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DETERMINATION OF SIZE AND SHAPE FEATURES OF HAZELNUTS USING MULTIVARIATE ANALYSIS

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ABSTRACT

Nut and kernel size, shape and some sensorial traits in ten hazelnut (*Corylus avellana* L.) cultivars were evaluated using an objective procedure based on multivariate analysis in order to obtain an important value of these cultivars for growers, processing and consumers. Cultivars were compared with nuts and kernels of *C. avellana* L. and *C. colurna* L. Significant differences in all physical properties were found among the cultivars, and also among cultivars and hazelnut species. A high correlation was found among some hazelnut traits. Cluster and principal component analysis supported results obtained by analysis of variance, and segregated genotypes in similar groups according to their characteristics evaluated. Procedure described may be useful in analyzing impacts of genotype *per se* on nut and kernel physical and sensorial properties, and also determine the factors for growers, breeders, especially for harvesting, sorting and other postharvest operations in order to establish optimal machine and equipment design.

Key words: cluster and principal component analysis, kernel, nut, physical traits

INTRODUCTION

Hazelnut is an important horticultural crop which covers more than 660,000 ha cultivated areas in world, and its production in 2014 was 713,451 tons [FAOSTAT 2017]. All parts of the hazelnut plant have high utility value. Of course, the most important values have nuts, i.e. kernel. Hazelnut kernels have been consumed all over the world either as natural blanched and roasted or as processed food and/or candy products such as chocolates, dairy, bakery etc. Moreover, kernel is rich source of fatty acids, phytosterols and antioxidant phenols, which are assumed to help control adverse effects on hypertension and to decrease blood cholesterol [Alasalvar et al. 2006]. Also, kernel and other organs contained more number of phytochemicals such as vitamins (B_1, B_6, E, α-tocopherol) [Köksal et al. 2006], carbohydrates, organic acids, dietary fiber, protein, essential oils, trace elements etc. [Aydin 2002, Solar and Stampar 2011, Najda and Gantner 2012]. From these purposes, hazelnuts are considered as a functional fruit crop in recent years and can be recommended for growers and consumers.

As many as 25 species originated from genus *Corylus* have been described, but 9 species are generally recognized [Thompson et al. 1996], i.e. five shrub species (*C. avellana*, *C. americana*, *C. cornuta*, *C. heterophylla* and *C. seiboldiana*) and four deciduous tree species (*C. colurna*, *C. chinensis*, *C. ferox* and *C. jacquemontii*) [Mehlenbacher 1991]. All species bear edible nuts. The cultivars that have the most

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importance in world production and trade are belongs to *C. avellana* L. [Mehlenbacher 1991]. Hazelnuts are relatively small, shrub-like trees that are wind pollinated. The nuts are formed during the summer and ripen in late summer to early autumn [Baldvin et al. 2003]. In most European cultivars, the ripe nuts fall to the ground and are then collected by sweeping or suction harvesters. In Serbia, the hazelnut production is small, but economically is very important [Milošević and Milošević 2012]. Earlier, under these conditions, hazel is grown from cuttings with bush as a training system (multistemmed plants with 4–5 separate stems), and then, it is spaced to 5 m by 4 m. At present, new hazelnut orchards in Serbia were established with cultivars grafted onto seedlings of *C. colurna* L. Training system is open vase with three to four primary branches. The planting distances between trees are 5 m × 3–4 m. Like other countries with high nut production, such as Turkey, Mediterranean countries, etc., harvesting and handling of the nut are carried out manually. The threshing is usually carried out on a hard floor with a homemade threshing machine. To optimize the threshing performance, its physical properties must be known [Aydin 2002]. Also, the physical properties of nuts and kernels, like those of other grains and seeds, are essential for the designing of equipment for handling, harvesting, processing and storing the nuts, or determining the behavior of the nut for its handling [Pliestic et al. 2006].

In the present study we thoroughly evaluated main nut and kernel physical and some sensorial attributes of ten hazelnut cultivars and two species from different regions. Evaluations were conducted over two years in order to provide a realistic value for the given cultivars as potential plant material for commercial growers as well as consumers. From this point, the main objective of the present study was to determine the size and shape properties of 10 hazelnut cultivars and two species by using multivariate analysis under western Serbian conditions.

MATERIALS AND METHODS

Plant material, experimental procedure and analysis of nut and kernel properties

Ten standard hazelnut cultivars, *C. avellana* L. and *C. colurna* L., all of different country origin, were used (tab. 1). Nuts of cultivars were collected in the plantation near Požega city (43°51'N, 20°03'E, 320–340 m a.s.l.), Western Serbia during two consecutive years (2014–2015). Nut orchards was established with 2-old-year rooted suckers in 2000 with bush (multi-stemmed plants with 4–5 separate stems) as a training system, and 5 × 4 m planting distance. Standard cultural practice was applied, except irrigation. Nuts of chosen *C. avellana* L. bush and *C. colurna* L. tree were collected in the local wood.

Table 1. Hazelnut genotypes, potential use and country of origin

Genotype	Genotype code	Potential use	Country of origin
1. Ennis	Ennis	In-shell	USA
2. Unknown	Unknown	Non defined	Serbia
3. Istarski Duguljasti	ID	Kernel	Croatia
4. Nocchione	Nocchione	In-shell	Italy
5. Tonda Gentile delle Langhe	TGL	Kernel	Italy
6. Tonda Gentile Romana	TGR	Kernel	Italy
7. Merveille de Bollwiller	M. Bollwiller	Pollinator	Germany
8. Segorbe	Segorbe	Kernel	Spain
9. Furfulak	Furfulak	In-shell	Turkey
10. Corabel	Corabel	In-shell or kernel	France
11. *Corylus avellana* L.	*C. avellana*	Breeding, rootstock	Serbia
12. *Corylus colurna* L.	*C. colurna*	Breeding, rootstock	Serbia

A sample of 100 nuts per each cultivar and/or species was randomly used for nut and kernel traits for each treatment. In laboratory of Department of Fruit Growing and Viticulture (Faculty of Agronomy in Čačak) nut samples were dried to constant mass prior to analyses and all measurements.

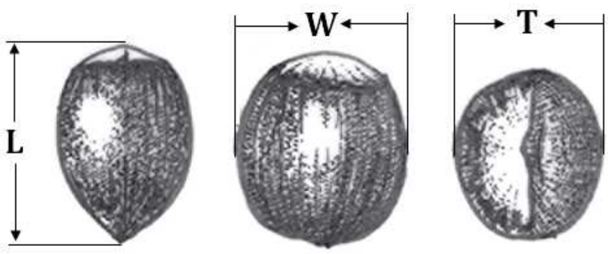

Fig. 1. Nut length (L), width (W) and thickness (T) [Bioversity… 2008]

Three linear dimensions (fig. 1) of nut as length (L), width (W), thickness (T) and shell thickness (ST) all in mm were measured with caliper Starrett 727 (Athol, MA, USA). Among these three linear dimensions, the highest was considered as the caliber (mm). For each sample, nut and kernel weight (g) were measured by digital balance Tehnica ET–1111 (Iskra, Horjul, Slovenia). For kernel analysis, the nuts were cracked by hand. After cracking, ST was measured on the convex side of each half using above caliper. The percent kernel was calculated by the following formula [Ozkan and Koyuncu 2005]:

$$PK = \frac{KW}{NW} \times 100 \quad (1)$$

where: *PK* – percent kernel, *KW* – kernel weight, *NW* – nut weight.

The taste of kernels was evaluated organoleptically by a group of panelists selected for this study and indexed with values from Bioversity… [2008], whereas kernel colour was identified according to method described by Köksal [2002].

Nut shape index was calculated with the following equation [Mohsenin 1980]:

$$NSI = \frac{W + T}{2L} \quad (2)$$

where: *NSI* – nut shape index, *L* – length, *W* – weight, *T* – thickness.

Nut shape was evaluated according to guidelines proposed by Bioversity… [2008].

Elongation was calculated by using the following relationship [Fıratlıgil-Durmuş et al. 2010]:

$$E = \frac{\text{Major axis lenght}}{\text{Minor axis lenght}} \quad (3)$$

where: *E* – elongation.

On the basis three linear dimensions of nuts, and then transformed to the parameter denominated “nut size” or arithmetic mean diameter (D_a), geometric mean diameter (D_g) and spericity (φ) were defined by using the following equations [Mohsenin 1980, Aydin 2002]:

$$D_a = \frac{L + W + T}{3} \quad (4)$$

where: D_a – arithmetic mean diameter (mm).

$$D_g = \sqrt[3]{LWT} \quad (5)$$

where: D_g – geometric mean diameter (mm),

$$\varphi = \frac{D_g}{L} \quad (6)$$

where: φ – sphericity.

The aspect ratio (R_a) was calculated [Altuntaş et al. 2005] as:

$$R_a = \frac{W}{L} \times 100 \quad (7)$$

where: R_a – aspect ratio (%).

The surface area (*S*) was calculated from the equation given by McCabe et al. [1986] as:

$$S = \pi D_g^2 \quad (8)$$

where: *S* – surface area (cm^2).

The nut volume (*V*) was calculated [Jain and Bal 1997] as:

$$V = \frac{\pi LWT}{6} \quad (9)$$

where: *V* – nut volume (cm^3).

Kernel content (KC) in relation to the nut volume was calculated [Oparnica and Vulić 2006] as:

$$KC = \frac{NW \times PK}{V \times 100} \tag{10}$$

where: KC – denotes kernel fill.

Data analysis

Analysis of variance (ANOVA) and Pearson's correlation coefficients were carried out using Microsoft Excel software package (Microsoft Corporation, Roselle, IL, USA). Fisher's least significant difference (LSD) test was used to calculate the means with 95% ($P \leq 0.05$) confidence. Clustering of genotypes into similarity groups was done using the method of UPGA (Unweighted Pair Group Average) with Statistica 8.0 software (StatSoft, Inc., Tulsa, Oklahoma, USA). Principal component analysis (PCA) was performed to evaluate relationships among variables and any possible cultivar groupings based on similar properties by using an XLSTAT procedure of computer statistical package (XLSTAT v. 7.5, Addinsoft, USA). All data are mean values for 2014 and 2015, due to differences between years were not significant. The hazelnut genotypes evaluated had almost the same shell moisture content (≈6.0%).

RESULTS AND DISCUSSION

Nut and kernel physical and sensorial properties

The mean values of dimensions, shape index, nut shape and elongation are given in Table 2. The highest length was observed in nuts of 'Ennis', and the lowest in *C. avellana*, although differences *C. avellana* versus 'Nocchione', 'Corabel' or *C. colurna* were not significant. 'Furfulak' produced significantly higher nut weight and thickness, whereas lower these values were found for 'ID'. Pliestic et al. [2006] reported that length, width and thickness of 'ID' were higher than those obtained in the present study, suggested that environmental conditions and cultural practices play a major role on fruit dimensions, as previously reported [Balta et al. 2006]. Wide variations regarding nut dimensions were previously found by many authors [Bostan and İslam 1999, Aydin 2002]. Among three dimensions, the highest was considered as the caliber. Data in Table 2 indicated that in 'Ennis', 'Unknown' genotype, 'ID', 'TGL', 'M. Bollwiller', 'Segorbe', 'Corabel' and *C. colurna* the highest nut dimension is length, whereas in 'Nocchione', 'TGR', 'Furfulak' and *C. avellana* the highest nut dimension is width. These values in the present study varied between 18.56 mm (*C. colurna*) and 26.84 mm ('Ennis'). Generally, all caliber values were much higher than those obtained by Solar and Stampar [2011] for same cultivars, and similar to data found by Milošević and Milošević [2012] in conditions like our, also for same cultivars. According to Solar and Stampar [2011], cultivars with nut calibers between 15.66 mm and 20.25 mm may be considered as suitable for the in-shell market owing to having large-caliber nuts. For example, beside others, 'Ennis' and 'Corabel' already play an important role on the international in-shell market [Mehlenbacher 1991], 'M. Bollwiller' is planted as pollinator in smaller extent, whereas 'ID' are known mainly in local Croatian, Slovene [Solar and Štampar 2009] and Serbian markets [Milošević and Milošević 2012]. *C. avellana* and *C. colurna* are recommended for breeding program and as rootstocks [Milošević 1997]. Cultivars with medium nut caliber may be interesting for table consumption. In addition, linear dimensions in hazelnuts can be useful for aperture size of machines, particularly in separation, and may also be useful in estimating the size of machine components.

Nut shape is determined by nut dimensions. Data from Table 2 showed that the highest values of shape index were produced by *C. colurna*, 'Nocchione' and 'Furfulak', and the lowest by 'ID'. In literature shape index of nuts of different hazelnut cultivars were reported between 0.67 and 1.20 [Yao and Mehlenbacher 2000] or between 0.70 and 1.01 [Solar and Stampar 2011], whereas in 'ID' and 'TGL' was 0.67 and 0.88, respectively [Oparnica and Vulić 2006], which confirmed our results. Also, above authors stated that this property is quite stable and can be used for cultivar description and evaluation of consumer preference as well. According to Bioversity… [2008], the dominant nut shape in our study is globular or roundish (≈42%), followed by oblate (25%) and conical (≈17%). 'ID' had long subcylin-

Table 2. Length, width and suture thickness size and shape attributes of hazelnut genotypes

Genotype	Length (mm)	Width (mm)	Thickness (mm)	Shape index	Nut shape*	Elongation
Ennis	26.84 ±0.26 a	22.64 ±0.21 b	20.59 ±0.29 b	0.81 ±0.01 d	2	1.31 ±0.02 b
Unknown	21.47 ±0.21 c	20.73 ±0.20 f	18.06 ±0.14 de	0.90 ±0.01 c	2	1.19 ±0.01 c
ID	23.31 ±0.19 b	14.27 ±0.13 j	11.37 ±0.14 i	0.55 ±0.00 e	6	2.05 ±0.03 a
Nocchione	18.30 ±0.17 ef	21.71 ±0.25 c	18.79 ±0.10 c	1.11 ±0.01 a	1	0.97 ±0.01 e
TGL	19.42 ±0.35 de	18.14 ±0.22 h	16.12 ±0.18 f	0.89 ±0.02 c	2	1.21 ±0.03 c
TGR	20.03 ±0.41 d	21.28 ±0.24 de	17.77 ±0.23 e	0.99 ±0.03 b	2	1.13 ±0.01 d
M. Bollwiller	22.35 ±0.26 bc	18.94 ±0.32 g	18.56 ±0.24 c	0.84 ±0.01 cd	3	1.21 ±0.02 c
Segorbe	22.04 ±0.29 c	20.92 ±0.21 ef	18.49 ±0.18 c	0.90 ±0.01 c	3	1.19 ±0.01 c
Furfulak	21.72 ±0.28 c	24.64 ±0.15 a	21.29 ±0.21 a	1.06 ±0.01 a	1	1.02 ±0.01 e
Corabel	18.59 ±0.21 ef	17.25 ±0.28 i	15.24 ±0.21 g	0.87 ±0.01 cd	2	1.22 ±0.01 c
C. avellana L.	17.76 ±0.28 f	21.35 ±0.33 cd	18.39 ±0.24 cd	1.12 ±0.02 a	1	0.97 ±0.01 e
C. colurna L.	18.56 ±0.16 ef	17.36 ±0.19 i	14.36 ±0.23 h	0.85 ±0.01 cd	4	1.30 ±0.02 b

Genotype codes correspond to those in Table 1
Means followed by different letter in the column are different as determined by the LSD test at $P \leq 0.05$
* Bioversity… [2008]: 1 – oblate; 2 – globular; 3 – conical; 4 – ovoid; 5 – short sub-cylindrical; 6 – long sub-cylindrical

Table 3. Nut and kernel weight, percent kernel, shell thickness and some sensory attributes of hazelnut genotypes

Genotype	Nut weight (g)	Kernel weight (g)	Percent kernel (%)	Shell thickness (mm)	Kernel colour	Kernel taste*
Ennis	3.97 ±0.09 a	1.61 ±0.03 ab	41.04 ±1.58 b-e	1.19 ±0.06 ef	Light-brown	2
Unknown	3.11 ±0.14 b	1.34 ±0.04 bc	45.33 ±2.94 a-d	1.39 ±0.05 cd	Light-brown	2
ID	1.67 ±0.06 e	0.79 ±0.03 efg	49.59 ±3.71 a	1.10 ±0.05 fg	Light-brown	2
Nocchione	2.86 ±0.06 bc	1.07 ±0.03 cde	37.53 ±0.37 e	1.58 ±0.04 b	Light-brown	3
TGL	2.46 ±0.08 cd	1.12 ±0.04 cd	47.09 ±2.87 ab	1.19 ±0.06 ef	Light-brown	3
TGR	3.30 ±0.09 b	1.32 ±0.03 bc	40.60 ±1.61 cde	1.52 ±0.06 bc	Light-brown	2
M. Bollwiller	2.86 ±0.09 bc	1.03 ±0.04 cde	36.52 ±1.60 e	1.10 ±0.05 fg	Light-brown	2
Segorbe	3.44 ±0.09 ab	1.57 ±0.07 ab	46.89 ±2.79 abc	1.23 ±0.05 def	Light-brown	2
Furfulak	4.00 ±0.12 a	1.76 ±0.04 a	44.99 ±2.07 a-d	1.35 ±0.04 cde	Light-brown	3
Corabel	2.18 ±0.08 d	0.89 ±0.03 def	42.00 ±2.03 b-e	1.26 ±0.06 def	Light-brown	2
C. avellana L.	1.32 ±0.11 e	0.53 ±0.04 g	40.02 ±0.99 de	0.95 ±0.05 g	Light-brown	2
C. colurna L.	1.86 ±0.06 de	0.67 ±0.04 fg	36.47 ±2.17 e	2.41 ±0.12 a	Light-brown	1

Genotype codes correspond to those in Table 1
Means followed by different letter in the column are different as determined by the LSD test at $P \leq 0.05$
* Bioversity… [2008]: 1 – unsatisfactory; 2 – satisfactory; 3 – very good

drical nut shape (≈8%), and *C. colurna* had ovoid nuts (≈8%). The most elongation was found for 'ID', and the least for 'Nocchione', 'Furfulak' and *C. avellana*. Data from other collections around the world suggested that elongation strongly depend on the cultivar [Menesatti et al. 2008].

With respect to nut weight, the highest and similar values were observed in 'Furfulak' and 'Ennis', and the lowest in *C. avellana* and 'ID' (tab. 3). In a previous works on hazelnut, nut weight varied and caused by the genetic constitution of cultivar, crop load, cultural practices and regions [Bostan and İslam 1999, Aziz et al. 2007, Cristofori et al. 2008, Solar and Štampar 2009]. For instance, average nut weight of 'Ennis', 'M. Bollwiller' and 'Segorbe' under Northeast Portugal conditions is 3.86, 2.81 and 2.35 g, respectively [Silva et al. 2007], whereas under Slovene conditions these values were 4.30, 3.41 and 2.37 g, respectively [Solar and Stampar 2011]. Generally, determination of nut weight for hazelnut cultivars may be useful in the separation and transportation of the fruit by hydrodynamic means.

The kernel weight was statistically higher in 'Furfulak' and lower in *C. avellana* (tab. 3). High variability among cultivars regarding kernel weight has been previously obtained by Yao and Mehlenbacher [2000] who reported that these values ranged from 0.538 g to 2.019 g. Moreover, Cristofori et al. [2008] revealed that average kernel weight of 'M. Bollwiller', 'Nocchione', 'TGL' and 'TGR' is 0.72, 1.08, 1.12 and 1.18 g, respectively. Previous studies conducted on Turkish hazelnuts noted a wide variation among cultivars, even within cultivars, on kernel weight [Balta et al. 2006]. High dissimilarity among our results and results observed by above authors for same and/or different nut genotypes could be connected with genetic differences, pedo-climatic conditions and cultural practices [Bostan and İslam 1999, Silva et al. 2007, Solar and Štampar 2009]. Finally, nuts of small to medium size and nut weight up to 3.2 g with crisp kernels are desired by the confectionary industry, while for the in-shell market, large and attractive nuts are considered the best [Mehlenbacher 1991].

The percent kernel is considered important property of industrial cultivars [Mehlenbacher 1991], and also for in-shell market [İslam 2003]. In the present study, most of cultivars had respectable values (tab. 3); the highest was observed in 'ID', and the lowest in 'Nocchione', 'M. Bollwiller' and *C. colurna*. Similar levels for one or both extremes have been previously reported [Bostan and İslam 1999, Yao and Mehlenbacher 2000, Silva et al. 2007, Cristofori et al. 2008, Solar and Stampar 2009, 2011]. In general, the difference in kernel percentage among cultivars is due to shell thickness, the cultivars with thin shell gave more kernel and *vice versa* [Aziz et al. 2007], which confirmed our results. On the other hand, kernel percentage shows very little variation by hazelnut plant, year or location, and is thus a highly important repeatable characteristic for cultivar identification [Mehlenbacher 1991].

Shell thickness significantly varied among nut genotypes (tab. 3). The greatest value was observed in *C. colurna*, and the lowest in *C. avellana*. *C. colurna*, which has thick shell, is used as a non-suckering rootstock worldwide. Germination of thick shelled nuts is aided by partially cracking the nut prior to stratification, as previously reported [Erdogan and Mehlenbacher 2000]. Regarding cultivars, the highest value had 'Nocchione', and the lowest 'ID' and 'M. Bollwiller', suggesting that those cultivars are easy–to––crack. Thin shells are also desirable from the growers' point of view, as such nuts need less time for drying and thus contribute to decreasing production costs [Bostan and İslam 1999, Solar and Stampar 2011, Milošević and Milošević 2012]. All genotypes in our study had light–brown colour of kernel, whereas most of cultivars had satisfactory kernel taste, which is in agreement with previous work on hazelnut [Balta et al. 2006]. Very good kernel taste had 'Nocchione', 'TGL' and 'Furfulak', while kernel of *C. colurna* had unsatisfactory taste. Balta et al. [2006] also reported that most of genotypes originated from *C. avellana* had satisfactory kernel taste.

Table 4. Arithmetic and geometric mean diameter, sphericity, aspect ratio, surface area, nut volume and kernel content in relation to the nut volume of hazelnut genotypes

Genotype	Arithmetic mean diameter (mm)	Geometric mean diameter (mm)	Sphericity	Aspect ratio (mm)	Surface area (cm^2)	Volume (cm^3)	Kernel content in relation to the nut volume
Ennis	15.81 ±0.15 a	23.21 ±0.20 a	0.86 ±0.01 b	84.48 ±0.94 d	16.93 ±0.29 a	6.57 ±0.17 a	0.247 ±0.01 d
Unknown	13.18 ±0.09 c	20.03 ±0.12 bc	0.93 ±0.01 b	96.72 ±1.33 c	12.60 ±0.15 cd	4.21 ±0.08 cd	0.321 ±0.01 abc
ID	11.56 ±0.08 g	15.58 ±0.12 g	0.67 ±0.00 c	61.27 ±0.63 e	7.63 ±0.12 h	1.98 ±0.05 h	0.402 ±0.02 a
Nocchione	12.36 ±0.07 de	19.54 ±0.12 cd	1.07 ± .01 a	118.78 ±1.50 a	11.99 ±0.15 e	3.91 ±0.07 de	0.277 ±0.01 bcd
TGL	11.85 ±0.12 f	17.82 ±0.15 e	0.92 ±0.01 b	93.89 ±1.82 c	9.99 ±0.17 f	2.97 ±0.07 f	0.381 ±0.01 a
TGR	12.60 ±0.20 d	19.62 ±0.22 cd	1.05 ±0.02 a	106.93 ±2.20 b	12.12 ±0.29 d	3.98 ±0.15 de	0.337 ±0.01 abc
M. Bollwiller	13.64 ±0.14 c	19.87 ±0.24 c	0.89 ±0.01 b	92.91 ±1.51 c	12.44 ±0.30 cd	4.14 ±0.15 cd	0.258 ±0.02 cd
Segorbe	13.51 ±0.14 c	20.42 ±0.17 b	0.93 ±0.01 b	113.68 ±1.13 ab	13.11 ±0.22 c	4.47 ±0.12 c	0.355 ±0.02 ab
Furfulak	14.34 ±0.13 b	22.50 ±0.16 b	1.04 ±0.01 a	84.76 ±1.00 d	15.91 ±0.23 b	5.98 ±0.13 b	0.296 ±0.01 bcd
Corabel	11.28 ±0.13 gh	16.96 ±0.19 f	0.91 ±0.01 b	95.19 ±1.51 c	9.06 ±0.21 g	2.57 ±0.09 g	0.355 ±0.02 ab
C. avellana L.	12.05 ±0.15 ef	19.09 ±0.23 d	1.08 ±0.01 a	120.59 ±2.16 a	11.48 ±0.27 e	3.67 ±0.13 e	0.148 ±0.01 e
C. colurna L.	10.98 ±1.00 h	16.65 ±0.14 f	0.90 ±0.01 b	93.58 ±1.04 c	8.72 ±0.15 g	2.43 ±0.06 g	0.110 ±0.02 e

Genotype codes correspond to those in Table 1
Means followed by different letter(s) in the same column are different as determined by the LSD test at $P \leq 0.05$

Data summarized in Table 4 showed that the highest arithmetic and geometric mean diameter values were found for 'Ennis', but the lowest were for *C. colurna*, i.e. 'Corabel', respectively. These interval ranges in general agreed with those reported from other collections grown in different regions around the world [Aydin 2002, Ozdemir and Akinci 2004]. The knowledge related to geometric mean diameter would be valuable in designing the grading process [Mohsenin 1980].

Data in Table 4 showed that differences among nut genotypes for sphericity, aspect ratio, surface area, nut volume and kernel content in relation to the nut volume were significant. The statistically lower values of sphericity and aspect ratio were produced by 'ID'. Moreover, the highest sphericity values were recorded in four genotypes (*C. avellana*, 'Nocchione', 'TGR' and 'Furfulak'), whereas the highest aspect ratio had two genotypes ('Nocchione' and *C. avellana*). Previous studies on hazelnut reported that sphericity in some genotypes varied from 0.86 to 0.99, [Demchik et al. 2016], whereas Aydin [2002] and Pliestic et al. [2006] reported sphericity values of 97.58% and 82.86% (equivalent values of 0.9758 and 0.8286) for 'Tombul' and 'ID', respectively. The some values form literature for same or different hazelnut genotypes are like ours, but some highly differed. The differences between the present results and those of the above authors were likely due to the genetic make up of cultivars and/or species, as previously reported [Aydin 2002, Aziz et al. 2007]. The fruit shape is determined in terms of its sphericity and aspect ratio. Moreover, sphericity is an expression of the shape of a solid related to that of a sphere of the same volume while the aspect ratio relates the width to the length of the fruit, being the indicative of its tendency toward its oblong shape [Mohsenin 1980, Altuntaş et al. 2005].

Surface area and nut volume were found between 7.63 cm^2 and 16.93 cm^2, and 1.98 cm^3 to 6.57 cm^3 for 'ID' and 'Nocchione', respectively. Considering this fact, it is clear that a large number of 'ID' nuts could be packed in the predetermined volume compared with the other cultivars. In addition, Aydin [2002]

Table 5. Estimates of the Pearson's correlation coefficients among main physical characteristics of nut and kernel of 12 hazelnut genotypes collected in the Western Serbia

Variables	L	W	T	NW	KW	PK	ST	D_g	φ	R_a	S	V
L	1.000	0.135	0.225	0.570	**0.584**	0.308	–0.326	0.504	–0.550	**–0.584**	0.541	0.574
W		1.000	**0.955**	**0.713**	**0.665**	–0.190	–0.084	**0.910**	**0.735**	0.456	**0.895**	**0.877**
T			1.000	**0.743**	**0.669**	–0.259	–0.196	**0.949**	**0.654**	0.431	**0.932**	**0.912**
NW				1.000	**0.968**	0.079	–0.049	**0.851**	0.215	–0.012	**0.853**	**0.852**
KW					1.000	0.312	–0.135	**0.798**	0.144	–0.076	**0.804**	**0.806**
PK						1.000	–0.438	–0.105	–0.427	–0.432	–0.087	–0.072
ST							1.000	–0.225	0.105	0.062	–0.224	–0.220
D_g								1.000	0.424	0.199	**0.998**	**0.992**
φ									1.000	**0.812**	0.384	0.343
R_a										1.000	0.148	0.097
S											1.000	**0.998**
V												1.000

For abbreviations of variables see section "Material and methods"
In bold, significant values at the level of significance $P = 0.05$

reported that nut volume of 'Tombul' hazelnut was 1.92 cm^3. In literature surface areas of nuts of different cultivars were recorded between 8.34–10.32 cm^2 [Ozdemir and Akinci 2004], which is quite close to the results of this investigation. These properties could be beneficial in proper prediction of nut drying rates and hence drying times in the dryer.

Regarding kernel content in relation to the nut volume, the best values were found in 'ID' and 'TGL', and the poorest in *C. avellana* and *C. colurna*. These data are in a good agreement with results of Oparnica and Vulić [2006] for same cultivars grown in conditions like our. Generally, this feature complements the knowledge of the percent kernel and shows that the nut is filled with the kernel.

Relationship among properties, cluster and PC analysis

As can be seen in Table 5, significant correlations were existed between some variables evaluated. Very strong positive correlation was observed between nut thickness and nut weight; therefore, both parameters can be used to predict each other. Additionally, nut weight positively correlated with nut width or nut thickness which composes the nut size. These findings are in harmony with the earlier results obtained on hazelnut [Yao and Mehlenbacher 2000]. Kernel weight significantly correlated with all nut dimensions or nut weight, indicating that genotypes with big nuts tend to higher kernel weight, as reported previously by Romero et al. [1997]. Interestingly, no correlation was found between the percent kernel and nut dimensions, nut weight and/or kernel weight. In contrast, İslam et al. [2005] recorded negative correlation of percent kernel *versus* nut size, nut weight or shell thickness. This indicates the overriding importance of shell thickness in determining percent kernel. There was no significant correlation between shell thickness and nut dimensions, nut and kernel weight and percent kernel. However, Mehlenbacher [1991] reported that kernel percentage, the ratio of kernel weight to nut weight, is a function of shell thickness. Probably, high discrepancies between our results and those of above authors could be explained by differences in the size of the group of genotypes studied. Moreover, it was observed that as the nut weight and nut thickness increase, geometric mean diameter, sphericity, surface area and nut volume

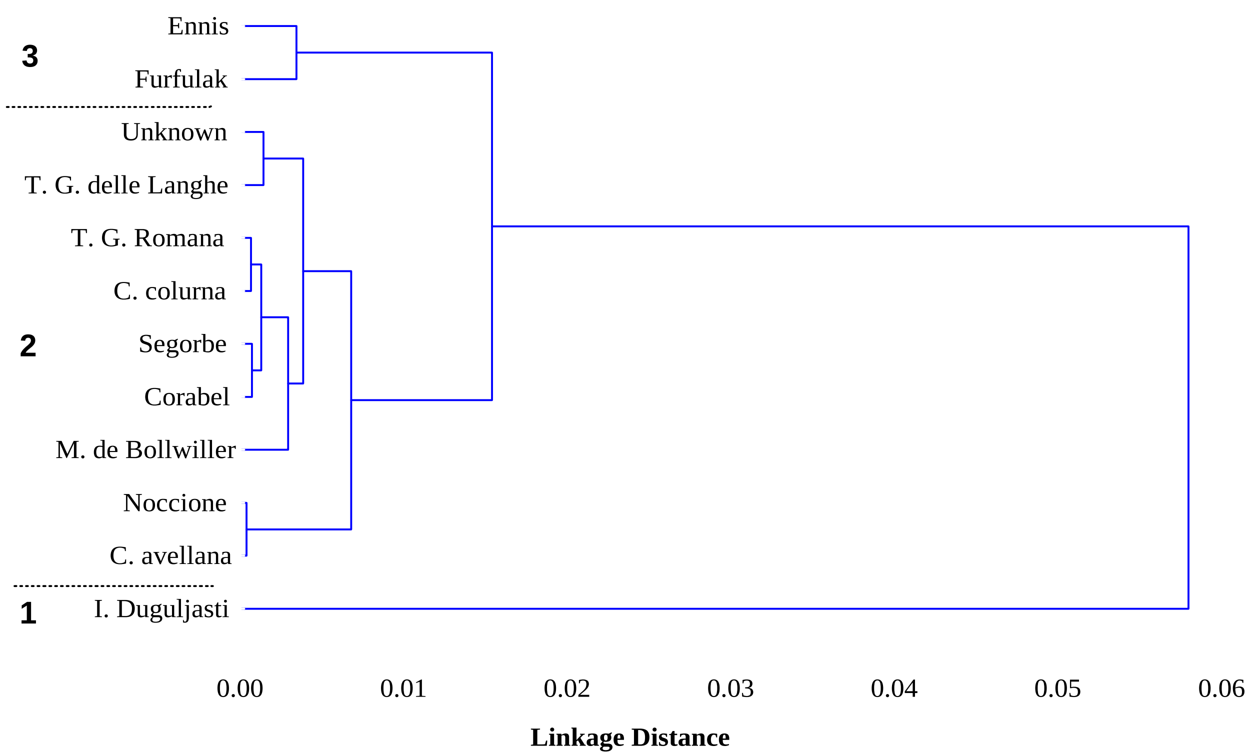

Fig. 2. Dendrogram of 12 hazelnut genotypes resulting from the unweighted pair group average (UPGA) method of arithmetic average cluster analysis based on Pearson's similarity coefficient obtained from 19 main physical and some sensorial properties

increased. Thus, significant correlations between these variables indices and the nut dimensions used in their calculation were expected [Yao and Mehlenbacher 2000]. Aspect ratio negatively and positively correlated with nut length and sphericity, respectively, reflects the importance of nut length in determining nut shape in general. As the geometric mean diameter increased, surface area and nut volume also increased; therefore, this parameter can be used to predict each other. Finally, positive correlation existed between nut volume and nut surface area, indicating that cultivars with high surface area tend to high nut volume.

As seen in the dendrogram (fig. 2), UPGA separates the hazelnut genotypes into three main groups. The first group includes one genotype ('ID'). This is small-fruited cultivar with long sub-cylindrical nut shape and the lowest of the most physical properties. *C. avellana*, 'Nocchione', 'M. Bollwiller', 'Corabel', 'Segorbe', *C. colurna*, 'TGR', 'TGL' and 'Unknown' genotypes, which comprise the second cluster, are, with exception *C. avellana* and *C. colurna*, cultivars with medium- to large nuts and kernel weight, the higher percent kernel, and medium- to high values of other properties evaluated. The third group contains two cultivars ('Furfulak' and 'Ennis'), which have the highest nut dimensions, nut and kernel weight, and the highest values for arithmetic and geometric mean diameter, surface area and nut volume.

Genetic disimilarity levels, i.e. genetic distance (*d*) ranged from 0.0025 to 0.058, suggesting a high similarity degree and low genetic distance among genotypes. The highest genetic similarity was found between 'Ennis' and 'Furfulak' or 'Corabel' and 'Segorbe'.

Table 6. Eigenvalues and proportion of total variability, eigenvectors of the first three principal components (PC), and component scores for 12 hazelnut genotypes

Variable	Component loadings			Genotype*	Component scores		
	PC1 $\lambda = 60.6$	PC2 $\lambda = 26.6$	PC3 $\lambda = 7.4$		PC1	PC2	PC3
Nut length	0.440	–0.824	–0.273	Ennis	4.126	–2.237	–1.388
Nut width	0.932	0.296	0.090	Unknown	0.850	–0.562	0.610
Nut thickness	0.953	0.248	–0.045	ID	–4.737	–3.471	0.133
Nut weight	0.890	–0.282	0.077	Nocchione	0.704	2.406	–0.096
Kernel weight	0.840	–0.384	0.276	TGL	–1.540	–0.327	1.162
Percent kernel	–0.093	–0.636	0.736	TGR	0.944	1.009	0.337
D_g**	0.990	–0.040	–0.082	M. Bollwiller	0.280	–0.096	–1.666
Sphericity	0.484	0.830	0.206	Segorbe	1.616	–0.465	1.214
Aspect ratio	0.242	0.868	0.181	Furfulak	4.121	–0.665	0.690
Surface area	0.985	–0.085	–0.100	Corabel	–2.523	0.416	0.155
Nut volume	0.976	–0.128	–0.119	*C. avellana* L.	–0.759	3.005	–0.048
				C. colurna L.	–3.082	0.986	–1.103
				Eigenvalue	6.67	2.93	0.81
				Variance (%)	60.65	26.61	7.39
				Cumulative	60.65	87.26	94.66

* Genotype codes correspond to those in Table 1
** D_g, geometric mean diameter

As it has been found that the characters are interrelated, so to have an idea about their independent impact, principal component analysis (PCA) was undertaken [Milošević et al. 2014]. The first three components in PCA contributed 94.65% of the variability among hazelnut genotypes for different properties evaluated (tab. 6). PC1, PC2 and PC3 accounted for 60.65%, 26.61% and 7.39%, respectively of the variability. Correlation between the original variables and the first three principal components are shown in Table 6. Positive values for PC1 indicate genotypes with higher nut width and thickness, nut and kernel weight, geometric mean diameter, surface area and nut volume as shown in Figure 3. Genotypes such as 'Ennis', 'Unknown', 'Segorbe' and 'Furfulak' are belongs to this group. Conversely, negative PC1 values correspond to genotypes with the smallest values for the properties above ('ID', 'TGL', 'Corabel' and '*C. colurna*'). This result shows that these variables are very important in distinguishing the hazelnut genotypes in terms of the dimensional properties. PC2 values represent genotypes with the highest sphericity and aspect ratio (fig. 3). This group is consisted of genotypes such as 'Nocchione', 'TGR' and *C. Avellana*'. The output shows that these descriptors are the second important variables depicting the shape properties of the hazelnut genotypes. PC3 values indicate that 'M. Bollwiller' has the smallest percent kernel (fig. 3). This result shows that this variable is very important in characterizing the hazelnut genotypes in terms of the kernel properties.

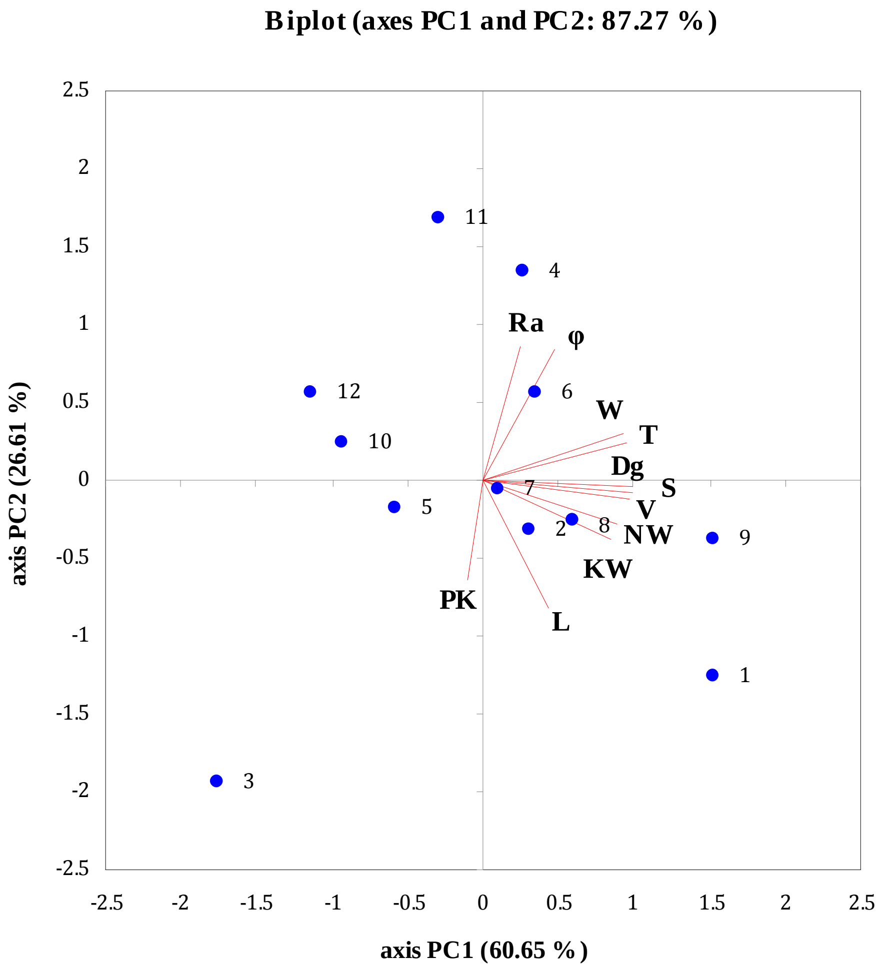

Fig. 3. Principal component analysis of 12 hazelnut genotypes resulting from analysis of 11 main physical properties (see Tables 1 and 5 for genotype codes and property abbreviations in biplot, respectively). PC1 (60.65%) is plotted on the *x*-axis and PC2 (26.61%) on the *y*-axis with the vectors representing the loadings of evaluated data along with the principal component scores

CONCLUSIONS

1. 'Furfulak' gives the biggest fruits in terms of nut width and thickness, shape and spericity index, nut and kernel weight, whereas 'Ennis' gives the highest values of nut length, nut weight, arithmetic and geometric mean diameters, surface area and nut volume.

2. The lowest values of most properties such as width, thickness, shape index, nut weight, sphericity, aspect ratio, surface area and nut volume were produced by 'Istarski Duguljasti', *C. avellana* and *C. colurna*, respectively.

3. All genotypes had light-brown kernel colour, whereas the most of them had satisfactory kernel taste.

4. Correlation coefficients between several variables indicated that fruit linear dimensions play an important role in relation to other physical properties evaluated.

5. Cluster and PC analysis made it possible to establish similar groups of hazelnut genotypes, accord-

ing to their size and shape characteristics, as well as to study relationships among physical properties.

6. Finally, we can propose that cultivar *per se* (genotype) was one important factor affecting physical and sensorial properties of hazelnut.

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