PAPER

ENGINEERING PROPERTIES OF TWO HAZELNUTS VARIETIES AND ITS KERNEL RELATION TO HARVEST AND THRESHING

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ABSTRACT

In this research, several engineering properties of two hazelnut cultivars (Palaz and Çakıldak varieties) were determined and compared in terms of linear dimensions, mass, sphericity, surface area, projected area, true and bulk densities, porosity, repose angle, shell ratio, terminal velocity, rupture force, energy, deformation and drag coefficient. These properties are necessary for the design of much equipment for harvesting, processing, and transportation, sorting, separating and packing. Also, rupture force and deformations were determined which are the most discriminant parameters that can be used to describe the behavior under compression. In both cultivars, these values were also determined within the kernels.

Keywords: hazelnut, pomological properties, strength properties

1. INTRODUCTION

Hazelnut is the nut of the hazel and therefore includes any of the nuts deriving from species of the genus Corylus, especially the nuts of the species Corylus avellana. It is also known as cobnut or filbert nut according to species (MARTIN *et al.*, 2014). A cob is roughly spherical to oval, about 15-25 millimeters (0.59-0.98 in) long and 10-15 millimeters (0.39-0.59 in) in diameter, with an outer fibrous husk surrounding a smooth shell (ANONYMOUS, 2016a)

It has been mentioned in historical documents that hazelnut was produced 2300 years ago in the Black Sea coast on the north of Turkey and it is known that hazelnut has been exported from Turkey to other countries for the last 6 centuries. Turkey, which is one of the few countries in the world with favorable weather conditions for hazelnut production, accounts for 75% of the global production and 70-75% of the exportation (ANONYMOUS, 2016b). The main hazelnut producing countries in the world are Turkey, Italy, Spain, USA and Greece. Although hazelnut is also produced in the Former Soviet Union, Iran, Romania and France, these countries do not have a major input in the world hazelnut trade. Turkey has an average production of 550,000 tons of shelled nuts in recent years. On the other hand, the production of Italy and Georgia, Additional important producing countries, varies between 100,000-125,000 tons and 40,000-80,000 tons respectively (ANONYMOUS, 2018).

The following hazelnut varieties are cultivated in Turkey: Tombul, Palaz, Cakildak, Kara, Fosa, Min-cane, Uzunmusa, Kan, Kargalak, Cavcava, Sivri, Aci, Kus, Yuvarlak Badem and Yassi Badem. They differ from each other in some properties (OZDEMIR and AKINCI, 2004). A specific know-ledge of some hazelnut engineering properties such as linear dimensions, shapes, porosity, volume, density, terminal velocity, rupture force, etc. and the variation between the hazelnut varieties is required to design of hazelnut processing instrument. The running of many types of machines is influenced accurately by the size and shape of the fruit enterer, and so in order to study a given process should be described accurately. For example, sphericity is one of the most important characteristics as it greatly affects the processability of hazelnuts for the food industry. For this reason, hazelnut varieties with better sphericity need to be grown more (MOHSENIN, 1980). The volume and density of agro-food products play an important role in applications such as design of silos, drying, mechanical compaction, stability of pellets and wafers, seperation and grading, evaluation of maturity, or quality evaluation (GLINSKI *et al.*, 2011). Terminal velocity and drag coefficient plays also a significant assignment for the separation, the pneumatic conveying off goods and the cleaning foreign materials (GUNER, 2007). Similarly, the rupture force is also important and indicates failure over a significant. In mechanical processing of the fruits, most of the damage occurs in the harvesting and threshing as well as mechanical conveying and other equipment (OZDEMIR and AKINCI, 2004). For example; dynamic forces during fruit transport and handling cause by far the most bruise damage (ZEEBROECK *et al.*, 2007). The evaluation of mechanical properties of hazelnuts (whole fruit, shell and kernel) has been developed over the past years with the objectives to obtain industrial processes and improve the use of hazelnuts as food ingredient. The experimental characterization of shells and kernels is a challenging topic to improve the quality of the final product. Many literature papers describe procedures to find the mechanical properties of raw and roasted kernels (BRAGA *et al.*, 1999; AYDIN, 2002; ALASALVAR *et al.*, 2003; DEMIR and CRONIN, 2004; ÖZDEMIR and AKINCI 2004; GHIRARDELLO *et al.*, 2009; DELPRETE and SESANA 2014) and the experimental testing on hazelnuts generally relies on compressive testing of kernel and shell by means of universal testing machines. In addition to these studies, some papers (e.g. GÜNER *et al*., 2003; KOYUNCU *et al*., 2004; VURSAVUŞ and ÖZGÜVEN, 2005; VALENTINI *et al*., 2006,) have experimental values of the compressive load needed to crack the shell of hazelnuts, walnuts and pine nuts.

Compressive force-crosshead displacement curves are widely used to measure textural properties in food products (CARCEL *et al.,* 2012): initial slope, maximum force, energy until failure and other curve-related parameters have been described and correlated with textural parameters of hazelnuts.

The physical characteristics of the hazelnut kernel have an important role on the crispness and crunchiness sensory parameters especially on the roasted nuts (SAKLAR *et al*., 1999) and the water activities have direct effects on mechanical characteristic (BORGES and PELEG, 1997). In a test campaign (DEMIR and CRONIN, 2004), a small rectangular prismatic specimen, including the inner cavity present in the core of each hazelnut, was cut from the whole kernel to simplify the calculation of stress and elastic modulus when a compressive axial force loads the specimen section. Again the specimen geometry affected the results and it did not allow obtaining material properties. DI MATTEO *et al*., (2012) evaluated also some mechanical properties of chemical-peeled hazelnut kernels, such as firmness and rigidity, to study an original industrial process to improve the kernel pellicle removal. A mechanical characterization of whole nut, kernel and shell was conducted (DELPRETE and SESANA, 2014) in order to aid the design and construction of selecting machines. These mechanical properties are affected by numerous factors, such as the moisture content and loading direction (CHENGMAO *et al*., 2017). Also, Nut shell characteristics, such as hardness and thickness, were measured and correlated to the biological cycle of the nut weevil of *Curculio nucum* (Coleoptera: Curculionidae) pest and to the damage by its larvae (GUIDONE *et al*., 2007) stress the importance of physical properties evaluation.

There were three aims of this study. The first was to investigate the some pomological (physical) properties of two hazel nut varieties and its kernel widely grown in the Turkey. The second aim was to determine of strength properties of nuts and kernels and last aim was to determine of some frictional and aerodynamic properties of nuts and its kernel.

2. MATERIALS AND METHODS

2.1. Sample preparation and material testing system

In this study, two hazelnut varieties (Palaz and Çakıldak) that chosen randomly were used for all the experiments. The 30 nuts and kernels in four replicates of each variety were tested. Samples were supplied from the different hazelnut growers (2015 harvest season; Samsun, Turkey). The experiments performed as soon as possible after hazelnuts purchased. Samples were kept in a refrigerator until analyses were performed. The hazelnuts were cleaned manually to remove all foreign matter, immature, broken or spoilt nuts. These experiments were carried out in the Laboratory of the Department of Agricultural Engineering, Ondokuz Mayıs Univesity, Samsun. The mechanical properties of hazelnuts under compression load were measured by a Lloyd Instrument Universal Testing Machine (Lloyd Instrument LRX Plus, Lloyd Instruments Ltd, An AMATEK Company). The device has three main parts: moving head, driving unit and data acquisition system (load cell, computer and connections and NEXYGEN Plus software) (Fig. 1).

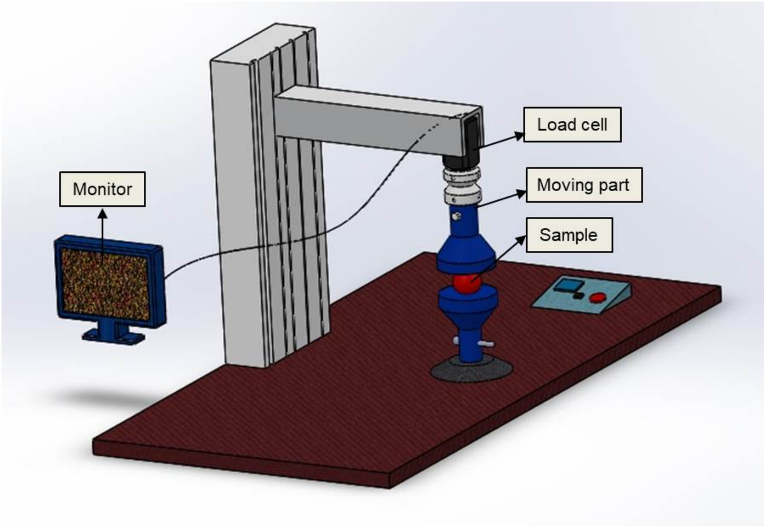

Figure 1. Lloyd instrument universal testing machine.

2.2. Determination of some pomological (physical) properties of nuts and kernels

The initial moisture content of hazelnut varieties (Palaz and Çakıldak) were determined by using a standard method and were found to vary between 6.38-7.38% and 6.52-7.71% db (db = dry basis) respectively (USDA, 1970).
To arrange the average linear dimensions (length (L), width (W) and thickness (T)) of the hazelnuts cultivars, a sample of 30 hazelnuts were randomly selected and the dimensions and mass of each hazel nuts used were determined. The dimensions of the hazelnuts were measured with a digital caliper, which had an accuracy of 0.01 mm. The geometric mean diameter, surface area and the sphericity of the hazelnuts were calculated by using the following relationships (MOHSENIN, 1980):

$$Dg = (LWT)^{1/3} \quad (1)$$

$$\phi = Dg/L*100 \quad (2)$$

$$S = \pi . Dg^2 \quad (3)$$

where, Dg is the geometric mean diameter in mm; ϕ is the sphericity in %; S is surface area in mm^2 and L is the length (mm), W is the width (mm) and T is the thickness (mm) (Fig. 2).

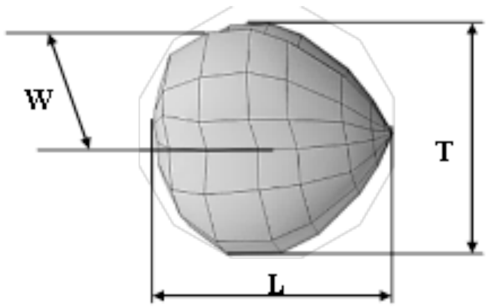

Figure 2. Three dimensions of nut.

Sample mass (M) and thousand mass (M1000) were measured by using a digital balance with a sensitivity of 0.001 g. The fruit mass was determined on 30 randomly selected hazelnuts and kernels and converted to a thousand mass. Also, shell ratio (Rs) was calculated by the measurement of nut mass (M) and shell mass (Ms) (ÖZDEMIR and AKINCI, 2004).
Projected area (P) (y axes) was determined from the pictures of hazelnuts and kernels which were taken by a digital camera (Canon 600 D), in comparison with the reference area to the sample area by using the Sigma Scan Pro 5 program.
The true density (ϱk), were determined using the liquid displacement method and The bulk density (ϱb) was determined with a weight per hectoliters tester which has calibrated in kilogram per hectoliters (DESHPANDE and OJHA, 1993; AYDIN, 2002; DEMIR *et al.*, 2002).
The porosity was determined by the following equation

$$\varepsilon=1-(\varrho b-\varrho k) \quad (4)$$

where (ϱb) is bulk density and (ϱk), is true density in kgm^{-3} (MOHSENIN, 1980; SITKEI, 1986).

2.3. Determination of strength properties of nuts and kernels

To determine the strength a property of hazelnuts and kernels, biological material test device (Lloyd Instrument Universal Testing Machine) was used (Fig. 1). In this study, hazelnuts and kernels were compressed between two parallel plates at a constant rate of 10 $mmmin^{-1}$ based on the preliminary tests.
Rupture force and deformation were determined from the force-deformation curve, where there is a sudden drop in force. To arrange the effect of loading positions on strength properties a coordinate system describing the three main compression positions of hazelnut and kernels is shown in Fig. 3. The energy absorbed in rupture point for was determined from the diagram by measuring the area under the force-deformation curves.

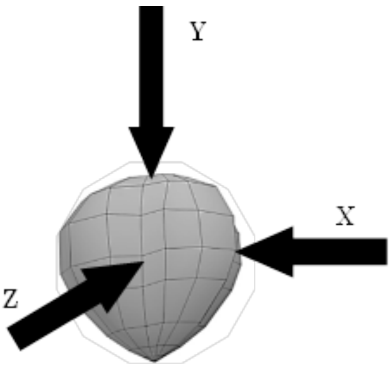

Figure 3. Applied force axis of nuts.

2.4. Determination of some frictional and aerodynamic properties nuts and its kernels

The determination of the angle of repose (ϕ) of nuts and kernels was used a funnel tube (smallest diameter 50 mm, biggest diameter 150 mm and height 300 mm) and a bow with discharge gate at the bottom. After filling the box with sample, the gate was quickly removed.
The height of fruit pile above the floor (h) and the diameter of the heap of sample (r) was measured and used to determine the angle of repose. The angle of repose was calculated with the measurement of the height (h) of conical shape at the center and radius (r) of the free samples over the surface (ERTEKIN *et al.*, 2006)

$$\phi = \tan^{-1}(h/r) \quad (5)$$

Terminal velocity was determined using a wind tunnel. For each test, a sample (nut, kernel) was dropped into the air stream from the top of the wind tunnel, and air was blown up the column to suspend the material in the air stream. The air velocity near the location of the sample suspension was measured by a digital hot-wire anemometer with an accuracy of 0.1 ms^{-1}.
In addition, the drag coefficient was calculated as following equation (Mohsenin 1980)

$$C_d = \frac{2mg(\rho_p - \rho_f)}{\rho_p \rho_f A_p V_t^2} \quad (6)$$

where: Ap is projected area of the particle (m^2), Cd is drag coefficient (-), g is acceleration due to gravity (9.81 ms^{-2}), m is mass of samples (kg), Vt is terminal velocity (ms^{-1}), ϱp is density of samples (kgm^{-3}) and ϱf is density of air (1.206 kgm^{-3})

3. RESULTS AND DISCUSSION

Frequency distributions of the dimensional properties of two hazelnut cultivars are given in Table 1.

Table 1. Frequency distributions of the dimensional properties of two hazelnut cultivars.

		Palaz		Çakıldak	
Dimensions	**Frequency**	**Nuts**	**Kernels**	**Nuts**	**Kernels**
Length (mm)		16.60-18.27	12.37-16.26	17.25-19.64	13.36-17.59
Width (mm)	%86.7	19.14-20.94	13.12-16.78	15.42-18.66	11.09-14.78
Thickness (mm)		16.35-17.96	11.98-15.27	14.38-16.40	9.89-13.49

According to the results of frequency distributions of the dimensional properties of two hazelnut and kernels cultivars; about 86.7% of the hazelnut were between 16.60 and 19.64 mm in length, 15.42 and 20.94 mm in width and 14.38 and 17.96 mm in thickness for both cultivars. Some physical properties of the Palaz and Çakıldak nuts and kernels are given in Tables 2 and 3.

The moisture contents were 6.63% and 6.96% for Palaz and Çakıldak nuts and 4.56% 4.50% for kernel respectively. While mean nut length was 17.73 mm, nut width was 19.89 mm and thickness was 17.08 mm and kernel length was 14.21 mm, kernel width was 14.94 mm and thickness was 13.36 mm for Palaz. These values were 18.44 mm, 16.85 mm, 15.20 mm and 14.70 mm, 12.75 mm, 11.82 mm for nuts and kernel of Çakıldak, respectively. All sizes of Palaz except length are bigger than those of Çakıldak.

Shell ratio (46.72 %) and thickness (1.21 mm) of the Palaz were higher than the Çakıldak (45.90 %) and (1.10 mm). For the Palaz, mean mass of nut and 1000 nuts mass was 1.58 g and 1591.98 g for nuts and 0.79 g and 793.61 g for kernels. The same values of Çakıldak were 1.59 g and 1612.18 g for nuts and 0.80 g and 792.23 g for kernels. When the nut mass in this study was compared with previous studies, the mean mass of the fruit was with in normal limits (GÜNER *et al*., 2003). The average value of the geometric mean diameter was calculated as 18.05 mm for Palaz and 16.76 mm for Çakıldak nuts, respectively. The same values were 14.12 mm and 13.00 mm for Palaz and Çakıldak kernels. Sphericity is an expression of a shape of a solid relative to that of a sphere of the same volume while the aspect ratio relates the width to the length of the fruit which is an indicative of its tendency toward being oblong in shape (ERTEKIN *et al*., 2006). These values were 1.042 and 0.91 for nuts and 1.37 and 0.89 for Palaz and Çakıldak, respectively.

Bulk densities for nuts and kernels of Palaz were between 392 kg/m^3 and 450 kg/m^3 and 482 kg/m^3 and 578 kg/m^3. The same values were between 406 kg/m^3 and 468 kg/m^3 and 483 kg/m^3 and 522 kg/m^3 for Çakıldak. The porosity ranged between 53.50% and 61.30% for Palaz nuts and 54.70% and 62.70% for Çakıldak nuts. The same values were between 58.70% and 64.30% for Palaz and 54.70% and 62.70% for Çakıldak for kernels. Bulk densities and porosities values were similar with the literature values (OZDEMIR AND AKINCI, 2004).

The mean surface and the projected area of the Palaz nut were found 889.17 mm^2 and 221.762 mm^2. For Çakıldak variety the same values were calculated as an 883.92 mm^2 and 211.740 mm^2 respectively. When the same properties were examined for the kernel of the Palaz and Çakıldak, the surface and the projected area were found 663.21 mm^2 and 167.23 mm^2, 533.03 mm^2 and 132.20 mm^2, respectively.

The mean and SD values of some mechanical properties of the two nut cultivars obtained from the measurements and calculations at moisture contents of 6.63% and 6.96% (w.b.) are shown in Table 4.

Table 2. Some physical properties of nuts.

	Cultivar							
	Palaz				Çakıldak			
	Min	**Max**	**Mean**	**S.D**	**Min**	**Max**	**Mean**	**S.D**
Length (mm)	15.53	18.43	17.33	0.024	15.06	20.01	18.44	0.045
Width (mm)	18.71	21.40	19.89	0.025	15.10	18.74	16.85	0.035
Thickness (mm)	16.21	18.21	17.08	0.021	13.92	16.42	15.20	0.024
Shell ratio (%)	44.33	48.71	46.72	0.230	44.69	46.78	45.90	0.215
Shell thickness (mm)	1.02	1.66	1.213	0.005	0.90	1.39	1.10	0.004
Geo. mean dia. (mm)	16.82	18.72	18.05	0.017	15.73	17.99	16.76	0.022
Sphericity	0.99	1.109	1.042	0.001	0.86	1.062	0.91	0.002
Surface area (mm^2)	889.17	1100.34	1024.65	1.957	777.66	1016.50	883.92	2.315
Projected area (mm^2)	221.76	298.84	257.23	0.785	201.73	247.13	211.74	0.598
True Density (kgm^{-3})	714.23	801.42	748.65	1.235	705.39	753.54	721.98	1.383
Bulk Density(kgm^{-3})	392.64	450.32	412.42	0.983	406.43	468.24	436.71	0.871
Porosity	0.53	0.613	0.587	0.005	0.54	0.62	0.59	0.004
Mass (g)	1.58	1.753	1.627	0.010	1.57	1.63	1.58	0.011
1000 Mass (g)	1591.98	1739.86	1669.25	12.26	1568.42	1634.83	1612.18	10.54

Table 3. Some physical properties of kernels.

	Cultivar							
	Palaz				Çakıldak			
	Min	**Max**	**Mean**	**S.D**	**Min**	**Max**	**Mean**	**S.D**
Lenght (mm)	12.08	17.010	14.21	0.057	10.16	18.87	14.70	0.060
Width (mm)	12.57	17.22	14.94	0.046	9.31	15.00	12.75	0.046
Thickness (mm)	11.26	15.79	13.36	0.037	8.82	13.87	11.82	0.046
Geo. mean dia. (mm)	12.88	15.52	14.12	0.025	10.83	14.78	13.00	0.033
Sphericity	0.84	1.15	1.37	0.004	0.69	1.18	0.89	0.004
Surface area (mm^2)	521.30	756.30	663.21	2.213	368.77	686.45	533.03	2.676
Projected area (mm^2)	140.79	198.50	167.23	0.898	112.64	178.06	132.20	0.785
True Density (kgm^{-3})	817.12	1020.12	984.42	3.452	824.56	978.76	845.31	4.349
Bulk Density (kgm^{-3})	482.17	578.67	523.23	1.924	483.33	522.35	489.60	1.345
Porosity	0.58	0.64	0.61	0.003	0.54	0.62	0.59	0.005
Mass (g)	0.78	0.92	0.842	0.012	0.72	0.84	0.79	0.015
1000 Mass (g)	793.61	934.51	869.73	10.25	735.25	865.79	792.23	10.743

The force values required to initiate nut rupture were obtained from the same experiments. From Table 4, it is seen that the rupture force was higher along the y-axis compared with the x- and z-axes for both cultivars. This could be because the area of contact between the nut pit and compression plates was larger along the y-axis than those along the x- and z-axes. This is in agreement with the finding of AKTAŞ *et al*. (2007).

Table 4. Some mechanical properties of nuts.

		Palaz				Çakıldak			
		Min	**Max**	**Mean**	**S.D**	**Min**	**Max**	**Mean**	**S.D**
Z axes	Rupture Force (N)	186.94	266.79	217.96	2.742	105.61	289.50	211.24	6.733
	Deformation (mm)	0.70	1.19	1.01	0.018	0.59	1.45	0.97	0.029
	Energy (J)	0.07	0.16	0.12	0.013	0.03	0.21	0.11	0.006
	Hardness (N/mm)	166.39	265.12	220.02	3.52	175.59	265.08	216.96	3.24
X axes	Rupture Force (N)	191.53	312.91	251.04	3.86	129.77	313.34	222.68	6.449
	Deformation(mm)	0.57	0.96	0.78	0.013	0.53	1.22	0.88	0.023
	Energy (J)	0.055	0.160	0.100	0.004	0.034	0.189	0.10	0.005
	Hardness (N/mm)	286.54	381.08	324.43	2.89	184.27	328.93	257.28	4.988
Y axes	Rupture Force (N)	191.81	339.39	274.88	5.341	155.61	396.46	239.57	7.248
	Deformation(mm)	0.56	1.32	0.97	0.023	0.45	2.77	1.02	0.067
	Energy (J)	0.051	0.23	0.13	0.005	0.04	0.27	0.10	0.007
	Hardness (N/mm)	244.47	342.78	288.25	3.442	95.32	408.73	273.16	8.272

In addition to rupture force, energy values, deformation and hardness were calculated as some mechanical properties. Maximum and minimum energy values except min energy for Çakıldak cultivar (0.034 J-x axes) were found along the y axes as 0.23 J for the Palaz and 0.27 J for the Çakıldak and 0.05 J for the Palaz. Depending on rupture force, maximum deformation was obtained on the y axes as a 1.32 mm and 2.77 mm for the Palaz and Çakıldak, respectively. The response of hardness to loading position in the x axes was higher than the hardness in the z and y axes loading position for the Palaz, while hardness value in the y axes was max for Çakıldak. This difference among the two type nut cultivars may be due to the shell properties of the varieties.
Terminal velocity, drag coefficient, repose angel and static and dynamic coefficient of the two hazelnut varieties and their kernels were given in Table 5.

Table 5. Terminal velocity, drag coefficient and repose angel of the Palaz and the Çakıldak.

		Cultivar							
		Palaz				Çakıldak			
		Min	Max	**Mean**	**S.D**	**Min**	**Max**	**Mean**	**S.D**
Nut	Terminal velocity (m/s)	11.26	13.89	13.15	0.744	11.84	13.67	13.30	0.544
	Drag coefficient	0.351	0.389	0.362	0.012	0.358	0.391	0.367	0.011
	Repose angel (°)	22.615	23.12	22.814	0.175	22.578	22.845	22.751	0.090
Kernel	Terminal velocity (m/s)	11.77	14.05	13.66	0.672	12.73	13.84	13.70	0.309
	Drag coefficient	0.363	0.377	0.369	0.005	0.370	0.388	0.377	0.005
	Repose angel (°)	24.231	25.813	24.934	0.464	23.887	24.867	24.53	0.389

The terminal velocity of hazelnuts and kernels, the values ranged from 13.26 to 13.89 m/s and from 11.77 to 14.05 m/s, respectively. The terminal velocity of kernels is higher than that of hazelnuts. These differences in results can be attributed to the increase in mass of the individual nut or the kernel per unit when their frontal areas were presented to the air stream to suspend the material.

The repose angle with hazelnuts and kernels were varying from 22.58° to 23.12° and from 23.89° to 25.81° respectively. This is due to the higher sphericity of hazelnuts and kernels which results from allowing them to slide and roll on each other.

4. CONCLUSION

Several physical and mechanical properties of the two (The Palaz and the Çakıldak) hazelnut varieties were described in order to design a specific machine for harvesting, threshing, conveying, cleaning, separating, storing, etc. according to these results. Some remarkable points for the study can be summarised as follows.

1. Moisture content was 6.63% for hazelnut and 4.56% for kernel of the Palaz cultivar and 6.96% for hazelnut and 4.50% for kernel of the Çakıldak cultivar. The average hazelnut length, width, thickness and geometric diameter were 17.34 mm, 19.90 mm, 17.09 mm and 18.06 mm for hazelnut and 14.21 mm, 14.94 mm, 13.36 mm and 14.13 mm for kernels of the Palaz, respectively. The average hazelnut length, width, thickness and geometric diameter were 18.45 mm, 19.85 mm, 15.21 mm and 16.77 mm for hazelnut and 14.71 mm, 12.75 mm, 11.82 mm and 13.00 mm for kernels of the Çakıldak, respectively. The average 1000 mass for hazelnut and kernels were 1669.25 g and 869.74 g for the Palaz and 1612.18 g, 792.24 g for the Çakıldak, respectively.
2. The mean true and bulk density, angle of repose and terminal velocity of the Palaz hazelnut and kernel were 748 kg/m^3 - 984 kg/m3, 412 kg/m^3 - 523 kg/m^3, 22.81° - 24.93° and 13.15 m/s - 13.66 m/s, respectively. The same values were 721 kg/m^3 - 845 kg/m^3, 436 kg/m^3- 489 kg/m^3, 22.75° - 24.53°and 13.30 m/s - 13.70 m/s, respectively.
3. The sphericity, surface area, projected area and porosity of the hazelnut and kernels were 1.04 % - 1.37 %, 1025 mm^2 - 663 mm^2, 257 mm^2 - 167 mm^2 and 0.59 - 0.61 for the Palaz cultivar, respectively. The same values were 0.91 % - 0.89 %, 883 mm^2 - 533 mm^2, 211 mm^2 - 132 mm^2 and 0.59 - 0.59 for the Çakıldak cultivar, respectively.
4. The rupture force was higher along the y-axis compared with the x- and z-axes for both cultivars. The biggest mean deformation value was 1.01 mm on z axes for the Palaz and 1.023 mm on y axes for the Çakıldak. The energy and hardness values of the Palaz cultivar were higher than the Çakıldak values within all axes.

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