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Physical properties of hazelnuts

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A b s t r a c t. The postharvest physical and mechanical properties of nuts and kernels of 12 common hazelnut genotypes sampled from a single collection were investigated. Considerable differences in most physical and mechanical properties were evident among the 12 hazelnut cultivars nut and kernel within the species *Corylus avellana* L.

K e y w o r d s: hazelnut, physical properties

INTRODUCTION

Hazelnut (*Corylus avellana* L.) is a native plant of Turkey flora and wild hazelnut shrubs are found in natural forests throughout Turkey (Ercisli, 2004). Current used hazelnut cultivars for nut production in Turkey are supposed to be derived from local wild populations over many centuries and *Corylus avellana* L., the main economically important species, has a relatively high genetic diversity in the country (Ayfer *et al*., 1986). Turkey is favourable climatic and soil conditions for high quality hazelnut production.

Hazelnuts orchards with major Turkish cultivars established along the north-south part of Black Sea coastline and hazelnut processing industries are also located in this region (Yavuz and Ercisli, 2006).

Turkey is by far the leading producer of hazelnuts, with average 70% of world production. The other important hazelnut producer countries are Italy, USA, Azerbaijan, Iran and Spain (Anonymous, 2007). Hazelnut is an important export crop of Turkey economy and the country is gradually expanding its hazelnut exports to European and to the other countries (Yavuz and Ercisli, 2006).

In Turkey, hazelnut fruits are generally hand picked and sometimes harvested by hitting the fruits with a long stick. At times, older trees are harvested by shaking the shrub/branches. The collected fruits decorticated to get nuts. When the hazelnut fruits harvested, the following procedures are conducted:

- dehusking, separating hull from nut,
- nut shelling, separating nut shell from kernel,
- drying and more recently,
- oil extraction which usually is done in years when hazelnut stocks is a very high in Turkey.

Data of postharvest physical and mechanical properties of plant materials are important for the adoption and design of several handling, packaging, storage and transportation systems (Akinoso and Raji, 2011; Jahromi *et al*., 2008; Ozturk *et al*., 2009; Yurtlu *et al*., 2010). In mechanical processing of the fruits, most of the damage occurs in the harvesting and threshing as well as mechanical conveying and other equipment. High force can cause to the fruit damage and then, the damage is the failure in the final processing of the fruit quality (Mohsenin, 1986). Previously some studies were conducted to determine physical and mechanical properties of hazelnut. In these studies a few hazelnut cultivars were compared each other for some physical and mechanical properties (Altuntas and Ozkan, 2008; Aydin, 2002; Guner *et al*., 2003; Kibar and Ozturk, 2009; Ozdemir and Akinci, 2004).

The present study aimed to investigate some physical and mechanical properties of twelve hazelnut cultivars nut and kernel.

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MATERIALS AND METHODS

Nine common hazelnut cultivars and three genotypes were used. The fruit samples were collected from the germplasm collection of the Hazelnut Research Institute in Giresun province of Turkey. Harvested fruits immediately transferred to the laboratory. Nut samples were dried to have standard moisture content prior to analyzes and measurements in the laboratory. All tests were carried out at the Biological Material Laboratory in Agricultural Machinery Department and Fruit Science Laboratory in Horticulture Department of Ataturk University, Erzurum, Turkey.

The skin colour of nuts as: *l* – brightness (100 – white, 0 – black), *a* (+ – red, - – green) and *b* (+ – yellow, - – blue) was measured on the cheek areas of 30 fruit with a Minolta Chroma Meter CR-400 (Minolta-Konica, Japan). Minolta a and b values were used to compute values for hue angle ($\alpha = 180 + \tan^{-1} b/a$) and chroma $(a^2 + b^2)^{1/2}$, two parameters that are effective for describing visual colour appearance (Bernalte *et al*., 2003).

Axial dimensions (Fig. 1) of hazelnut nut and kernel as length, *L*, width, *W,* and thickness, *T*, were measured by using a digital calliper gauge with a sensitivity of 0.01 mm. Nut and kernel masses were measured by using a digital balance with a sensitivity of 0.001 g. Geometric mean diameter, D_g, and sphericity, ϕ, were calculated according to Mohsenin (1986); and Omobuwajo *et al*. (2000). The surface area, *S*, of the fruit was calculated from the relationship given by Baryeh (2001). Kernel ratio was determined by Ozdemir and Akinci (2004) as kernel mass/nut mass x 100%.The mechanical properties for two compression axes (X, Y) (Fig. 1) of the nuts and kernels were determined by a quasi-static loading device (Turgut *et al*., 1998). The device consists of three main units:

– a load cell connected to a stationary upper plate,
– a lower plate mounted to a driving unit,
– a PC equipped with a data acquisition system (DAS).

A single nut was placed on the lower plate and the plate moved up with a fixed speed of 1.62 mm min^{-1} compressing the nut between two parallel plates until it ruptured (ASAE, 2005). The load cell sensed the force applied to the sample which increased with time and transmitted the data to the DAS. The test was repeated ten times. From the fixed loading speed and time the deformation occurred during the loading was determined. Rupture force and deformation measured at rupture point (Altuntas and Yildiz, 2007). The energy absorbed during the loading up to rupture was calculated from the area under the load-deformation curve (Mohsenin, 1986). Hardness, *Q*, was calculated by dividing the rupture force by the deformation at rupture (Sirisomboon *et al*., 2007).

Descriptive statistics was carried out on the twelve hazelnut genotypes, and the difference between the mean values was investigated by using the Duncan tests by using Anova.

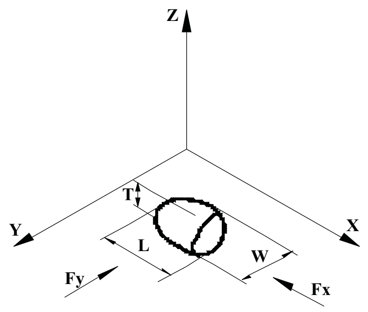

Fig. 1. Three axes and three perpendicular dimensions of kernels and nuts (X – longitudinal axis, Y – transverse axis, Z – thickness axis), Fx, Fy – rupture forces.

RESULTS AND DISCUSSION

The colour and physical properties of nuts and kernels in twelve hazelnut cultivars are presented in Tables 1 and 2. As indicated some colour parameters were significantly ($p<0.01$) effected by cultivars. Among hazelnut cultivars, cv. Sivri had more bright nuts with the highest *l* value (34.95) whereas cv. K-24/2 had the darker nuts (*l* -17.33). The *a* and *b* values of nuts and kernels were also widely varied among hazelnut cultivars which were between 8.67-14.33% for *a* and 13.23-23.82% for *b* values for nuts and were between 9.44-12.63% on *a* value and between 18.08-24.01% on *b* value for kernels. The nut colour intensity (Chroma) were found between 15.90 and 27.84% among hazelnut cultivars. There were statistically important differences on nuts and kernels among hazelnut cultivars in terms of all physical properties. The axial dimensions (length, width and thickness) of cultivars varied from 18.91 to 25.47; 15.09 to 21.20, and 12.76 to 21.20 mm for nuts and 14.79 to 21.08, 11.27 to 16.33, and 8.91 to 16.06 mm for kernels.

Among the cultivars, cv. Kargalak had the highest average nut and kernel mass (4.15 and 1.82 g). Previous studies conducted on Turkish hazelnuts revealed a wide variation among cultivars, even within cultivars, on nut and kernel mass and axial dimensions of nuts and kernels (Beyhan, 2007; Guner *et al*., 2003; Kibar and Ozturk, 2009; Ozdemir and Akinci, 2004). Erdogan and Aygun (2005) determined nut mass of seven hazelnut genotypes between 1.33-2.91 g. To determine nut mass for hazelnut cultivars may be useful in the separation and transportation of the fruit by hydrodynamic means. The importance of determining axial dimensions in hazelnut cultivars can be useful for aperture size of machines, particularly in separation. These dimensions may also be useful in estimating the size of machine components. As well known, fruit shape is determined by fruit dimensions and fruit shape is a useful indicator for morphological description of cultivars (Beyer *et al*., 2002) and evaluation of consumer preference as well. Geometric mean

T a b l e 1. Some colour properties of hazelnuts

Cultivars and genotypes	*l**	*a**	*b**	Hue angle (°)	Chroma
			Nuts		
Allah verdi	27.17±8.82 bcd	11.04±1.99 bcde	19.48±3.17 bcd	60.47±2.36 a	22.41 3.63 bcd
Foşa	23.70±7.43 cde	12.01±2.03 abcd	18.18±3.54 bcd	56.39±2.67 bc	21.81 3.96 bcd
K-1/1	27.20±7.72 bcd	11.38±2.39 bcde	19.89±5.72 abcd	59.59±3.73 ab	22.96 6.03 bcd
K-19/6	24.97±6.66 cd	8.67±3.33 e	13.23±2.86 f	57.60±6.13 abc	15.90 4.03 e
K-24/2	17.33±5.28 e	10.46±2.42 cde	16.29±2.86 def	57.51±3.15 abc	19.38 3.58 de
Kargalak	33.35±7.15 ab	14.33±4.19 a	23.82±6.61 a	59.24±3.32 abc	27.84 7.70 a
Kuş	26.58±5.06 bcd	13.65±2.19 ab	22.10±4.08 ab	58.10±3.40 abc	26.02 4.39 ab
Mincane	21.07±8.50 de	9.53±3.37 de	13.81±4.18 ef	55.71±3.13 c	16.80 5.31 e
Sivri	34.95±2.51 a	13.15±1.73 abc	21.35±2.21 abc	58.36±3.11 abc	25.10 2.43 abc
Uzun Musa	27.36±8.38 bcd	10.29±2.13 de	15.74±3.83 def	56.59±3.38 bc	18.83 4.24 de
Yassi badem	26.87±7.95 bcd	10.75±3.48 cde	17.45±3.91 cde	58.98±4.38 abc	20.53 5.05 cde
Yuvarlak badem	29.41±8.07 abc	13.23±3.03 abc	21.14±5.30 abc	57.91±2.73 abc	24.97 5.99 abc
Significant level	**	**	**	ns	**
			Kernels		
Allah verdi	28.83±8.65 abc	12.63±1.03 a	22.55±1.55 abc	60.72±2.09 bc	25.86±1.62 a
Foşa	28.61±9.45 abc	12.16±1.82 ab	22.21±2.26 abcd	61.37±1.89 bc	25.33±2.77 ab
K-1/1	28.55±9.41 abc	10.14±1.17 ef	20.38±1.79 de	63.54±2.16 ab	22.78±1.95 c
K-19/6	24.31±3.76 c	9.44±1.25 f	18.08±1.19 f	62.39±4.04 b	20.44±0.96 d
K-24/2	26.02±7.03 bc	11.96±1.19 abcd	20.32±1.27 de	59.55±2.29 c	23.59±1.46 bc
Kargalak	24.35±5.48 c	11.46±1.23 abcde	19.41±1.78 ef	59.41±2.33 c	22.56±1.96 c
Kuş	30.80±7.41 abc	12.29±1.46 ab	22.22±1.38 abcd	61.04±3.35 bc	25.43±1.35 ab
Mincane	24.28±4.52 c	10.52±1.25 def	19.96±1.69 e	62.12±3.55 bc	22.60 1.55 c
Sivri	32.01±5.14 abc	10.64±1.86 cdef	23.22±2.81 ab	65.51±2.39 a	25.56±3.22 ab
Uzun Musa	29.85±10.33 abc	10.91±1.04 bcde	20.93±2.18 cde	62.43±1.26 b	23.61±2.36 bc
Yassi badem	34.96±8.26 a	12.06±2.06 abc	24.01±2.52 a	63.42±3.02 ab	26.91±2.92 a
Yuvarlak badem	33.59±8.62 ab	11.70±1.72 abcd	22.02±1.77 bcd	62.09±2.89 bc	24.96±2.14 ab
Significant level	*	**	**	**	**

Significant levels at: *5 and **1%, ns – not significants, a-b letters indicate the statistical difference within same column.

diameter, D_g, of nuts and kernels was the highest in cv. Kargalak (22.41 and 16.64 mm) while the lowest in cv Sivri (16.15 and 13.05 mm) (Table 2). Ozdemir and Akinci (2004) determined average geometric diameter of 4 hazelnut cultivars between 12.04-13.54 mm for kernels and 16.30-18.65 mm for nuts. Guner *et al*. (2003) reported the geometric mean diameter of 4 hazelnut cultivars between 16.52-18.56 mm for nuts and 12.20-14.17 mm for kernels. Aydin (2002) found the geometric mean diameter of cv. Tombul as 17.83 mm. The knowledge related to geometric mean diameter would be valuable in designing the grading process.

The cultivar dependent surface area were observed among hazelnut nuts and kernels of cultivars which were 8.21-15.82 cm^2 for nuts and 5.36-8.74 cm^2, for kernels, respectively (Table 2). In literature surface areas of nuts and kernels of different hazelnut cultivars were reported between 8.34-10.92 and 4.55-5.77 cm^2 (Ozdemir and Akinci, 2004). Considering the surface area results, it is clear that less number of Kargalak cultivar nuts and kernels could be packed in the predetermined volume compared with the other cultivars.The kernel ratio of hazelnut cultivars varied from 44.64 (cv. Kargalak) to 62.91% (cv. Uzun Musa) (Fig. 2).

T a b l e 2. Some physical properties of hazelnuts

Hazelnuts	*l* (mm)	*W* (mm)	*T* (mm)	Mass (g)	D_g (mm)	ϕ (%)	*S* (cm^2)
				Nuts			
Allah verdi	20.76±0.99 de	18.07±0.94 d	18.07±0.94 d	2.49±0.30 ef	18.92±0.76 c	91.26±4.06 d	11.26±0.89 c
Foşa	20.52±0.82 e	18.61±0.93 c	18.59±0.89 c	2.37±0.27 f	19.21±0.69 c	93.71±3.85 c	11.61±0.84 c
K-1/1	21.11±0.75 d	20.45±0.88 b	20.11±0.85 b	2.94±0.42 b	20.55±0.71 b	97.35±2.29 a	13.28±0.92 b
K-19/6	22.28±1.16 b	20.20±1.48 b	20.04±1.37 b	2.84±0.59 bc	20.81±1.17 b	93.45±4.15 c	13.64±1.53 b
K-24/2	21.70±0.96 c	20.25±0.92 b	20.19±0.85 b	2.72±0.43 cd	20.70±0.74 b	95.47±3.29 b	13.48±0.97 b
Kargalak	25.08±1.56 a	21.20±1.22 a	21.20±1.22 a	4.15±0.59 a	22.41±1.12 a	89.51±4.03 e	15.82±1.58 a
Kuş	21.74±2.00 c	16.59±1.64 f	16.58±1.62 f	2.33±0.66 f	18.13±1.44 d	83.70±6.22 f	10.39±1.66 d
Mincane	19.04±0.97 f	17.20±1.02 e	17.06±0.94 e	2.02±0.39 g	17.74±0.79 e	93.25±3.90 c	9.90±0.87 e
Sivri	20.53±0.83 e	15.09±0.93 g	13.62±0.96 g	1.84±0.29 h	16.15±0.68 f	78.70±3.05 g	8.21±0.69 f
Uzun Musa	18.91±1.02 f	17.11±0.95 e	16.99±0.86 ef	1.80±0.39 h	17.64±0.72 e	93.43±4.44 c	9.79±0.80 e
Yassi badem	25.05±1.59 a	16.91±1.21 ef	12.76±1.12 h	2.61±0.56 de	17.52±0.88 e	70.17±4.74 h	9.67±0.96 e
Yuvarlak badem	25.47±1.03 a	15.32±1.35 g	13.85±1.05 g	2.30±0.31 f	17.53±0.86 e	68.88±3.66 h	9.67±0.93 e
Significant level	**	**	**	**	**	**	**
				Kernels			
Allah verdi	16.45±0.99 ef	14.25±0.91 d	14.25±0.91 d	1.18±0.12 d	14.94±0.79 c	90.96±4.32 d	7.03±0.74 c
Foşa	16.25±0.97 f	14.39±1.06 d	14.38±1.04 d	1.28±0.16 c	14.97±0.83 c	92.31±5.33 cd	7.06±0.78 c
K-1/1	16.85±1.04 de	15.14±1.03 c	14.77±1.09 c	1.50±0.24 b	15.55±0.79 b	92.46±5.34 cd	7.61±0.74 b
K-19/6	17.29±1.02 cd	16.11±1.34 a	15.84±1.26 ab	1.46±0.26 b	16.39±1.12 a	94.83±3.46 b	8.48±1.14 a
K-24/2	16.89±0.70 de	16.33±0.73 a	16.06±0.58 a	1.50±0.18 b	16.42±0.58 a	97.26±2.26 a	8.48±0.59 a
Kargalak	18.99±2.96 b	15.62±1.07 b	15.62±1.07 b	1.82±0.29 a	16.64±1.26 a	88.54±7.45 e	8.74±1.34 a
Kuş	17.59±1.43 c	13.76±1.08 e	13.76±1.08 ef	1.25±0.28 cd	14.92±0.98 c	85.07±5.38 f	7.02±0.92 c
Mincane	14.79±0.88 h	14.05±1.21 de	13.59±0.89 f	1.05±0.15 ef	14.13±0.87 d	95.58±3.73 ab	6.29±0.76 d
Sivri	16.47±0.78 ef	12.44±0.85 f	10.87±0.73 g	0.99±0.15 f	13.05±0.57 f	79.30±3.24 g	5.36±0.47 f
Uzun Musa	15.71±0.99 g	14.43±1.36 d	14.11±0.98 de	1.11±0.21 e	14.72±0.93 c	93.80±4.89 bc	6.83±0.87 c
Yassi badem	20.74±1.39 a	12.35±0.92 f	8.91±0.94 i	1.21±0.19 cd	13.14 0.64 f	63.55±4.36 h	5.43±0.53 f
Yuvarlak badem	21.08±0.86 a	11.27±1.00 g	10.46±0.67 h	1.27±0.14 c	13.52±0.59 e	64.22±3.01 h	5.76±0.51 e
Significant level	**	**	**	**	**	**	**

*Explanations as in the Table 1.

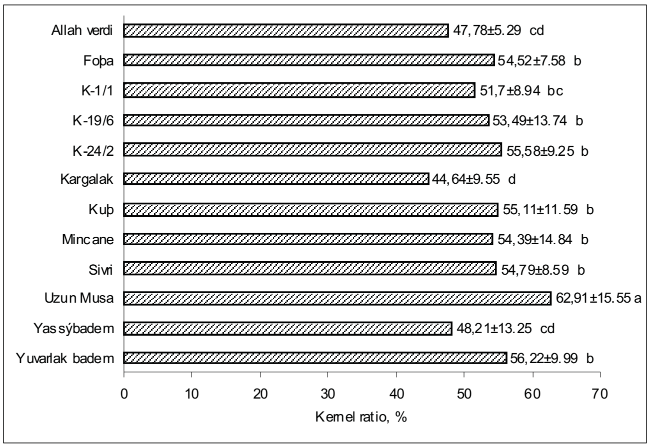

Fig. 2. Kernel ratio of hazelnut cultivars and genotypes.

The sphericity of hazelnut cultivars was found to be 68.88- 97.35% for nuts and 63.55-97.26% for kernels (Table 2). All the varieties were close to sphere in shape except cvs. Kargalak, Kuş, Sivri, Yassı Badem and Yuvarlak badem have sphericity less than 90%. This was mainly due to large variation in the three axial dimensions of these varieties. The shape of cv. Yassı badem and Yuvarlak badem looks like ellipsoid. Guner *et al.* (2003) found the sphericity of 4 hazelnut cultivars between 84.91-94.56% for nuts.

Tables 3-4 indicate that cultivars affected significantly all mechanical measurements of nuts and kernels.The values of rupture force, deformation, energy absorbed by the fruit up to rupture, and hardness (longitudinal axis base) of hazelnut cultivars are given in Table 3.

T a b l e 3. Some mechanical properties of hazelnuts at longitudinal (X) axis

Cultivars and genotypes	Rupture force (N)	Deformation (mm)	Energy absorbed (Nmm)	Hardness (N mm^{-1})
		Nuts		
Allah verdi	469.64±78.35 a	1.76±0.32 a	419.02±134.98 a	270.34±42.76 b
Foşa	313.67±65.86 bcd	1.31±0.37 bcd	216.11±99.28 cd	245.44±35.14 bcde
K-1/1	280.62±59.83 cd	1.24±0.25 cd	180.35±71.91 d	226.07±25.84 def
K-19/6	384.92±60.50 b	1.48±0.28 abc	292.24 100.61 bc	261.64±17.96 bcd
K-24/2	304.58±92.06 cd	1.44±0.30 bcd	228.17±102.75 cd	211.21±48.44 ef
Kargalak	334.67±54.48 bc	1.46±0.17 abcd	247.39±63.95 cd	229.66±34.43 cdef
Kuş	350.48±117.79 bc	1.57±0.39 ab	290.79±146.73 bc	222.85±48.65 def
Mincane	336.05±63.09 bc	1.31±0.34 bcd	223.26±80.70 cd	266.62±60.43 bc
Sivri	357.99±74.68 bc	1.33±0.35 bcd	247.23±114.99 cd	275.12±39.49 b
Uzun Musa	243.38±31.21 d	1.26±0.27 cd	156.49±50.09 d	197.23±28.55 f
Yassi badem	477.95±118.58 a	1.49±0.26 abc	370.67±152.79 ab	316.68±35.08 a
Yuvarlak badem	283.42±48.39 cd	1.16±0.17 d	166.35±47.68 d	246.01±36.12 bcde
Significant level	**	**	**	**
		Kernels		
Allah verdi	83.48±7.36 bc	3.94±0.59 a	165.14±32.89 bc	21.54±3.12 d
Foşa	85.22±13.89 abc	2.91±0.83 cde	128.34±54.31 cde	30.22±4.36 bc
K-1/1	81.20±14.85 c	2.79±0.53 cde	115.65±36.86 def	29.35±4.49 bc
K-19/6	77.09±18.89 cd	2.51±0.54 def	98.78±38.54 ef	31.49±8.86 bc
K-24/2	77.44±15.53 cd	2.93±0.73 cde	117.54±48.34 def	26.87±3.41 bcd
Kargalak	75.26±19.14 cd	1.93±0.54 f	75.66±35.32 f	39.95±8.69 a
Kuş	90.03±16.66 abc	3.26±0.88 bc	150.64±59.07 bcd	29.43±9.48 bc
Mincane	74.73±12.10 cd	2.53±0.81 def	97.48±41.66 ef	33.79±18.11 ab
Sivri	79.98±17.95 cd	3.09±0.59 cd	127.72±48.98 cde	25.92±3.09 cd
Uzun Musa	64.15±21.90 d	2.38±0.65 ef	81.48±51.98 ef	27.11±5.98 bcd
Yassi badem	99.56±10.67 a	4.24±0.61 a	213.31±48.03 a	23.63±2.08 cd
Yuvarlak badem	98.16±17.18 ab	3.85±0.73 ab	192.59±59.19 ab	25.77±3.85 cd
Significant level	**	**	**	**

*Explanations as in the Table 1.

The values of rupture force, deformation, energy absorbed and hardness were found to be between 243.38-477.95 N, 1.16-1.76 mm, 156.49-419.02 N mm and 197.23-316.68 N mm^{-1} for nuts and 64.15-99.56 N, 1.93-4.24 mm, 75.66-213.31 N mm and 21.54-39.95 N mm^{-1} for kernels. The values of rupture force, deformation, energy absorbed and hardness were found to be between 177.83-460.89 N, 1.14-1.54 mm, 105.53-346.50 N mm and 155.59- 321.21 N mm^{-1} for nuts and 73.42-97.55 N, 1.01-2.17 mm, 37.75- 107.43 N mm and 44.13-77.94 N mm^{-1} for kernels (Table 4). Guner *et al.* (2003) reported the rupture force values of 4 cultivars between 148.75 and 247-74 N for nuts and 67.80-80.19 N for kernels. Ozdemir and Akinci (2004) also determined the values of rupture force of four hazelnut cultivars between 93.85-232.70 N for nuts and 50.10-64.19 N for kernels.

The force needed to rupture a nut is the highest and for the kernel it is the lowest. This is because the nut has a hard shell and the kernel has soft texture. In generally, the deformation at rupture point of kernels was the highest and that of the nut was the lowest. This indicates that nut needed the lowest strain to rupture compared to kernel. The hardness of the nut was the highest as a hard skin covered the kernel. The energy used was the highest and that of the kernel was the lowest. This value indicated how easily the material can be broken.

T a b l e 4. Some mechanical properties of hazelnuts at transverse (Y) axis

Cultivars and genotypes	Rupture force (N)	Deformation (mm)	Energy absorbed (Nmm)	Hardness (N mm^{-1})
		Nuts		
Allah verdi	421.64±36.13 a	1.37 0.45 abc	313.39 194.44 ab	311.41 58.61 a
Foşa	281.06±54.81 bc	1.37 0.25 abc	196.49 75.98 cde	207.86 31.03 c
K-1/1	266.72±53.67 bc	1.21 0.25 bc	167.36 67.58 cde	220.72 21.49 bc
K-19/6	321.98±77.30 b	1.54 0.24 a	251.67 82.52 bc	210.55 44.88 c
K-24/2	290.76±72.78 bc	1.38 0.23 abc	206.91 82.54 cde	209.57 28.38 c
Kargalak	280.77±46.56 bc	1.21 0.24 bc	173.54 58.81 cde	234.62 34.13 bc
Kuş	337.62±98.99 b	1.37 0.35 abc	243.84 131.03 bcd	247.06 43.73 bc
Mincane	322.64±103.54 b	1.23 0.22 bc	207.19 99.52 cde	258.33 60.17 b
Sivri	285.87±66.69 bc	1.33 0.18 abc	194.44 65.29 cde	213.58 36.21 c
Uzun Musa	177.83±48.21 d	1.14 0.23 c	105.53 47.83 e	155.59 20.17 d
Yassi badem	460.89±66.37 a	1.47 0.33 ab	346.50 121.47 a	321.21 48.80 a
Yuvarlak badem	218.55±44.43 cd	1.32 0.26 abc	148.67 53.83 de	166.48 26.62 d
Significant level	**	ns	**	**
		Kernels		
Allah verdi	87.85±11.26 abc	2.05±0.41 ab	90.71±25.23 abc	44.13±9.89 d
Foşa	94.49±13.28 a	2.01±0.43 abc	96.44±28.85 ab	48.24±8.85 cd
K-1/1	95.63±13.16 a	1.93±0.42 abc	93.53±28.56 ab	52.22±16.26 cd
K-19/6	88.89±19.99 abc	1.73±0.66 abc	80.39±41.02 abc	56.21±21.12 cd
K-24/2	90.38±17.41 ab	1.79±0.62 abc	84.87±40.84 abc	53.19±9.76 cd
Kargalak	97.55±15.13 a	2.17±0.56 a	107.43±36.74 a	46.99±10.59 cd
Kuş	91.44±18.25 ab	1.56±0.37 cd	73.28±27.69 bc	60.33±13.26 bc
Mincane	83.13±18.41 abc	1.60±0.42 bcd	69.36±33.25 bcd	52.72±7.87 cd
Sivri	76.74±15.41 bc	1.11±0.31 e	43.06±16.13 de	72.60±20.64 ab
Uzun Musa	83.39±17.16 abc	1.79±0.41 abc	74.69±20.75 bc	48.21±12.69 cd
Yassi badem	96.06±19.87 a	1.27±0.31 de	62.56±23.09 cde	77.94±16.66 a
Yuvarlak badem	73.42±11.90 c	1.01±0.24 e	37.75±11.84 e	76.33±17.42 a
Significant level	*	**	**	**

*Explanations as in the Table 1.

Hardness is one of the most relevant properties in quality characterization of the hazelnuts for processing industry. Mechanical properties such as rupture force, hardness and energy used for rupturing nut and kernel are useful information in designing the dehulling or nut shelling machine. The rupture force indicates the minimum force required for dehulling the fruit or shelling the nut. The deformation at rupture point can be used for the determination of the gap size between the surfaces to compress the fruit or nut for dehulling or shelling (Sirisomboon *et al*., 2007).

CONCLUSIONS

1. Among the cultivars, cv. Kargalak had the highest average nut and kernel mass (4.15 and 1.82 g).
2. The axial dimensions (length, width and thickness) of cultivars varied from 18.91 to 25.47, 15.09 to 21.20, and 12.76 to 21.20 mm for nuts and 14.79 to 21.08, 11.27 to 16.33, and 8.91 to 16.06 mm for kernels.
3. Geometric mean diameter of nut and kernel was the highest in cv Kargalak (22.41 and 16.64 mm) while the lowest in cv Sivri (16.15 and 13.05 mm).

4. The sphericity and surface areas of nuts was found to be 68.88-97.35% and 8.21-15.82 cm^2 among hazelnut cultivars.

5. The cultivar Kargalak had the highest colour intensity (27.84% as chroma) whereas cv. K-19/6 had the lowest one (15.90% as chroma).

6. The average rupture force (N) and hardness (N mm^{-1}) were between 177.83-477.95 and 155.59-321.21 for nuts and 64.15-99.56 and 21.54-77.94 for kernels, respectively.

7. The differences between the physical and mechanical properties of hazelnut cultivars should be considered in optimizing hazelnut mechanization and processing.

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