal orientation had the highest load alone. Even though the total variance of 7.66% in PC3 was very low, the difference resulted from the variation at sharp-edge of the almond cultivar (Fig. 4). 'Ferrostar' was located under the canonical function 3 axis (Fig. 5b). This location made 'Ferrostar' different from the other cultivars, due to its elliptical form dissimilar the others in horizontal orientation. According to the descriptive shape features given in Table 3, it was also observed that 'Ferrostar' had the highest roundness, elongation and aspect ratio averages.

PC1 in horizontal orientation as indicated in Table 4 had the greatest load of canonical function 4. This load was originated from the variation of 71.71% in horizontal orientation. The variation was based prominently on the width of the almond cultivar (Fig. 4). Thus, 'Marta' under the canonical function 4 axis with the lowest width average (Table 4) was located under the canonical function 4 (Fig. 5c).

Discussion

This study focused on identification of some size and shape features of almond cultivars and comparison of the almond shapes with elliptic Fourier descriptors. The highest longitudinal, surface and gravitational averages were observed in 'Bertina', 'Glorieta' and 'Ferragnes' cultivars. In terms of the general features, 'Marta' had the lowest averages excluding mass, thickness and projected area in suture orientation. Among the almond cultivars, 'Lauranne' and 'Ferrostar' had the lowest mass and thickness averages. In a previous study of Altuntas et al. (2010), volume, surface and longitudinal averages of 'Nonpareil', 'Picantili' and 'Drake' almond cultivars were found to be lower than those of the other cultivars. With regard to mass averages, 'Picantili' (2.77 g) had similar values with 'Ferrostar' (2.60 g) and 'Lauranne' (2.75 g).

Koyuncu et al. (2004) reported that the rapture energy for walnut decreased with increasing geometric mean diameters. Hence, it can be concluded that the rupture energy for 'Bertina', 'Glorieta' and 'Ferragnes' cultivars was lower than the other cultivars. Khazaei et al. (2002) reported the average absorbed energy of almond as 540 mJ, 482 mJ and 450 mJ for loading rates of 5, 10 and 200 mm/min, respectively. Arslan and Vursavuş (2006) reported that the lowest rupture force was obtained from the horizontal orientation of almond, the average rupture force varied between 388.30 and 218.69 N in moisture contents ranging from %6.16 to %26.79, the rupture force decreased as the moisture content of almond increased, and the nut became deformed after the compression processing of almond with high moisture content in suture orientation.

Loghavi et al. (2011) notified that almond cultivars were assumed as oval for shape index values of above 1.50 and spherical otherwise. Because the shape index averages of seven almond cultivars used in present study was higher than 1.50, all cultivars can be defined as oval in shape. 'Ferradual' with a sphericity of 71.6% was considered as spherical. As compared to 'Nonpareil', 'Picantili' and 'Drake cultivars with sphericity of between 52.72 and 60.83% in the study of Altuntas et al. (2010), it was found that all cultivars excluding 'Ferrostar' had a higher sphericity average. Among the cultivars, 'Ferrostar' had the highest elongation, roundness and aspect ratio averages.

Conclusion

Elliptic Fourier analysis revealed that the greatest variation among the almond cultivars were observed in width dimension in horizontal orientation and thickness dimension in suture orientation. The results of pairwise comparison obtained using Elliptic Fourier descriptors indicated that

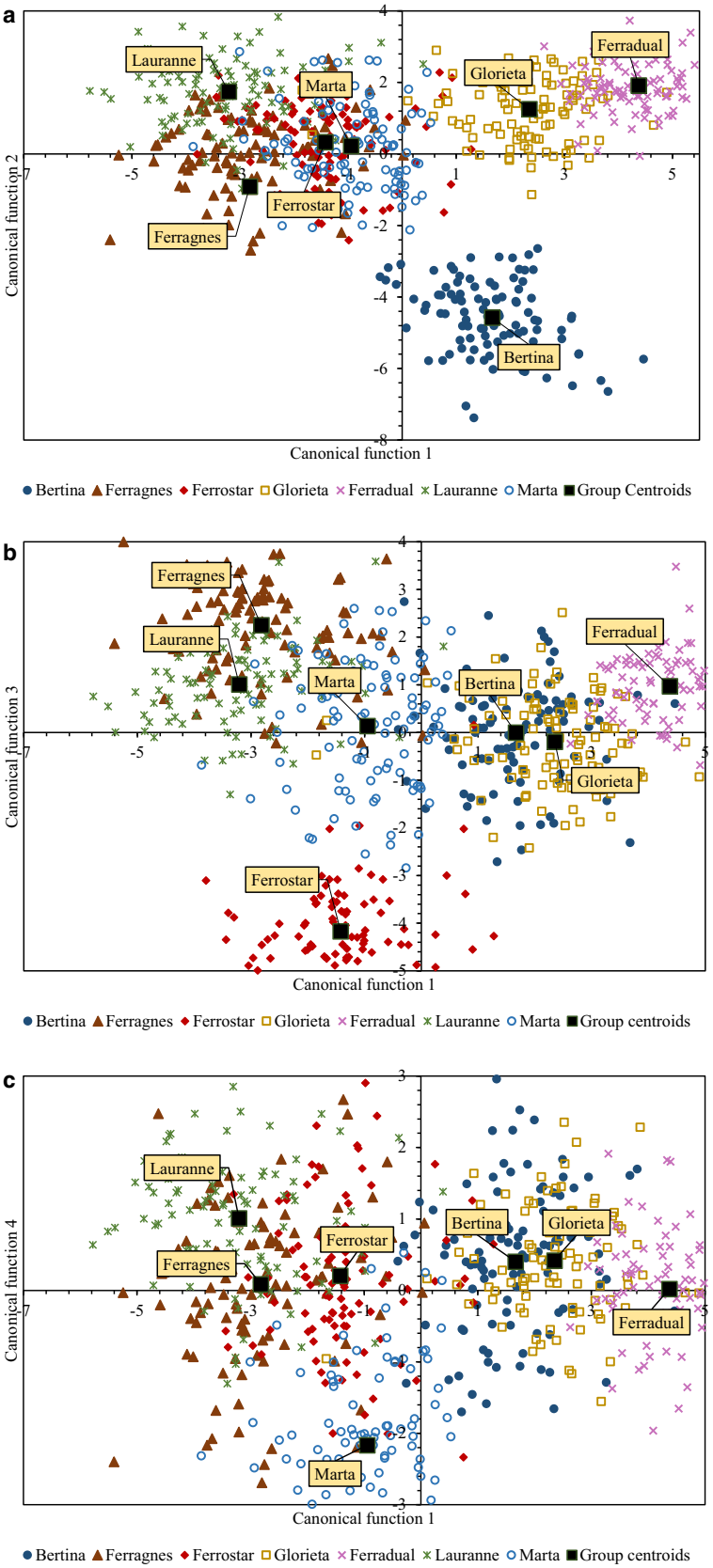


Fig. 5 Scatter plots of the almond cultivars in terms of the discriminant scores and group centroids **a** function 1 and function 2, **b** function 1 and function 3, **c** function 1 and function 4

almond cultivars presented different features in shape. To sum up, elliptic Fourier analysis successfully identified and distinguished shape features of the almond cultivars.

Conflict of interest B. Demir, B. Sayinci, N. Çetin, M. Yaman and R. Çömlek declare that they have no competing interests.

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