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Determining of Some Engineering Properties for Harvest and Post Harvest Applications of Two Common Cultivated Hazelnuts Cultivars in Türkiye

Türkiye'de Yaygın Olarak Yetiştirilen İki Fındık Çeşidinin Hasat ve Hasat Sonrası Uygulamalar İçin Mühendislik Özelliklerinin Belirlenmesi

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Abstract: In this study, some engineering characteristics (physical properties, colour characteristics, coefficients of static friction and mechanical behaviours) of the shelled and kernel of Çakıldak and Foşa hazelnut cultivars cultivated in Türkiye were investigated for harvest and post harvest applications. The moisture contents of Çakıldak and Foşa cultivars for shelled hazelnut 8.69-7.56% (% wet basis) and kernel hazelnut 5.37- 4.64% (% wet basis), respectively. Statistically significant ($p<0.01$) differences were observed in fruit mass, hundred fruit mass, fruit volume, bulk density and true density of hazelnut cultivars in shelled and kernel cultivars. Çakıldak cultivar showed the highest L^* value in shelled fruits and the Foşa cultivar in kernel fruit hazelnut. The highest coefficient of static friction values showed on the rubber surface among the two cultivars for both shelled and kernel. As a result of the mechanical tests, a statistically significant difference was observed in both cultivars at the different loading speeds and axes for rupture force values. Knowing the engineering characteristics (physical properties, colour characteristics, coefficients of static friction and mechanical behaviours) of hazelnut cultivars is thought to be an important data source and contributes to the cleaning, transportation, packaging, storage, processing, classification and engineering studies be developed for harvesting and threshing and post-harvest applications.

Keywords: Hazelnut cultivars, physical and colour characteristics, coefficient of static friction, mechanical behaviours.

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Öz: Bu çalışmada, Çakıldak ve Foşa fındık çeşitlerinin hasat ve hasat sonrası uygulamalar için kabuklu ve iç meyvelerinin bazı mühendislik özellikleri (fiziksel özellikler, renk özellikleri, statik sürtünme katsayıları ve mekanik davranışlar) incelenmiştir. Çakıldak ve Foşa çeşidi kabuklu fındık meyveleri için nem içerikleri sırasıyla %8.69-7.56 (% yaş bazda) ve iç fındık için %5.37-4.64 (% yaş bazda) olarak belirlenmiştir. Kabuklu ve iç fındık meyvelerinde kütle, yüz meyve kütlesi, meyve hacmi, yığın yoğunluğu ve meyve hacim ağırlığı çeşitler için istatistiksel olarak önemli ($p<0.01$) farklılıklar göstermiştir. Çakıldak çeşidi kabuklu meyvelerde en yüksek L^* değerini, iç fındıkta ise Foşa çeşidi göstermiştir. Hem kabuklu hem de iç fındık için çeşitler arasında en yüksek statik sürtünme katsayısı değerleri kauçuk yüzeyde görülmüştür. Mekanik testler sonucunda her iki çeşitte farklı yükleme hızlarında ve eksenlerde kopma kuvveti değerlerinde istatistiksel olarak önemli bir fark gözlenmiştir. Fındık çeşitlerinin mühendislik özelliklerinin (fiziksel özellikleri, renk özellikleri, statik sürtünme katsayıları ve mekanik davranışları) bilinmesinin önemli bir veri kaynağı olacağı ve ekim, hasat ve harmanlama ve hasat sonrası mekanizasyon için temizleme, taşıma, paketleme, depolama, işleme, sınıflandırma gibi mühendislik çalışmalarının geliştirilmesine katkı sağlayacağı düşünülmektedir.

Anahtar Kelimeler: Fındık çeşitleri, fiziksel ve renk özellikleri, statik sürtünme katsayısı, mekanik davranışlar.

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INTRODUCTION

Hazelnut is the most widely cultivated hard-shelled fruit in the world after almonds. The cultivated cultivars of hazelnut are grown in Turkey, Italy, Spain, the USA, Chile, China, Iran, France, Azerbaijan, Russia and Georgia (TEPGE, 2021). In our country, the cultivation of hazelnut was first started in the Eastern Black Sea Region and spread to the Western Black Sea Region and then to other regions with the guarantee of the purchase of hazelnuts by the state. Provinces, where hazelnut production is common in Turkey, are Ordu, Samsun, Giresun, Sakarya, Düzce and Trabzon. In Turkey, 80-85% of hazelnuts produced are exported and 15-20% of them are consumed in the domestic market (TMO, 2019).

According to the data of FAO (2019), world hazelnut production is 1.125 thousand tons in a 1 million ha area. Important hazelnut-producing countries in the world are Turkey, Italy, USA, Azerbaijan, Georgia, France, Iran, China and Chile. Turkey ranks first in hazelnut production and export in the world. According to TUIK data, hazelnut production in Turkey has changed between 665 and 775 thousand tons in the last five years. According to the data for 2021, the amount of hazelnut production in Turkey was 684 thousand tons (TUIK, 2021).

Hazelnut yields in Trabzon, Giresun and Ordu provinces are lower than in Zonguldak, Sakarya and Düzce provinces. An increase is observed in the planting areas in this region due to the higher farm sizes and yields of the producers in Kocaeli, Sakarya and Düzce provinces.

The low level of productivity in Turkey, which is the world's largest hazelnut producer, also negatively affects profitability. To obtain more and quality products from the unit area, competitive and sustainable hazelnut farming, where productivity is prioritized, should be implemented. To increase the yield and quality of hazelnut, it is necessary to develop and expand good agricultural practices.

Hazelnut consumption in Turkey is mostly made for a snack, and the consumption of hazelnut oil, hazelnut chocolate, ground hazelnut and other products remains below the desired level. Internal consumption cannot be increased to the required extent. To increase the consumption of hazelnut and its products, consumer-oriented production models should be applied. The biggest problem in the hazelnut production region is the lack of storage infrastructure. In this context, all institutions and organizations should be encouraged to activate licensed storage. Quality is very important in the marketing of a product. In this context, all manufacturers, large and small, throughout Turkey should be encouraged to make quality production (TMO, 2020).

Obtaining information about both the construction materials and the properties of the stored product is considered important in the design of storage structures for hazelnuts. Mechanical properties such as friction depend on the surface structure of the hazelnut and the arrangement of the grains. Deformation of the hazelnut also makes it increasingly important for estimating loads on storage structures for crops (Molenda et al., 2004).

Hazelnut fruit is not only consumed as a nut but also widely used in pastry, halvah, dessert and especially in the chocolate industry. Hazelnut is a rich source of folic acid, vitamins E, K and C, and minerals such as iron, zinc, copper, protein and fibre. It contains unsaturated fatty acids, then, it is also a therapeutic food in terms of heart health (Gündüz et al., 2018).

Knowledge of the engineering characteristics (geometric and volumetric properties, colour properties, static friction coefficient and mechanical behaviors) of the hazelnut cultivars is necessary to design hazelnut processing equipment. They are important for the adoption and design of several packaging, handling, transportation and storage systems. The functioning of many machines used for post-harvest application and the food industry is influenced by the size, shape and sphericity the most important properties. The volume and density of the fruits play an important role in post-harvest technological processes and the evaluation of product quality. Most of the damage occurs in the post harvest application as well as mechanical conveying and other equipment in the mechanical processing of agricultural materials especially fruits.

It is important to determine hazelnut fruit quality in terms of dimensions, colour and mechanical damage. Knowledge of engineering characteristics is crucial as they are necessary to determine and guarantee the quality of the product.

In this study, some engineering characteristics (physical properties, colour characteristics, static friction coefficient and mechanical behaviours) of Çakıldak and Foşa hazelnut cultivars were determined in terms of designing, developing, and projecting the necessary equipment harvesting, and post-harvest applications.

Many researchers have conducted studies on the physical properties, colour change and mechanical properties of hazelnuts (Aydın, 2002; Güner et al., 2003; Özdemir and Akıncı, 2004; Altuntas and Özkan, 2008; Delprete and Sesana, 2014; Çetin et al., 2020).

MATERIAL AND METHOD

In this study, Çakıldak and Foşa hazelnut fruits were harvested from a farmer's garden in Samsun in the 2021 season. Çakıldak cultivar, on the other hand, has been used because it is a cultivar that is produced quite a lot in Turkey and has a high yield. Engineering characteristics of hazelnut vary according to the cultivar. Foşa hazelnut is one of the first cultivars that comes to mind when it comes to hazelnut cultivars, as well as a large and flamboyant cultivar in Türkiye. While the bark of the Foşa cultivar is darker, on the contrary, the bark of the Çakıldak cultivar is lighter. Hazelnut fruits were brought to Tokat Gaziosmanpaşa University, Faculty of Agriculture, Biosystem Engineering Department as soon as possible. Some engineering characteristics (geometric and volumetric properties, colour properties, static friction coefficient and mechanical behaviors) were determined in the Biological Material Laboratory. Damaged and broken fruits were excluded from the experiments. Foşa and Çakıldak hazelnut samples used in this experiment for shelled and kernel are presented in Figures 1 and 2, respectively.

Figure 1. Samples of the shelled and kernel of the Foşa hazelnut cultivar.
Şekil 1. Foşa fındık çeşidinin kabuklu ve iç örnekleri.

Figure 2. Samples of the shelled and kernel of Çakıldak hazelnut cultivar.
Şekil 2. Çakıldak fındık çeşidinin kabuklu ve iç örnekleri.

To determine some geometric and volumetric characteristics of shelled and kernel hazelnut fruits, 100 fruits were used. The size dimensions of hazelnut samples were determined with a digital caliper (with an accuracy 0.01 mm) (Figure 3). For geometric mean diameter, sphericity and surface area were used 100 hazelnut samples and they were determined from Equations 1, 2, and 3, respectively (Mohsenin, 1980).

$$G_d = (L_g \mathrm{x} W_t \mathrm{x} T_c)^{1/3} \quad (1)$$

$$S_h = \left[\left(G_d / L_g\right)\right] \mathrm{x} 100 \quad (2)$$

$$S_f = \pi \, \mathrm{x} (G_d)^2 \quad (3)$$

Here;

L_g : length,

W_t: width,

T_c : thickness

G_d : geometric mean diameter,

S_h : sphericity,

S_f : surface area

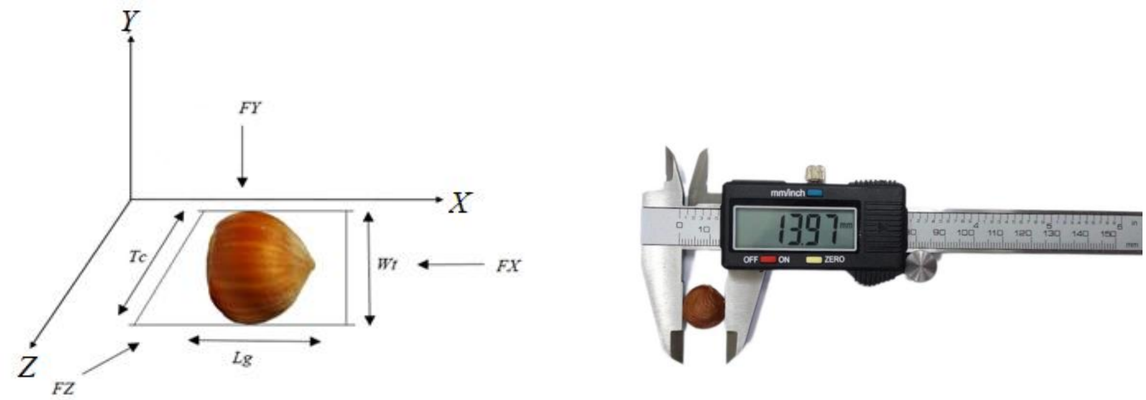

Figure 3. Representation of the axial dimensions (*FX, FY, FZ*) forces and measurement of size dimensions of kernel hazelnuts sample.

Şekil 3. Eksenel boyutlarının (FX, FY, FZ) kuvvetlerinin görünümü ve iç fındık örneğinin boyut boyutlarının ölçümü.

Fruit masses (M_f) were measured with a digital electronic balance (with an accuracy of 0.001 g). For the measurement of hundred fruit masses (H_{mf}), the average of 100 fruit masses was taken in 4 replicates. The liquid displacement method was used to determine the fruit density (F_d, (kg m^{-3}) for the shelled and kernel hazelnut fruits. Pure water was used as a fluid (Saçılık et al., 2003). The hectoliter method was used for the bulk density (B_d) (kg m^{-3}). The porosity value (P_r) was used as a ratio of bulk density and fruit density. The following equation was used for fruit volume (F_v) (Mohsenin, 1980).

$$F_v = \frac{\pi}{6} \mathrm{x} (L_g \mathrm{x} W_t \mathrm{x} T_c) \quad (4)$$

A colorimeter device was used to determine the colour characteristics of shelled and kernel hazelnut cultivars. For colour characteristics, *L**, *a**, *b**, hue angle and chroma were determined. Hue angle and chroma were determined by the equations below (McGuire,1992).

$$C_r = [\,(a^*)^2 + (b^*)^2\,]^{0.5} \tag{5}$$

$$h^{\circ} = \tan^{-1} \text{x}\ \frac{b^*}{a^*} \tag{6}$$

In the measurement of coefficients of friction for hazelnut cultivars, PVC, laminate, galvanized sheet, rubber and plywood surfaces were used with a friction measurement device (Yılmaz and Altuntas, 2020). For the measurement friction of the coefficient, the inclination angle was taken into account as tanα basis at the time the fruits start to move from friction surfaces.

In compression tests against the mechanical force for the behaviour of hazelnut cultivars for shelled and kernel, a Biological Material Test Device (Sundoo HP-500) was used. This device has a dynamometer, a stand, a motorized motion unit and a computer-connected. In the tests, the force and time curves were also taken graphically, and the force (R_f) and deformation values (D_f) of the fruits were determined. In the compression test, three different loading speeds (30 mm min^{-1}, 60 mm min^{-1}, 90 mm min^{-1}) used were used. The absorbed energy, hardness and power required for rupturing were determined with the following equations (Mohsenin, 1980).

$$Ea = \frac{R_f \text{x} D_f}{2} \tag{7}$$

$$H_s = \frac{R_f}{D_f} \tag{8}$$

$$P_{rr} = \frac{A_e\,\text{x}H_s}{60000\text{x}D_f} \tag{9}$$

Here;

A_e : Absorbed energy (N mm),

R_f : Rupture force (N),

D_f : Deformation (mm),

H_s : Hardness (N mm^{-1}),

P_{rr} : Power required for rupturing (W),

Lsp: Loading speed (mm min^{-1}).

SPSS 17 (Statistical Package for Social Sciences) program was used for the statistical evaluations of the research results. It was determined that the normality tests performed before the analysis of the variance of the data were suitable for statistical analysis. By using a one-way analysis of variance in the study, the effect of cultivars on the parameters examined with Duncan's multiple comparison tests was determined. An analysis of variance was performed for deformation, hardness and rupture force and power parameters are taken into account with loading speed and axes.

RESULTS AND DISCUSSION

The moisture contents of Çakıldak and Foşa hazelnut cultivars were determined as 8.69 and 7.56% wet basis for shelled fruits and 5.37 - 4.64% w.b, respectively. The results of the engineering characteristics (geometric, volumetric, colour, static friction properties and mechanical behaviour) of hazelnut cultivars were examined for both shelled and kernel fruits, respectively.

Geometric Characteristics

The geometric characteristics of hazelnut fruit are given in Table 1. The highest surface area was determined as 980.09 mm^2 in the shelled Foşa cultivar and the lowest as 557.54 mm^2 in the kernel Çakıldak cultivar. The highest values in terms of size were obtained in the shelled and kernel Foşa cultivars. While the length and width of the shelled fruits showed very important statistical differences for both cultivars, they were determined to be nonsignificant in the kernel fruits. In terms of geometric mean diameters, it was observed that while it was important in shelled for two cultivars, it was insignificant in barkless.

Karaosmanoğlu and Üstün (2007) reported that the width value of the kernel fruit was found to be the highest value at 14.78 mm in Düzce Foşa and the lowest at 12.16 mm in the Samsun Çakıldak fruits ($p<0.05$), among the cultivars, respectively. Özdemir and Akıncı (2004) reported that the fruit length, width and thickness values for the Çakıldak cultivar as 18.55 mm, 16.80 mm and 15.67 mm, respectively. When compared with the studies, it was observed that similar and close values were obtained in this study. Selvi et al. (2020) reported that the sphericity, geometric mean diameter and surface area mean values found as 0.91, 16.76 mm and 883.92 mm^2 in the shell, and 0.89, 13.0 mm and 533.03 mm^2 in the kernels for Çakıldak hazelnut cultivar, respectively. When compared with the studies, it was observed that similar and close values were obtained in this study.

Table 1. Geometric characteristics of hazelnut cultivars.
Çizelge 1. Fındık çeşitlerinin geometrik özellikleri.

	Cultivars	*L_g (mm)*	*W_t (mm)*	*T_c (mm)*	*G_d (mm)*	*Sh (%)*	*Sf (mm^2)*
Shelled	***Çakıldak***	19.71±0.19**	16.97±0.43**	15.46±0.41^{ns}	17.23±0.28**	87.54±1.44^{ns}	934.95±29.50*
	Foşa	20.29±0.41**	17.65±0.38**	15.53±0.31^{ns}	17.66±0.30**	87.05±0.66^{ns}	980.09±34.25*
	F value	**16.73**	**13.98**	**0.18**	**11.03**	**0.97**	**9.97**
Kernel	***Çakıldak***	15.59±0.50^{ns}	13.01±0.64^{ns}	11.68±0.70b*	13.29±0.57^{ns}	85.11±2.12^{ns}	557.54±47.13^{ns}
	Foşa	15.92±4.36^{ns}	13.40±0.35^{ns}	12.24±0.38a*	13.74±0.35^{ns}	86.14±0.70^{ns}	594.01±29.43^{ns}
	F value	**2.82**	**2.81**	**5.02**	**4.35**	**2.11**	**4.31**

*L_g: Length (mm), Wt: Width (mm), Tc: Thickness (mm), Gd: Geometric mean diameter (mm), Sh: Sphericity (%), Sf: Surface area (mm^2), ±: standard deviation, **: $p<0.01$, *: $p<0.05$; ^{ns}: nonsignificant*

Mass and Volumetric Characteristics

The mass and volumetric characteristics of hazelnut fruit are given in Table 2. The highest value in terms of fruit mass was observed in the Foşa cultivar with 2.27 g for shelled and 1.23 kernel fruit, respectively. The lowest porosity valuee were found as 55.49% and 49.34% for shelled and kernel fruits in the Çakıldak cultivar, respectively. In this study, while the fruit mass, hundred masses, fruit volume, bulk and fruit densities showed significant differences, the porosity was found to be nonsignificant.

Table 2. Mass and volumetric characteristics of hazelnut cultivars.
Çizelge 2. Fındık çeşitlerinin kütle ve hacimsel özellikleri.

	Cultivars	*M_f (g)*	*H_{mf} (g)*	*F_v (mm^3)*	*B_d (kg m^{-3})*	*F_d (kg m^{-3})*	*Pr (%)*
Shelled	***Çakıldak***	2.02±0.12b*	197.67±3.92b**	391,18±19.94b**	358.55±11.69b**	808.72±59.4b**	55.49±3.38^{ns}
	Foşa	2.27±0.25a*	219.05±6.19a**	274,90±21.06c**	393.06±2.85a**	966.76±62.06a**	59.21±2.55^{ns}
	F value	**8.29**	**34.02**	**100.42**	**41.14**	**16.92**	**3.88**
Kernel	***Çakıldak***	1.11±0.88b**	111.43±2.09b**	1255.71±156.35b*	436.65±7.32a**	865.57±60.51^{ns}	49.34±3.90^{ns}
	Foşa	1.23±0.70a**	122.76±2.11a**	1379.95±100.11a*	409.98±8.48b**	865.22±37.65^{ns}	52.55±2.19^{ns}
	F value	**13.10**	**58.17**	**4.48**	**28.33**	**0**	**2.57**

*M_f: Fruit mass (g), H_{mf}: Hundred mass (g), F_v: Fruit volume (mm^3), B_d: Bulk density (kg m^{-3}), F_d: Fruit density (kg m^{-3}), Pr: Porosity (%), ±: standard deviation, **: $p<0.01$, *: $p<0.05$; ^{ns}: nonsignificant*

Karaosmanoğlu and Üstün (2007) reported that the highest kernel fruit mass is 1.37 g in the Düzce Foşa cultivar, while Ercisli et al. (2011), found that the fruit mass of the Foşa cultivar is 2.37 g shelled and 1.28 g kernel hazelnut, respectively.

Özdemir and Akıncı (2004) found that the mass of the shelled hazelnut was 1.599 g and the kernel mass was 0.924 g, respectively. Kibar and Öztürk (2009) found that the lowest values for bulk and fruit densities were 417.43 kg m^{-3} and 788.00 kg m^{-3} in Çakıldak cultivars, respectively.

Colour Characteristics

The colour characteristics of the hazelnut cultivar are given in Table 3. The highest *L** colour characteristic value was observed in the barkless Foşa cultivar with 37.02. Considering the results of variance analysis, it was found to be statistically insignificant in terms of colour characteristics in shelled hazelnut cultivars.

Table 3. Colour characteristics of hazelnut cultivars.
Çizelge 3. Fındık çeşitlerinin renk özellikleri.

	Cultivars	L^*	a^*	b^*	C_r	$h°$
Shelled	Çakıldak	29.20 ± 5.25^{ns}	11.21 ± 4.08^{ns}	9.53 ± 3.59^{ns}	14.74 ± 5.36^{ns}	40.04 ± 3.98^{ns}
	Foşa	25.32 ± 3.15^{ns}	12.18 ± 2.60^{ns}	8.59 ± 1.34^{ns}	14.93 ± 2.78^{ns}	40.98 ± 2.40^{ns}
	F value	**4.00**	**0.40**	**0.61**	**0.01**	**0.41**
Kernel	Çakıldak	$32.63\pm2.22b^*$	8.97 ± 1.27^{ns}	$7.01\pm1.19^*$	$11.41\pm1.62^*$	$37.97\pm3.18b^*$
	Foşa	$37.02\pm4.36a^*$	10.24 ± 2.11^{ns}	$9.15\pm2.34^*$	$13.74\pm3.10^*$	$41.44\pm2.44a^*$
	F value	**8.07**	**2.63**	**6.64**	**4.46**	**7.53**

*±: standard deviation, **: $p<0.01$, *: $p<0.05$; ^{ns}: nonsignificant*

Çetin et al. (2020) determined the *L** brightness value to be 42.14 in shelled hazelnut, 39.10 in kernel hazelnut in the Çakıldak cultivar, and 40.82 in shelled hazelnut, and 41.87 in kernel hazelnut in the Foşa cultivar. In another study, Ercisli et al. (2011) examined *L**, *a** and *b** values of 23.70, 12.01, 18.18 for the Foşa cultivar in shelled hazelnut and 28.61, 12.16, 22.21 in kernel hazelnut, respectively.

Coefficient of the Friction

The coefficients of friction values were examined on five different surfaces (PVC, galvanized sheet, laminate, plywood, rubber) for Çakıldak and Foşa hazelnut cultivars. The highest values in shelled and kernel hazelnuts were obtained on the rubber surface. According to the results of variance analysis, significant differences were observed on the laminated surface of shelled hazelnuts. In contrast, significant differences were observed in PVC and galvanized surfaces in kernel hazelnuts (Table 4).

Table 4. The coefficient of friction on different surfaces in hazelnut cultivars.
Çizelge 4. Fındık çeşitlerinde farklı yüzeylerdeki sürtünme katsayısı.

	Cultivars	PVC	Galvanized steel	Laminate	Plywood	Rubber
Shelled	Çakıldak	0.286 ± 0.0133^{ns}	0.301 ± 0.015^{ns}	$0.208\pm0.015a^*$	0.290 ± 0.016^{ns}	0.368 ± 0.017^{ns}
	Foşa	0.267 ± 0.0132^{ns}	0.275 ± 0.021^{ns}	$0.175\pm0.018b^*$	0.298 ± 0.010^{ns}	0.348 ± 0.016^{ns}
	F value	**5.00**	**4.89**	**9.43**	**0.80**	**3.58**
Kernel	Çakıldak	$0.271\pm0.016b^{**}$	$0.232\pm0.026b^{**}$	0.238 ± 0.016^{ns}	0.309 ± 0.016^{ns}	0.459 ± 0.028^{ns}
	Foşa	$0.313\pm0.011a^{**}$	$0.317\pm0.011a^{**}$	0.238 ± 0.010^{ns}	0.317 ± 0.011^{ns}	0.445 ± 0.000^{ns}
	F value	**24.39**	**43.99**	**0.00**	**0.80**	**1.35**

*±: standard deviation, **: $p<0.01$, *: $p<0.05$; ^{ns}: nonsignificant, PVC: Polivinil Klorür*

Özdemir and Akıncı (2004) reported that the coefficient of friction was 0.265 on the plywood surface in the shell, and 0.221 on the galvanized steel. Statistically, the plywood in the shell showed significant differences, while the coefficient of friction was insignificant on the galvanized surface of the Çakıldak cultivar.

Mechanical Properties

Different loading speeds of hazelnut cultivars and the rupture force, deformation, absorbed energy, hardness and rupture power values in the loading axes are given in Table 5 for the shelled and kernel hazelnuts, respectively.

Table 5. Changes in mechanical behaviours according to loading speeds and axes of shelled and kernel hazelnuts for two cultivars.

Çizelge 5. İki çeşit kabuklu ve iç fındıkların yükleme hızları ve eksenlerine göre mekanik davranışlarının değişimi.

	Cultivars	Lps	L_{ax}	R_f (N)	D_f (mm)	A_e (N mm)	H_s (N mm^{-1})	P_{rr} (W)
Shelled	Çakıldak	30	X-	160.68±14.07^{ns}	3.68±0.72^{ns}	291.88±39.32^{ns}	45.75±13.55^{ns}	0.040±0.0035^{ns}
			Y-	179.22±14.18^{ns}	4.01±0.32^{ns}	359.36±43.04^{ns}	44.93±84.69^{ns}	0.045±0.0035^{ns}
			Z-	163.28±6.64^{ns}	4.32±0.68^{ns}	353.16±57.72^{ns}	38.66±7.19^{ns}	0.041±0.0017^{ns}
			F value	**3.41**	**1.45**	**3.10**	**0.88**	**3.41**
		60	X-	133.14±16.48b**	4.74±1.02^{ns}	312.74±68.08b**	29.41±8.04ab*	0.067±0.008b**
			Y-	187.50±10.46a**	5.12±0.62^{ns}	478.08±38.63a**	37.19±6.11a*	0.094±0.005a**
			Z-	132.32±15.85b**	5.44±0.76^{ns}	359.39±58.25b**	24.72±4.79b*	0.066±0.007b**
			F value	**23.72**	**0.93**	**11.45**	**4.77**	**23.72**
		90	X-	167.58±8.34a**	6.70±0.68a**	561.74±69.41a**	25.21±2.77^{ns}	0.125±0.006a**
			Y-	174.24±15.26a**	6.18±0.25a**	538.51±50.58a**	28.23±2.79^{ns}	0.131±0.011a**
			Z-	138.00±13.52b**	5.13±0.41b**	353.50±40.37b**	27.08±3.88^{ns}	0.104±0.010b**
			F value	**11.50**	**13.72**	**21.69**	**1.14**	**11.50**
	Foşa	30	X-	167.20±28.26b*	3.21±0.92^{ns}	264.99±76.86^{ns}	55.98±20.11^{ns}	0.041±0.007b*
			Y-	206.72±16.73a*	4.03±1.27^{ns}	421.64±152.29^{ns}	55.19±15.94^{ns}	0.050±0.004a*
			Z-	197.26±20.36ab*	4.20±0.80^{ns}	409.83±62.65^{ns}	49.04±14.25^{ns}	0.049±0.005ab*
			F value	**4.28**	**1.37**	**3.46**	**0.25**	**4.28**
		60	X-	140.58±21.63b*	4.06±0.71ns	283.78±52.22ns	35.56±8.71b*	0.07±0.011b**
			Y-	271.26±79.59a*	4.56±1.43ns	647.64±388.87ns	61.91±17.71a*	0.14±0.039a**
			Z-	214.86±24.92a*	5.15±1.16ns	546.89±108.90ns	44.58±17.48ab*	0.11±0.012a**
			F value	**1.03**	**2.73**	**2.78**	**1.61**	**157.91**
		90	X-	205.26±26.96b**	5.90±1.28ns	609.01±162.57ns	35.81±7.24ns	0.15±0.020a**
			Y-	174.00±30.55b**	6.02±1.47ns	516.92±137.55ns	31.48±15.13ns	0.13±0.023a**
			Z-	256.56±34.45a**	5.90±1.95ns	762.06±279.73ns	46.21±11.93ns	0.19±0.026b**
			F value	**0.51**	**8.11**	**3.26**	**4.28**	**33.00**
Kernel	Çakıldak	30	X-	77.16±15.02^{ns}	3.61±0.26c**	137.97±17.72b**	21.66±5.70a*	0.019±0.0038c**
			Y-	71.98±7.32^{ns}	7.05±0.52a**	254.50±39.39a**	10.22±0.88b*	0.036±0.0037b**
			Z-	83.60±9.93^{ns}	5.44±1.21b**	226.17±50.33a**	16.11±4.86ab*	0.063±0.0075a**
			F value	**1.34**	**24.44**	**12.60**	**8.63**	**86.59**
		60	X-	60.48±3.44^{ns}	3.97±0.88^{ns}	120.26±29.52^{ns}	15.97±4.29^{ns}	0.015±0.0001c**
			Y-	56.22±8.29^{ns}	4.14±0.39^{ns}	116.37±21.02^{ns}	13.68±2.59^{ns}	0.028±0.0041b**
			Z-	60.46±2.64^{ns}	5.10±1.07^{ns}	154.25±32.09^{ns}	12.29±2.64^{ns}	0.045±0.0020a**
			F value	**1.03**	**2.73**	**2.78**	**1.61**	**157.91**
		90	X-	84.18±5.84^{ns}	4.09±1.31b**	171.72±56.83^{ns}	23.25±11.01a*	0.021±0.0015c**
			Y-	79.26±10.13^{ns}	5.59±0.88ab**	218.56±17.55^{ns}	14.63±3.69ab*	0.039±0.0051b**
			Z-	77.34±15.05^{ns}	7.07±1.28a**	278.44±98.21^{ns}	11.02±1.87b*	0.058±0.0113a**
			F value	**0.51**	**8.11**	**3.26**	**4.28**	**33.00**
	Foşa	30	X-	76.76±9.26^{ns}	3.21±0.19b**	123.67±19.26b**	23.89±2.48ab**	0.019±0.002c**
			Y-	97.16±14.10^{ns}	3.19±0.57b**	152.56±18.15b**	31.64±8.66a**	0.049±0.007b**
			Z-	81.48±13.04^{ns}	5.59±1.43a**	223.30±47.80a**	15.80±47.80b**	0.061±0.009a**
			F value	**3.76**	**11.88**	**13.21**	**7.60**	**46.07**
		60	X-	94.94±14.25^{ns}	4.63±0.99^{ns}	216.51±40.56^{ns}	21.74±7.53^{ns}	0.024±0.036c**
			Y-	80.34±8.81^{ns}	4.83±0.85^{ns}	196.56±56.13^{ns}	16.82±1.91^{ns}	0.060±0.0066a**
			Z-	85.38±13.70^{ns}	5.16±1.15^{ns}	217.14±38.22^{ns}	17.30±4.59^{ns}	0.043±0.0068b**
			F value	**1.76**	**0.36**	**0.33**	**1.36**	**48.43**
		90	X-	112.62±15.85a*	3.13±0.67^{ns}	173.56±27.30^{ns}	37.98±13.02^{ns}	0.028±0.004c**
			Y-	98.32±16.47ab*	4.55±1.83^{ns}	216.91±72.46^{ns}	25.61±12.81^{ns}	0.074±0.012a**
			Z-	88.48±6.88b*	3.38±0.39^{ns}	149.92±23.23^{ns}	26.41±3.64^{ns}	0.044±0.003b**
			F value	**3.88**	**2.20**	**2.65**	**2.07**	**44.50**

*±: standard deviation, **: $p<0.01$, *: $p<0.05$; ^{ns}: nonsignificant, Lps: Loading speed (mm min^{-1}), L_{ax}: Loadin axes Rf : Rupture force (N), D_f: Deformation (mm), A_e : Absorbed energy (N mm), H_s : Hardness (N mm^{-1}), P_{rr} : Power required for rupturing (W).*

The highest force value for shelled hazelnut was 187.50 N in the Y axis at 60 mm min^{-1} speed in the Çakıldak cultivar and 271.26 N in the 60 mm min^{-1} Y axis in the Foşa cultivar. Regarding hardness, the highest value for the Foça cultivar was 30 mm min^{-1} in shelled and kernel hazelnut fruits. The power required for rupture showed statistically significant differences in the two cultivars at different speeds (except for Çakıldak-shelled, 30 mm min^{-1}), in the shelled and kernel hazelnuts, respectively. While significant differences were observed in the hardness values at 60 mm min^{-1} for Çakıldak and Foşa in shelled they were nonsignificant at the same speed for kernel hazelnut fruits.

Ercisli et al. (2011) found hardness values were 313.67 N mm^{-1} and 245.44 N mm^{-1} in the shelled hazelnuts and 85.22 N mm^{-1} and 30.22 N mm^{-1} in the kernel fruits for the Foşa cultivar. Güner et al. (2003) found the force values for rupturing to be 393.86 N and 71.02 N in the shelled and kernel fruits, and the deformation values to be 6.44 mm and 3.75 mm in the shelled and kernel fruits in Çakıldak cultivar, respectively.

CONCLUSION

Knowing the engineering characteristics (physical, mechanical, colour and coefficient of friction properties) of hazelnut, which has such an important place in Turkey, is important for the transportation, cleaning, sorting, classification, processing and storage processes and designs of these shelled and kernel fruits. Some engineering characteristics of Çakıldak and Foşa cultivars determined in this study are as follows:

-The coefficient of friction values were found to be the highest on the rubber surface and the lowest on the laminate surface in the shelled and kernel fruits of hazelnut cultivars statistically.

-The bulk and fruit densities for the shelled and kernel fruits of the hazelnut were 358.55 and 808.72 kg m^{-3} and 436.65 and 865.57 kg m^{-3}, respectively, while the bulk and fruit densities were found as 393.06 and 966.76 kg m^{-3} and 409.98 and 865.22 kg m^{-3} for the Foşa cultivar.

- As a result of the mechanical tests, Foşa was the cultivar that had the highest force in shelled and kernel hazelnut fruits.

-The power required for rupture in the kernel fruit of the hazelnut was found to be important at all loading speeds and axes.

- While the geometric mean diameter values showed statistically significant differences of 17.23 and 17.66 mm for kernel fruits for Çakıldak and Foşa cultivars, respectively.

-The differences between the engineering characteristics of hazelnut cultivars should be considered in hazelnut harvest and post-harvest mechanization and food enterprises.

-The differences between the rupture forces of hazelnut cultivars are considered important in the design of special machines for harvest and post-harvest technologies.

CONFLICT OF INTEREST

The authors report under this title that there are no conflicts of interest.

DECLARATION OF AUTHOR CONTRIBUTION

The authors report under this title that there are no conflicts of interest.

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